Project Deliverable [H]: Prototype III and Customer Feedback

GNG1103[F]: Engineering Design

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Abstract:

In this deliverable, Team 5 constructed the third prototype (consisting of an electrical and sensor system), as well as the final design of the panel, while keeping in mind the $100 CAD budget. The final prototype of the panel was created physically, as well as on Onshape to comprehensively determine the conditions of functionality of the heated panel solution. Prototype test plans, as well as testing and stopping criteria and objectives were created to help test both the electrical/sensor prototype as well as the overall function of the final design. The testing criteria, and subsequent analyses, were specific enough to determine the limitations and conditions of each electrical component with respect to mat function, and the final prototype tests were created to test all three subsystems constructed in the current and previous two deliverables (i.e. electrical, drainage, assembly). These tests were performed in a variety of temperature and moisture conditions, resulting in a 'full-picture' of how the mat functions in various environments. Feedback from the client, as well as lessons learned from the previous two prototypes were also incorporated into improving the prototypes constructed in this deliverable. The Gantt chart on Wrike was also updated to highlight the team's progress on the tasks required to complete this deliverable.

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Introduction:

In this project deliverable, Team 5 will create the third prototype and assemble all components together to result in a complete, functioning, final prototype of a heated mat panel. Due to cost constraints, one functioning and representative panel of the heated mat solution will be constructed to meet the client's needs, under a budget of $100 CAD. In Project Deliverable F, the assembly of the system was constructed and tested, while a similar process was undertaken for the drainage system prototype in Project Deliverable G. For the third prototype in Project Deliverable H, the electrical and sensor system will be constructed, tested, and assembled. After ensuring the full functionality of all subsystems, the final assembly of all subsystems will be completed into a comprehensive final design. Preliminary analysis and testing of the final prototype will be done in this deliverable, but will continue after the submission of this deliverable, and before design day, to further integrate improvements needed to enhance the functionality of the final prototype. Onshape designs will also be used to highlight various components of the final solution. Tests of the physical prototype will be undertaken to verify the functionality of the wires, sensors, Arduino UNO kit, as well as the efficacy of the written codes for the application of the heated panel; this will be discussed in further detail in the testing and stopping objectives and prototyping test plans. As this prototype consists of electrical components, a simple functionality test will be able to determine if adjustments are needed to be made to improve the prototype. From these tests, analytical and graphical models will be constructed under various moisture and temperature conditions to determine any conditions and constraints that may inhibit function of the sensors and circuitry. The final prototype will also be tested for overall functionality, as highlighted in the testing objectives and test plan. As design is an iterative process, to improve upon each prototype, Team 5 will provide a review of lessons learnt from the previous two deliverables, and will discuss a justification on the implementation of these points of improvement in the current prototype. Lastly, prototype and final design images will be included in the appendices, along with an updated Wrike plan, which will highlight the team's progress for the project.

Prototyping Objectives:

Team 5 has made two prototypes, previous to this deliverable. The first prototype focused on the assembly sub-system, which included the outer shell and the connectors. From this prototype, the team learned that the dimensions of the panels need to be kept to a height that makes stepping onto the surface effortless for people using a wheelchair. We were also able to determine that for further prototyping, the design should have the connectors placed towards the corners, to not be in the way of the drainage system running parallel with each panel when they are connected. Additionally, we learned that the heating wires will need to be coiled in a way that prevents any areas from bunching up and possibly increasing chances of short-circuiting and/or fire hazards. The second prototype was built onto the design from the first, which included adding a functional drainage system that was capable of transferring melted snow or ice from the top surface of the heating panel and funnelling it down and out of the panels into the sewer manholes. Tests were performed on the system to see how well the system could handle a large amount of precipitation and a typical amount of melting. We were able to learn the degree of slope needed to adequately drain the water. We also learned that with a large amount of melting, the pipes would not be able to drain all the water from the inner pipes without adding a feature which will aid with drainage. Thus moving forward, it was established that a block would be placed at the spot in the pipe which collected the leftover water to encourage all the melted snow to drain out of the system.

Taking what was learned in the first two prototypes, we will now develop the third and final prototype. This prototype will aim at incorporating all three subsystems, and thus will be adding the electrical sub-system which will have the heating wire, the temperature and moisture sensors, as well as the power box. One objective of this prototype will be to successfully incorporate each subsystem while still having a functional design; ideally we would like to see each subsystem working when being used to melt snow, and the testing will allow us to decide if steps need to be taken to improve the effectiveness of the heating system after this prototype is made. Another objective will be to have both the temperature and rainfall sensors work to their desired abilities, which will mean that they can signal to the panels when there is precipitation and if it's cold enough for the precipitation to turn into ice or snow. Lastly, we would like the prototype to easily and effectively melt any snow or ice on the surface, after all that is the purpose of the product and if it's not capable of doing that to a high degree of effectiveness then changes will need to be made. The team will test and analyze the prototype to meet these objectives and then determine if any final improvements need to be made before finalizing the product.

Testing Plan:

See Appendix A: Prototyping III Test Plan Table 2: Prototyping Test Plan.

Testing & Stopping Objectives:

Over the course of the project deliverables directly related to the building of a prototype, many testing objectives were created. Most of these objectives were tested with the completion of each subsystem; but we had also created additional testing objectives that could only be executed upon the completion of the final prototype. The first phase of testing, as specified in detail in the report associated with Project Deliverable F, focused mostly on the the specified testing that needed to be done for the optimization of the assembly system as an individual subsystem. Having a solid, functioning basis that acted as a strong foundation for more complicated and intricate elements of the design was essential. The second phase of testing extended to allow for more analytical and numerical data to be observed and analyzed. This phase of prototyping is explained in more detail in the previously completed report of Project Deliverable G. The drainage system was thoroughly experimented upon to determine any changes that needed to be implemented. In this final prototyping report, the main focus will be the electrical and power subsystems as well as the overall functionality of the design in harmony with each and every individual element.

From the assembly system experimentation, the final testing that was required was assessing the effectiveness of anti-slip coating. In order to do this, an experimental testing objective was created to determine how much liquid on the surface will cause a significant decrease in traction on the surface layer of the system. This will be tested by sliding an object with some weight across the surface of the system while progressively adding more liquid to the system. This will allow for the friction coefficient of the surface to be tested. We tested this using two options of potential materials, sandpaper tape or spray-on sandpaper, and came to the conclusion that the spray-on application of sand paper-like material is the better material as it demonstrated a higher coefficient of friction through experimentation. We also tested the minimum functionable temperature of the overall system to ensure that the functionality of the device will remain optimal at any external environmental conditions. This will be tested experimentally by connecting all elements of the device together and test if the materials used will be able to maintain a relatively constant temperature in the range of 2-4 degrees Celsius; and the goal is for the system temperature to not drop below 0 degree Celsius. For other experiments, the results were simple and easy to implement onto the final prototype. The information obtained from these experiments demonstrated the high functionality of the assembly system as a subsystem of a whole.

From the drainage system expermination, the final testing was used to identify any flaws or potential problems that may arise from the individualized elements of the pipes within the drainage system and their functionality. The dissipation of current from each connector was tested with a research-based analysis to verify the optimality of the connector pieces. We determined how much internal resistance is present in the electrical system. As this device is a component-based system, there is the possibility that numerous individual plates will be connected together. As the electrical subsystem is an individually functionable system, the point of attachment between the two points of the input and output can have long term negative impacts on the functionality of the device. We learned that the internal resistance was zero, thus if the materials and elements are maintained and used as instructed, no/minimal energy will be lost to resistance between plates of the device. In order to create a device that matched the design specifications of the client derived by customer statement from the many opportunities we had to speak with our client, it was determined that wheelchair-friendly design was a functional requirement. We tested the ideal curvature angle for an anti tripping/wheelchair friendly device. A comparative analysis of other such products found on the market was executed and concluded that ramped devices are optimal. After an ideal angle range was found, testing for one that would work with the materials purchased as well as the ease of a wheelchair over the ramp was required. Additionally, as this device has the main goal to be a cost-efficient solution, compared to salting, in the long run, the longevity of materials chosen must be sufficient. We tested this objective by a research-based analysis of the typical life of basis and surface materials. Our main concern was how well the external friction-creating surface would maintain its coefficient of friction. Corrosion has the effect of decreasing the coefficient of friction which would disable the purpose of the anti-slip surface material. We determined that a sandpaper-like material would be optimal and can be changed as required. We picked this option over silicon as silicon becomes highly slippery when wet. The results and information obtained from the numerous experimental procedures allowed us to make essential changes to our drainage subsystem before we incorporated into the harmony of the full device.

Finally, the electrical and power subsystem was tested. This analysis was to be done once all subcomponents of the device were solidified. As the electrical subsystem is entangled within the foundational structure of our finalized device, this is the point at which the electrical and heating functionality objectives will be tested. All the associated sensores, the temperature and moisture/rain sensors will be tested at different environmental conditions which will reflect the external winter conditions in which this device will be implemented. This experimentation will be done using the physical materials and graphing the outputs derived from the control system arduino UNO device. We will also use the functionality of the relay attachment to ensure the sensors at different distances from the control box on the plates will transmis an accurate signal back to the control box.

In order to test the final subsystem of our device; all electrically-base elements had to be tested thoroughly. Initial testing started with testing the conditions and limitations of functionality of the moisture sensor. The moisture sensor was integrated into the electrical system; using graphical analysis tools, we verified the dependent relationship between the electrical state and the moisture sensor. When moisture is sensed in a cold and wet environment, the sensors will send a signal to the electrical control system which will act accordingly when set on AUTO. The ability to automatically allow functionality of the mat will increase the energy efficiency and reduce operating and maintenance costs of the heated mat panel. The same kind of analysis was done with the operating range of the temperature sensor. The operating range for our sensor was −40°C to +125°C which exceeds the requirements of our device. Immediate testing was done around the temperature range at which the device will typically be operational and the output temperatures followed a consistent pattern with the controlled external environment concluding the high accuracy of the sensor as analysed by Figure 2: *Determine the Functionality Range of the Temperature Sensor with respect to the Device Code*. The heated coil functionality was also tested in order to ensure that all materials would be functional with the outputted thermal energy for the heating wire as well as be able to melt falling/fallen precipitate/ice on the surface of the device. A temperature range of 2-3°C must be maintained. More detailed results and testing plan design can be found within Table 2; *Prototyping Test Plan* of Appendix A: Prototyping III Test Plan.

All the objectives presented in this report were derived from communication and feedback received from the multiple opportunities we had to meet with our client. The reason for the creation of our testing objective criteria was to verify the feasibility of each individual element of our device. We analysed the areas of the device where the functionality would be risky and had great potential to be inoperative once implemented into the combined system. It was critical to test the subsystems as well as the functionality of the overall system in order to reduce risk and uncertainty during integration of subsystems into the combined, final device.

Justification & Reasoning:

In the previous deliverables [PD-F] and [PD-G], two out of the three main subsystems were individually prototyped and tested. Throughout the prototyping phase of this project, Team 5 had focused on developing one of the two-panel types based on the original design of the system. The two-panel types are: the draining panels consist of a T-shape piping system that safely removes the water from the system via a hose into a public sewer drain; the connecting panel is placed between the drainage panels, consisting of a straight pipe that transports water between panels. When the panels are assembled, the power supply and drainage between the panels would be connected, to allow for a continuous line of panels to be operated. Due to cost limitations, both panels cannot be fully developed and tested. However, Team 5 chose to develop the more complicated panel, the drainage panel, to ensure the safe removal of water from the system. The development of the connecting panel will be discussed further in the user manual.

The first prototype developed in [PD-F], was assembled out of second-hand materials to allow for a visual representation of the final product. The focus of this prototype was to test the assembly subsystem component. The prototype was not constructed out of the materials listed in the BOM in [PD-E], due to limitations in obtaining all the required materials (shipping delays, differences in availabilities of team members, etc.). As a result, the test plans for the upcoming prototypes II and III were developed in detail, as the amount of testing provided from this initial prototype was limited. From this prototype, Team 5 was able to reflect on how the components of each subsystem will be integrated into the final product. One of the limitations Team 5 came across in the initial design (that was not built to scale) was the potential height of the final system with all the components within. Team 5 had to reconsider and adjust the dimensioning of the individual subsystems in order to ensure the panel height dimensions would be appropriate within the application setting.

The second prototype developed in [PD-G], was assembled out of the materials listed in the BOM. During the second phase of prototyping, the drainage subsystem was constructed and tested in detail. The test plan developed in [PD-F] was modified and updated to include further testing methods presented in [PD-G]. As the basic concept of the drainage subsystem is to safely remove excess liquid away from the system, a general analysis of the water flow throughout the drainage system (rate of drainage) was performed via the application of basic fluid mechanics properties, such as Bernoulli's Analysis. This allowed for Team 5 to gather numerical data regarding the average flow rate and velocity characteristics of the drainage system. This analysis was performed on the two pipes within the system: the gutter pipe (3x24" PVC) and drainage pipe (¾"x5' PEX). The gutter pipe purchased for this prototype did not match the colour of the pipe listed in the BOM; a white pipe was listed, and a black pipe was purchased. There were no specific aesthetic requirements for the materials of the drainage subsystem, as these components are covered in the final product and will only be visual when the system is disassembled. Due to spacing limitations, the diameter of the gutter pipe was too large and required to be cut directly in half to fit within the system. The open face of the pipe was placed facing towards the grated surface to allow for the water to be collected and transferred to the drainage pipe to be removed from the system. The testing analysis performed (Bernoulli's analysis), did not take into account the reduction in pipe diameter, therefore the results provided are rough estimates of the maximum capabilities of the drainage subsystem. Based on research performed on the precipitation and snow/rainfall levels, the amount of fluid that will be collected within the subsystem in winter application should not exceed the amount tested. Although the reduction in pipe size of the grated surface is a limitation to the numerical data collected for prototype II, it is understood that the subsystem must function at a rate to remove the liquid from the subsystem without flooding. From the numerical data collected, an increase in the amount of liquid applied to the system results in an increase in the rate of drainage. However, based on the data presented, the rate of the liquid draining through the grated surface is less than the drainage rate of the liquid leaving the system, reducing the risk of the system flooding.

Approaching the third round of prototyping, the results from prototype II allow for Team 5 to recognize different types of limitations that may occur when assembling the final product. Prototype III incorporates the components of the electrical subsystem and other subsystems to function synchronously. The test plan completed in [PD-G] provided insight into the basic requirements of the drainage system. The test plan completed throughout this deliverable should provide Team 5 with more detail in how the electrical subsystem functions overall, as well as the functionality of the electrical subsystem in the presence and influence of other subsystems. The electrical subsystem has the most components required to assemble and implement into the system. The system requires two functioning sensors: a temperature sensor and humidity sensor, Arduino hardware and code, a power source, as well as connecting the heated wire. Techniques such as soldering and coding will be implemented through the assembly of prototype III. The test plan for prototype III will provide Team 5 with more numerical data regarding the overall functionality of the system. This will allow for final modifications to the product to be made before design day.

Client Feedback:

Prior to creating prototype III, Team 5 presented in front of the class with the client, Jonathan Rousseau, present to ask questions and give feedback. He was happy with the team's progress so far and raised some good questions regarding the design. He was concerned that the plastic material which the team initially used for the panel surface, would be melted due to the heating wire and would also not be able to sustain pedestrian load. This was taken into consideration while re-evaluating surface materials for the panel, and resulted in Team 5 deciding to use a sheet metal panel with a spray on top to provide the necessary traction. This solution helped mitigate both the pedestrian load sustaining issue, as well as melting, and as a bonus, allowed for better traction on the panel surface. There was also some concern about what would keep the panel stationary so it does not move while in use. This was addressed by how the panels would connect. With the electrical and physical connection of each panel, it would lock the others in place making it too big to move with normal foot traffic. There was one final question about whether or not the panels could be controlled wirelessly. Although this is relatively easy to implement to the existing design, it is not feasible due to budget constraints at this time but would be a great addition for Team 5 down the road. This prototype was designed with the ability to add that capability in the future without changing existing circuitry in the control box.

Analytical & Numerical Results:

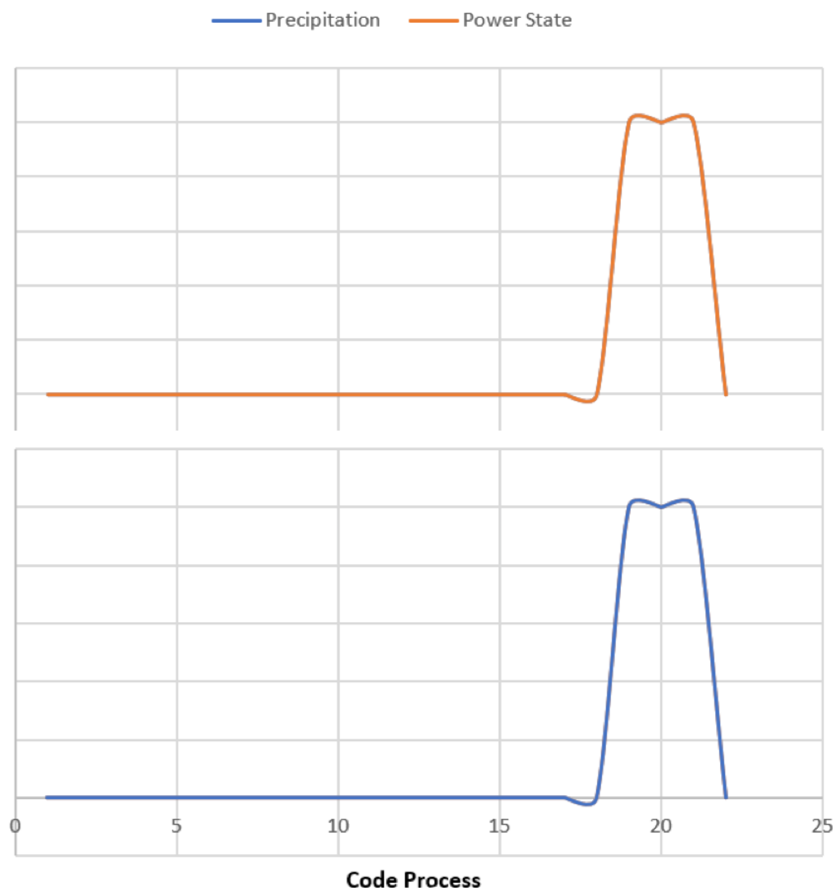


Figure 1: Accuracy of the Power State dependant on the Output Signal of Precipitation Sensor

This two panelled parallel graph serves as a comparative, analytical analysis tool for determining the power state as a dependent variable of the observed environmental precipitation state. As the precipitation sensor on the device senses environmental precipitation (wetness), the power output will automatically be turned on and commence the drying process on the surface of the device. When the precipitation sensor no longer senses a cold and wet external environment, the control box is signaled, specifically the power control, and turns off electrical input into the device. This operation is only functional when the AUTO setting is selected. If one wants to manually switch on/off and power supply, the sensors will not be functional as power state controllers.

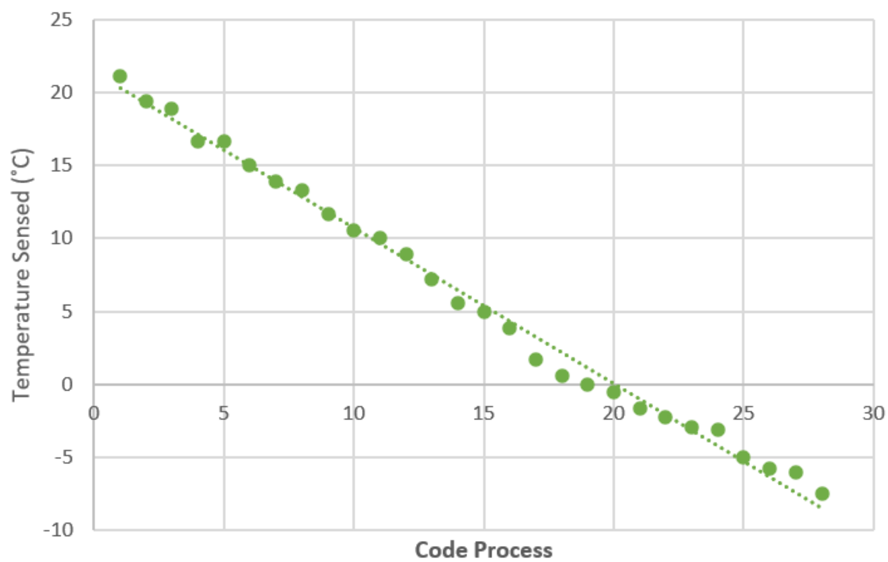


Figure 2: Determine the Functionality Range of the Temperature Sensor with respect to the Device Code

From Figure 2, it can be determined that the temperature sensor meets the device requirements and passes all the testing objectives that rely on the functionality of the temperature sensor and its corresponding numerical output. The range of which this temperature sensor is able to sense and relay the information back to the control box exceeds the minimal requirements of the device. The physical temperature sensor has an operating range of−40°C to +125°C thus is equipped to sufficiently deliver temperature readings back to the control box of the device.

Additional testing was completed to check the overall relay capabilities of the system, as discussed in the prototyping test plan in Appendix A. The raw data from this testing is included in the attached Excel file with the submission. Overall, it was found that for the aforementioned temperatures and moisture contents, the system effectively turned the heating wire on/off as needed. The success of this is also demonstrated through the turning on of an LED light in the circuit when the heating wire is on, and vice versa for when the heating wire is turned off.

Lastly, to test the overall system, the following data was collected over three trial runs of ice melting on the panel:

Table 1: Raw Data for testing the overall functionality of the heated panel

Trial	Amount of ice on panel surface	Surrounding Temperature (degrees Celsius)	Moisture condition on the panel (as per the sensor)	Heating wire on?	Time taken for ice to melt and travel through the system (s)	Percentage of water collected (%)
1	32 cubes	20	WET	OFF	6	96
2	32 cubes	-2	WET	ON	6	93
3	3 cubes	-2	DRY	OFF	-	-

In Table 1, the data shows that the system is very efficient at melting ice from the panel surface and relaying through the drainage system over a variety of temperatures, such as room temperature and outside environment. Additionally, it is important to note that for the 3 ice cubes, the moisture sensor detected the panel surface as dry, thus not turning on the heating wire (which ensures the success of the relay and sensors), so the amount of ice melted and collected through the system is none, as the heating wire did not turn on, just like it was supposed to do. In contrast, it is seen that for the ‘wet’ condition (i.e. using 32 ice cubes), the moisture sensor turned on the heating wire and allowed for quick disposal of melted ice through the system, with a relatively high collected melt ratio. This shows that the mat drains an average of 94.5% of water on the panel surface when the heating wire is on. Additional trials will be taken in the future to continue to explore this trend. Lastly, the data shows that both the temperature and moisture sensor conditions need to be met for the heating wire to turn on, which is good for energy efficiency and low long-term cost for the panel, as it will not function unless both temperature and moisture conditions are met. This is shown as at room temperature, the mat did not turn on, despite the fact that the panel was ‘wet’; likewise, the heating mat did not turn on at -2 degrees Celsius as the panel was ‘dry’. Overall, these results show that our heating panel (and all of its subsystems) works very effectively, in a variety of climate conditions.

Prototyping:

Physical Prototype:

To create this prototype the rest of the materials from the bill of materials were used and assembled. The circuit that controlled the power to the mat was first done on a breadboard and then when everything was working, the circuit was transferred to a PCB board and soldered into place. This is all encased in a sheet metal control panel that has two wires leading from it. One goes to the power source and one goes to the mat to provide power. This prototype uses a standard extension cord connection instead of the special connectors for ease of use in testing but this would change for the final product. There is a switch that turns the box on always and one that only turns it on when the temperature is below 0°C and it is snowing out. Sheet metal was chosen as the surface of the panel due to its effective heat transfer and load-sustaining properties, and the heating wire was coiled beneath this material to ensure that maximum surface area of the panel was heated. Please reference Appendix B. Table 3.

OnShape Prototype:

The OnShape Design (CAD) was modified from the previous [PD-G] to allow for the overall representation of the design to include the three main subsystems that have been prototyped throughout the course of this project. These three subsystems are: the assembly unit, the drainage system, and the electrical component. This model was based on the materials listed in the BOM, including proper dimensioning and selection of such materials, please reference [PD-E. Table 2.]. The model includes an electrical box that will contain the temperature sensor, humidity sensor, and the connect to power (standard household outlet). The holes in the box represent where these elements will exist on the final product. The OnShape model will undergo further modification, in preparation of design day, however the OnShape design will not be the final product presented to the client. Please reference Appendix C. Table 4.

Wrike Link:

https://www.wrike.com/open.htm?id=626625048

Conclusion:

In this deliverable, Team 5 has completed the design of the electrical and sensor subsystem for the final prototype and constructed a final physical and Onshape prototype design for the heated panel. First, Team 5 developed testing and stopping objectives along with a prototype test plan, consisting of eight tests to determine both the functionality of the electrical and sensor components in the electrical subsystem, along with the efficacy of the final heated panel by placing it in ‘real’ climate (temperature and moisture) conditions, collecting water to test drainage, and thus determining that the final design is suitable for meeting the client’s needs. Additional analysis was also completed for each electrical component, with graphs and a spreadsheet highlighting raw data from the testing. Overall, each sensor was functional for a range of temperature and moisture values, while the heating wire was extremely well-suited to Ottawa weather, and could function up to a maximum of -40 degrees Celsius, as stated by the manufacturer. Additionally, client feedback from recent interactions, as well as reflection and justifications provided from the previous two prototypes allowed for improvements and mitigation of flaws to be applied to the current prototype. This was done while keeping in mind the budget of $100 CAD. Lastly, the Wrike plan was updated to display the team’s progress on the final project for the course.

Appendices:

Appendix A: Prototyping III Test Plan

Table 2: Prototyping Test Plan

Test ID	Test Objective (Why)	Description of Prototype used and of Basic Test Method (What)	Description of Results to be Recorded and how these results will be used (How)	Estimated Test duration and planned start date (When)
Prototype 3: Electrical/Sensor System				
1	Testing the conditions and limitations of functionality of the moisture sensor	Once the moisture sensor is integrated with the electrical system, we must check the moisture conditions in which it functions and does not function. This will help 'tell' the mat to turn the heating function on or off, depending on the weather condition, and will thus increase the energy efficiency and reduce operating and maintenance costs of the heated mat panel.	To determine the level of moisture which must be present on the mat surface for the heating element to turn on/off, different known volumes of water will be poured over the mat to determine when the sensor picks up moisture. Additionally, the serial monitor will be observed to determine and record if the volumes of water detected by the sensor are accurate with the known volume of water poured on the mat. The results will ensure that the sensor is working properly, and the conditions of functionality will be reported to the customer in the user manual [PD-K].	The planned duration for this exercise, after the coding and integration of the moisture sensor in the circuit, will be approximately 0.5-1 hour, for recording results and pouring different water volumes on the mat. The planned start date for this task is 23/3/2021. If there are issues, they will be troubleshooted, and testing will resume on 26/3/2021 for the same estimated duration.
2	Testing the conditions and limitations of functionality of the temperature sensor	Once the temperature sensor is integrated with the electrical system, we must check the temperature conditions in which it functions and does not function. This will help 'tell' the mat to turn the heating function on or off, depending on the weather condition, and will thus increase the energy efficiency and reduce operating and maintenance costs of the heated mat panel.	To determine the temperatures that must be present to turn the heating element of the mat on/off, the sensor and circuitry will be tested in different temperature locations, such as in the fridge (with temperatures ranging from 1-5 degrees Celsius), along with the freezer which operates at 0 degrees Celsius. Additionally, the temperature sensor will be placed in the house with central heating at approx. 20 degrees Celsius, along with being placed outside in varying weather conditions in the weeks of 15/3/2021 - 26/3/2021. The outside temperature ranged from negative degrees to double digit temperatures which highlights the typical climate of Ottawa in winter-spring conditions. These results will be recorded by observing the serial monitor which will verify if the temperature sensor is working properly, and will help determine the typical temperatures at which the heating element is switched on/off. The results will be displayed in the user manual [PD-K].	The planned duration for this testing is 10 minutes per test, including set-up and tear-down of the experiment. However, there will need to be multiple dates of testing depending on the weather conditions, as we want to test the sensor in varying temperature scenarios. The estimated start date of this task is 15/3/2021, and testing will continue until 27/3/2021 to allow a broader range of temperatures to test the sensor in.
3	Testing the heated coil functionality	Once the circuitry of the system is assembled and the heated coil is integrated into the system, we must check if the heated coil functions properly, i.e. turns on/off when prompted and if it heats to a sufficient temperature (around 2 degrees Celsius).	To determine if the heated coil turns on/off on command, the coil will be plugged into the electrical socket, and will be checked for sufficient heating (at least 2 degrees Celsius) by using a thermometer which will read the temperature of the coil. This will also be tested in cold temperatures, inside a deep freezer to ensure that the coil does not fail and continues to function properly when facing extreme cold. These results will be recorded manually, and will verify if the heated coil can deliver the temperature stated on its packaging. Additionally, testing the heating wire in the freezer will result in simulating melting conditions on the mat surface by observing if the frozen residue on the freezer walls can melt due to the heat transfer provided in the freezer's frigid environment. Lastly, the time taken to begin the melting process in the freezer will be recorded as this mimics when the snow	The duration for this test is the amount of time taken for the heated coil to start the melting process of ice residue in the freezer. Estimated duration of this would be 3 minutes or less. The start and end date of this experiment is 26/3/2021.

<table>
<tr><td></td><td></td><td></td><td>will start to melt (despite cold surrounding temperature) once in contact with the mat.</td><td></td></tr>
<tr><td>4</td><td>Checking the overall functionality of the relay, with respect to the mat heating function</td><td>The relay testing is an overall test of functionality of the circuitry, Arduino UNO code, temperature and moisture sensors, along with the heated coil. This brings together all individually tested electrical components, and highlights the harmony with which each component works to turn on/off the heating element. This is the ultimate test of the third subsystem of the heated mat panel. Essentially, once the wiring is plugged into a standard 120 V socket, the temperature and moisture condition of the environment will be assessed and should turn on/off the mat based on these conditions.</td><td>The circuitry will be plugged into a standard 120 V socket, which will bring the current into the Arduino UNO and temperature and moisture sensors. The serial monitor will record the values for temperature and moisture in the surrounding environment, which will relay a signal to the heating element to turn on or off, which will signal the success of the test as well as the successful functionality of each individual component in the circuit and its written code. This test will be repeated in various temperature conditions, such as in subzero conditions, and in warmer environments such as in-house, to test if the system relay works properly as described above in various climates. These results will be noted and incorporated in PD-K and presentations of the final design.</td><td>The expected duration of this task is 0.5 hours max, per location of testing. The start date is 25/3/2021, and will continue until various climate (temperature and moisture) conditions are tested to show comprehensive functionality of the relay.</td></tr>
<tr><td>5</td><td>Testing the dissipation of current from each connector</td><td>We must determine how much internal resistance is present in the electrical system. As this device is a component-based system, there is the possibility that numerous individual plates will be connected together. As the electrical subsystem is an individually functionable system, the point of attachment between the two points of the input and output can have long term negative impacts on the functionality of the device.</td><td>Must determine the percent efficiency of the materials used; the Automatic Electric Heat Cable Kit by Frost Kinghas many reviews on many sites, research must be done in order to determine this critical information. Research-based verification is optimal as this test will determine a long term feasible solution which is hard to create with our resources.

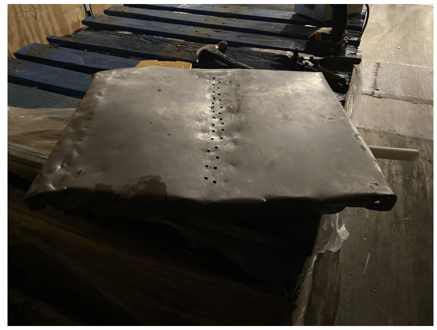
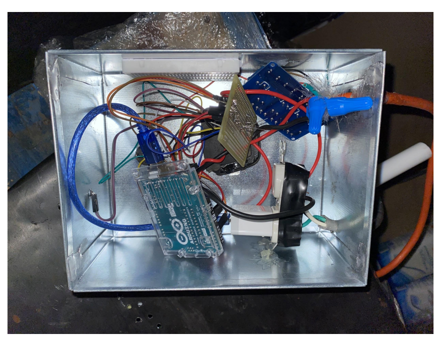
Insulating R-value = 0
[https://www.homedepot.com/p/Frost-King-9-ft-Automatic-Electric-Heat-Cable-Kit-HC9A/205933690#product-overview]</td><td>Research other companies and hardware stores that sell this exact device. Determine, through customer reviews and product information the insulation resistance value (1 hour; minimum five sites)</td></tr>
<tr><td colspan="5">Final Prototype Testing (assembly, drainage and electrical)</td></tr>
<tr><td>6</td><td>Determining the iIdeal curvature for anti tripping/wheel chair friendly device</td><td>Comparative analysis of other such products found on the market. Ramped devices are optimal. After an ideal angle range is found, test for one that would work with the materials purchased as well as the ease of a wheelchair over the ramp</td><td>Must determine the ramp angle using research as well as physical experiments. Maximum slope for hand-propelled wheelchair ramps should be 1" of rise to every 12" of length (4.8 degree angle)
[https://www.brainline.org/article/wheelchair-ramp-information#:~:text=Maximum%20slope%20for%20hand%2Dpropelled,(48%22%20is%20ideal).]
<table><tr><th>Dimensions of single end component</th><th>Angle required</th><th>Length of the ramp required</th></tr><tr><td>5 in. x 20 in. x 15 in</td><td>4.8 degrees</td><td>59 inches</td></tr></table>**Pythagorean Theorem applied**

It can be confirmed that 59 inches is a very large length and that this component cannot be part of our final prototype due to budget limitations</td><td>A small scaled device was implemented to test the ramp angle (2:1 scaled) and it was sufficient. With a large budget/more resources having an effective ramp would be an ideal component of the device.</td></tr>
</table>

7	Typical life of basis materials (typical life) of surface material	Our main concern was how well the external friction-creating surface would maintain its coefficient of friction for. Corrosion has the effect of decreasing the coefficient of friction which would disable the purpose of the anti-slip surface material. We picked this option over silicon as silicon becomes highly slippery when wet.	Research information about the sandpaper to determine how well the sandpaper alternative really is. Coefficient of friction: **[Sandpaper on wood>silicon on rubber]** Sandpaper can be toughened by using different materials, but in general this device will probably require additional tracks and grooves.	A large section of sandpaper was used as a" welcome mat" type device one which repetitively rubbed the soles of our shoes. A lot of sandpaper residue was found on the soles of our shoes. This was done in less than 10 minutes therefore it can be confirmed that a sandpaper solution will not be ideal, yet it can be a seasonally replaceable
8	Testing the efficacy of the heating, drainage, and electrical systems with respect to overall heated mat panel function	This is the final, and most important test of the final prototype, which helps determine the overall functionality of the heated mat panel, and requires the full functioning of all three subsystems: electrical/sensor, drainage, and overall assembly. The goal of the heated mat panel is to turn on or off given the temperature and moisture conditions of the environment surrounding the mat, and then melt snow/ice off of the mat surface, and lastly, successfully drain the water through pipes, and out of the system (into manholes). If any issues arise in the individual subsystems, and/or in the overall functionality of the mat, these issues will be recorded and addressed after this deliverable, and before design day.	For this final test, we were initially hoping to test the mat panel in our driveways by placing the mat in its real function environment. Ideally, the snow/ice would be placed on the mat panel, and the function of the melting and drainage would be tested by using snow/ice. However, due to recent warm temperatures and natural snowmelt, we adapted our idea by simulating winter conditions by using a large number of ice cubes (at least 32) and placing them uniform distance apart until the entire mat panel is covered. The mat would then be plugged into a standard 120 V socket, and the temperature and moisture sensors would ideally recognize that the mat needs to turn on. This can also be done by placing the mat panel by a deep freezer or performing the test in a rink setting. The mat would then be tested to see if the ice is melting (with a recording of how long it took to melt), and then the drainage of the ice would be tested (by recording the amount of time taken for the ice to drain out of the system). Additionally, the amount of water in the ice be recorded, and the melted ice will be collected in a bucket (volume will be measured), to see how well the drainage system functions by transmitting water. Ideally, all of the ice on the panel will flow into the drainage and be collected at the end. This result will be recorded manually, and may be used to demonstrate the final prototype in presentations.	The estimated duration of this task will be 0.5 hours, including set-up, tear-down, and calculations/recording of data. The start date of this task is 26/3/2021, and will continue sporadically until the day before design day (7/4/2021), to ensure multiple trials and successes of the final solution.

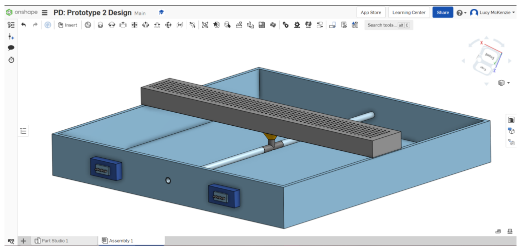
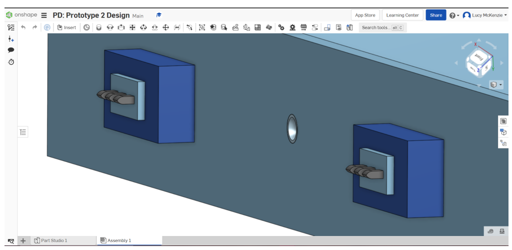
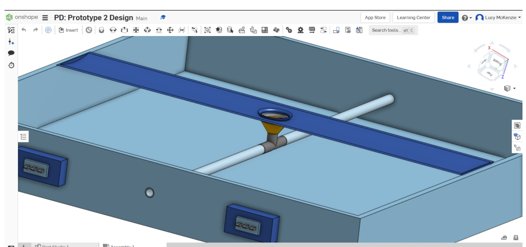
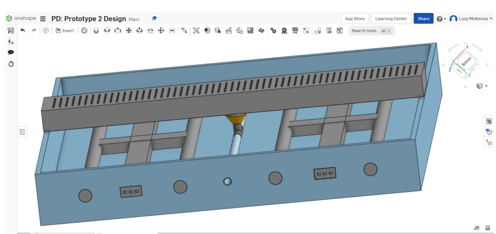
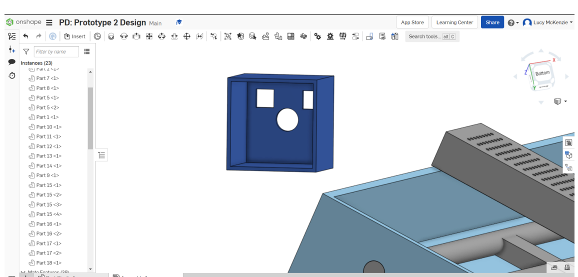
Appendix B: Physical Prototype III Images

Table 3: Physical Prototype III Images

Top view - surface of panel	
Side view - panel with top and drainage pipe on right	
Front view - control box with rain sensor visible on top and manual override switch on front. Grey cable is power coming in and orange is power to the panel	
Top view - interior of control box	

Appendix C: OnShape Prototype III Screenshots

Table 4: OnShape Prototype III Screenshots

View of Design	Screenshot
Overall System	
Assembly Subsystem	
Drainage Subsystem	
Electrical Subsystem	
	
Link to OnShape Platform	https://cad.onshape.com/documents/db9810abd37e6fa39e9326b7/w/4d8be3c85ba8c5cf7b83e25e/e/5c6118eab30f657fcdcd49f7