University of Ottawa: Faculty of Engineering, Department of Mechanical Engineering

MCG2101A: Introduction to Design

PYRAPIDE: The Automatic Ice Pyramid Builder

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Executive Summary

- The designed solution is based on a gantry setup. The prototype uses a rotating cylindrical cam with three different tracks to guide the motion as it places the ice blocks. The three tracks built into the cylindrical cam are used to control three different motions: XZ_1 motion, XZ_2 motion, and Y motion. The tracks are mathematically designed to determine the motion of the cam followers, which extend from the cam and connect to shifting forks in the gearbox.
- The prototype is 11.32 meters long, 3.26 meters wide, and 5.41 meters high. Collapsible legs of the prototype allow for the height to reduce to less than 2.6 meters, the maximum allowable height on a trailer for transportation.
- The flow of water through an impeller and into the cooler is used to replace the requirement for a motor to generate a rotational input. The rotating impeller shaft input turns a Geneva drive, which is connected to two Geneva wheels, each controlling a different feature of the prototype.
- One Geneva wheel controls the cylindrical cam timing mechanism and the input clutches to ensure the appropriate motions will be performed. The other Geneva wheel regulates the transmission, which applies the force for movement in the allowed direction, predetermined by the cylindrical cam.
- Motion in the Y-direction is controlled using the wheels of the prototype, connected to the transmission through a series of shafts and miter gears. Motion in the X and Z directions are controlled using the two pulley mechanisms that are also connected to the transmission.
- Motions are be engaged and disengaged in the transmission using three separate clutches that are connected to the cam followers, which follow the cylindrical cam tracks. The cam followers connect to the clutches using a system of pushrods, bellcranks, and a shifting fork.
- The peltier cooler is attached to a telescoping mechanism which uses the XZ pulley mechanisms to raise or lower its location using a winch, depending on the programmed pathway of the pyramid build.
- Interchangeability of the cylindrical cam and using different cam track paths would allow for any different ice pyramid to be built with only minor modifications to the overall structure of the prototype.
- This prototype is simple to set up, only uses one motor, and gets most of its input energy from the rotating impeller. It is also easy to transport on a flatbed truck to any location requested by the tourists.

Table of Contents

List of Figures

List of Tables

1. Introduction

The purpose of the prototype developed by Team 6 is to design a machine that will automatically build ice lodges to accommodate tourists coming to the capital city. This technical report is accompanied by an assembly drawing of the prototype and should be used as a reference while reading this report. Parts discussed in the report are followed by a number in square brackets, which is referencing the item number of the part in the assembly drawing.

1.1. Problem Statement

The problem statement provided to the team in January 2017 highlighted the following important characteristics that the machine design must follow. The ice lodge will have the shape of a square igloo, with the general pyramid shape. Ice blocks that will be used measure 60cm by 60cm by 30cm and the machine must place these blocks in successive layers. Each layer will consist of a perimeter square to create a lodging with an empty, hollow interior. The base of the pyramid lodge will consist of a 10 by 10 block perimeter square laid on the ground, with each successive layer containing a perimeter square with four fewer blocks. The bottom perimeter square, therefore, will have outer dimensions of 600cm by 600cm. An optional block may be placed on the top of the pyramid, although this is not necessary; the pyramid will consist of 180 blocks, or 181 blocks if the last optional block is added. The machine must be able to build the ice lodges automatically without any human intervention, other than initially starting and stopping the machine. The machine must also be able to build ice lodges at any location requested by the tourists, so ease of transportation is advantageous. Ice blocks are made in a peltier cooler, which is capable of producing one frozen block every 30 seconds. To avoid spilling any water, the valve connecting the water supply to the peltier cooler must automatically close when the peltier cooler is full, and automatically open when the cooler is empty. The peltier cooler must have a hinge or sliding mechanism on its bottom in order to remove or release the frozen ice block. The lodge-building machine must be able to receive the block from the cooler and then lay them in a manner that conforms to the required shape. The machine must only build the ice pyramid from the outside and cannot work from inside the hollow perimeter square. Loads on the lodge must also be minimized as it is being built. The machine operates on electricity supplied from a generator and so all mechanical power must be supplied by no more than three electric motors. The machine may not use any electric controllers with the exception of contact limit switches, and motions of the machine laying down the ice blocks must be purely mechanical. Simplicity, reliability, and elegance of the machine is paramount. A complete and exhaustive list of the operational characteristics and their hierarchical structure from the design mandate methodology is listed in Appendix B of the report.

1.2. Design Solution Overview

The complete prototype solution is shown in Figure 1. The designed solution uses a rotating cylindrical cam [19] with three different tracks [26] to guide the motion of the pyramid-building machine. The three tracks built into the cylindrical cam are used to control three different motions, referred to as XZ_1 motion, XZ_2 motion, and Y motion. The tracks are mathematically designed to determine the motion of the cam followers [24], which extend from the cam and connect to shifting forks [39] in the gearbox. Using the movement of the three followers along each independent track in the cylindrical cam, the shift forks can engage and disengage the different gearbox components to control the XZ_1, XZ_2 or Y motion of the machine.

Figure SEQ Figure * ARABIC 1. Three-dimensional SolidWorks rendering of ice pyramid building prototype.

The ice blocks are created by the prototype in a closed box that uses four thin and ultra-efficient peltier coolers as the walls of the box. Water is pumped from a source reservoir, drives the motion of an impeller [5], and flows through a one-way check valve [50-53] attached to a float box [49] to fill the peltier cooler [48]. Once the peltier cooler has filled with water, which is indicated by the displacement of the float box, the valve closes and blocks the flow of the water into the cooler. The water inside the cooler is able to completely freeze into an ice block after 30 seconds from the peltier cooler walls of the box. Once the ice block is frozen, a motor input slides the bottom doors of the cooler [56-60] open in a method analogous to that of the mechanism used for automatic garage doors. A gas damper [51] attached to the float box delays the opening of the valve and water flow while the bottom of the cooler box is open and the previous ice block is being placed. Once the bottom door has closed, the peltier cooler filling and freezing process repeats itself.

The energy generated using the flow of water through the impeller and to the peltier cooler is used as a substitute for an electric motor. Specifically, the rotation of the impeller blades caused from the water flow is used to drive the main input. The continuous rotation of the impeller is used to rotate a Geneva drive [6] input, which drives two separate Geneva wheels [13]. One Geneva wheel controls the intermittent sequential motion of the cylindrical cam through the worm gear [69] and engages or disengages the gearbox. The second Geneva wheel controls the rotation of the gears in the gearbox, which allows for the appropriate movement in the desired XZ_1, XZ_2, or Y direction.

The height of the peltier cooler box is adjusted using a telescoping system [44-47], which interacts with two independent sets of pulleys [22]. These two sets of pulleys work together to control the height and position of the peltier cooler box when the frozen ice block is placed. When the two pulley mechanisms rotate in the same direction, the carriage pulley [53] attached to the peltier cooler box also rotates, spinning the carriage winch [55] and raising the peltier cooler by a programmed amount. This telescoping height system is in contrast to the translation movement of the carriage [43] along the carriage guide rails, which occurs when the two sets of pulleys are rotating in opposite directions relative to one another.

All elements of the prototype are contained in a setup similar to a gantry crane. Similar to gantry cranes, the prototype developed is fitted with a carrier holding the peltier cooler and can move parallel along the frame. The legs [72-75] of the prototype are collapsible to ensure that it can fit on the flatbed of a truck for transportation. A complete overview of the prototype with its frame [1] removed is illustrated below, in Figure 2. Each different component of the prototype will be discussed separately in the ensuing pages of the report. The sections will give a detailed analysis of the different components, how they work, and why they are a good solution.

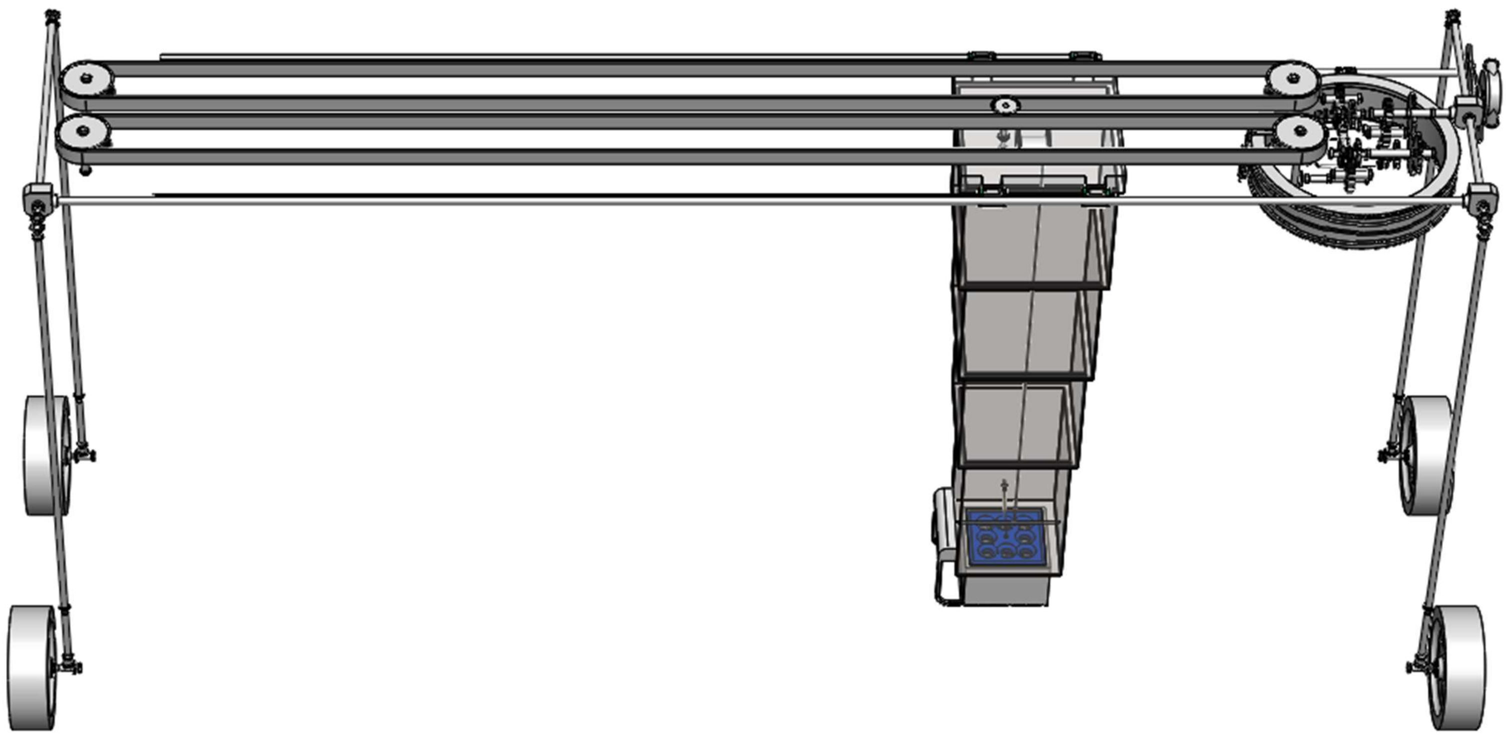


Figure SEQ Figure * ARABIC 2. General schematic of prototype mechanisms; outer frame removed.

2. Water Pump

Water is pumped from a reservoir, travels through the impeller [5], and flows into the peltier cooler [48] through a one-way check valve that closes when the peltier cooler is full and the water is freezing. The pump selected for pumping the water, shown in Figure 3 below, uses a single-phase open 110V motor from Baldor3

Figure 3. Single-phase open 110V motor from Baldor.

3. Impeller

The impeller created on SolidWorks is illustrated in Figure 4. As the pump drives the water from the reservoir towards the peltier cooler, it must first travel through the impeller. The water flows into the impeller from one side, drives the sweeping blades in a circular motion, and then exits the impeller. The continuous flow of the water drives the impeller, which acts as a dynamic pump and increases the flow velocity and kinetic energy of the fluid. As the three-dimensional rendering in Figure 4 also illustrates, the rotational energy of the water that is driving the motion of the impeller is converted into shaft work, providing a continuous rotational input to the Geneva drive [6]. This is used to replace the need for a motor to drive the counting and moving mechanisms of the prototype.

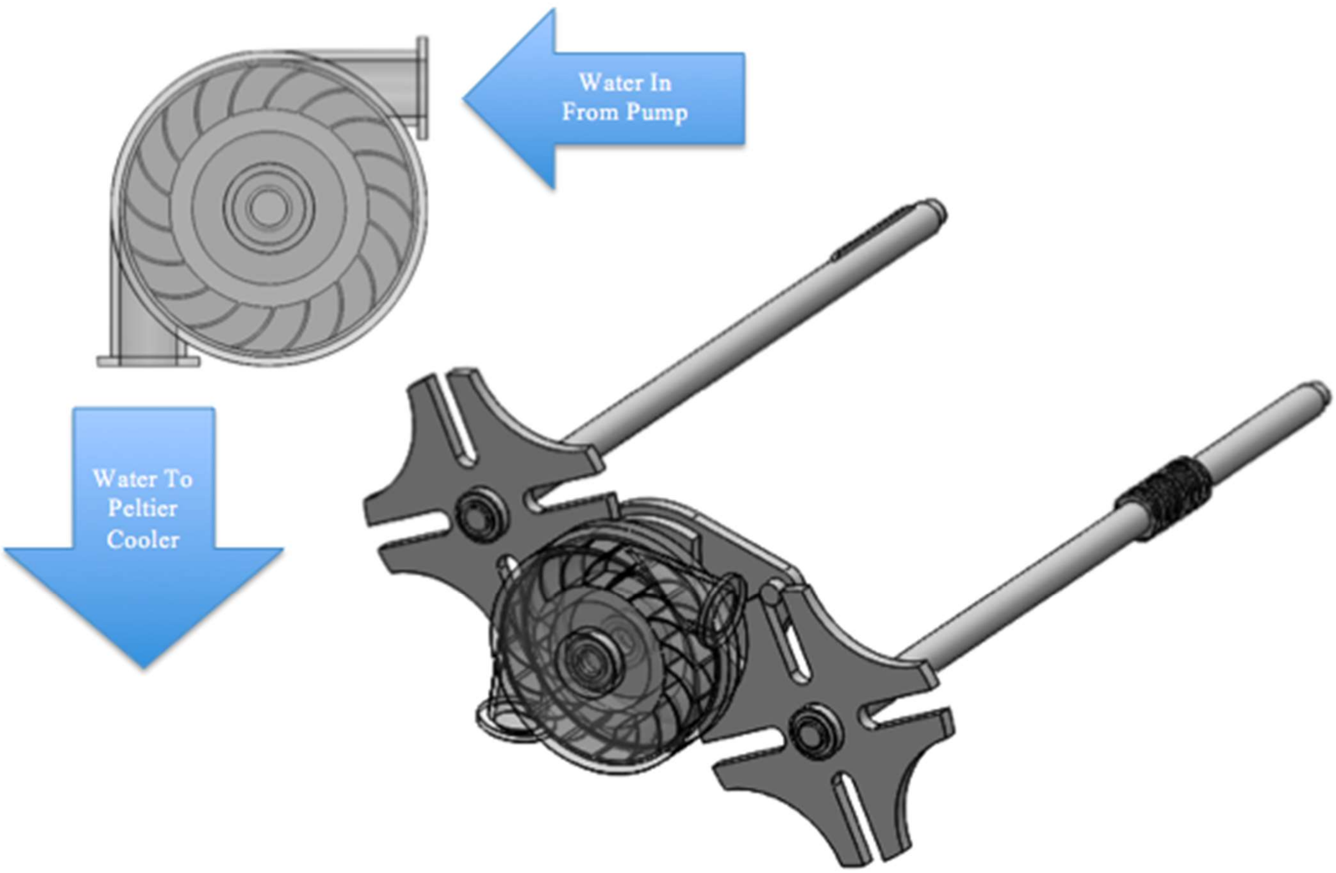
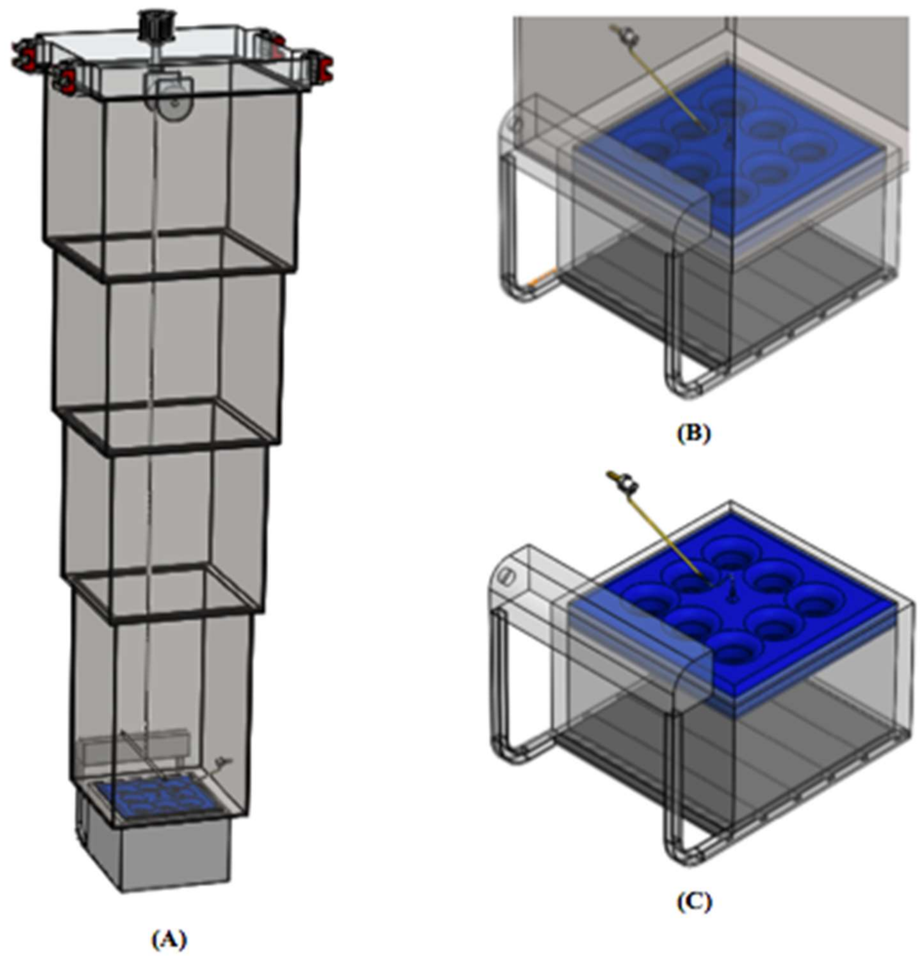


Figure 4. SolidWorks rendering of impeller, used to input a continuous rotation to the Geneva drive.

4. Peltier Cooler

The design of the peltier cooler box [48] is illustrated in Figure 5. The inner dimensions of the peltier cooler box are 60cm by 60cm by 30cm, allowing for ice blocks of the appropriate size to be created. The four side walls of the box are made of thin and ultra-efficient peltier coolers powered by electricity using flexible wiring. The four peltier coolers are capable of creating a frozen ice block from water in 30 seconds. To remove the block, the bottom of the box is able to slide open following a track [, similar to the mechanism used for garage doors.

To create the ice blocks, water flows from the reservoir, through the pump and impeller, and into the peltier cooler box through a one-way check valve connected to a float box. As the liquid water flows in through the valve, it passes through the holes built into the float box and fills the cooler box. As the water level inside the cooler box increases, the float ball will rise. Once the cooler box is filled up to the required 30cm height, the rod connecting the float box to the check valve will close the valve and impede further water flow. After 30 seconds when the peltier cooler walls have completely frozen the water into a solid ice block, the bottom door of the cooler is able to slide open along a set of L-shaped guide rails. The bottom door is made up of five separate, watertight panels so that it is flexible and can



open along this shape, minimizing the space it occupies. The bottom door is able to open and close from a power input provided by a small, lightweight motor attached to the peltier cooler box.

As also illustrated in Figure 5 above, the peltier cooler is attached to a telescoping mechanism that controls the height of the cooler during the placement of the ice blocks; the mechanical movement associated with telescoping peltier cooler mechanism is discussed further into the report.

Figure 5. (A) SolidWorks rendering of the complete telescoping peltier cooler box; (B) Transparent wall SolidWorks render of peltier cooler box; (C) Isometric and isolated SolidWorks rendering of the peltier cooler with two transparent walls.

5. Input Geneva Mechanisms

The continuous rotating shaft work created by the impeller from the water flow is used to drive the rotation of the cylindrical cam counting mechanism as well as the XZ_1, XZ_2, and Y motions from the gearbox system. These two sequences are controlled independently using the continuous input from a Geneva drive that communicates with two Geneva wheels to intermittently control both systems. The Geneva mechanism, cylindrical cam counting mechanism, and motion transmission gearbox are illustrated in the two SolidWorks rendered images below, Figure 6 and Figure 7.

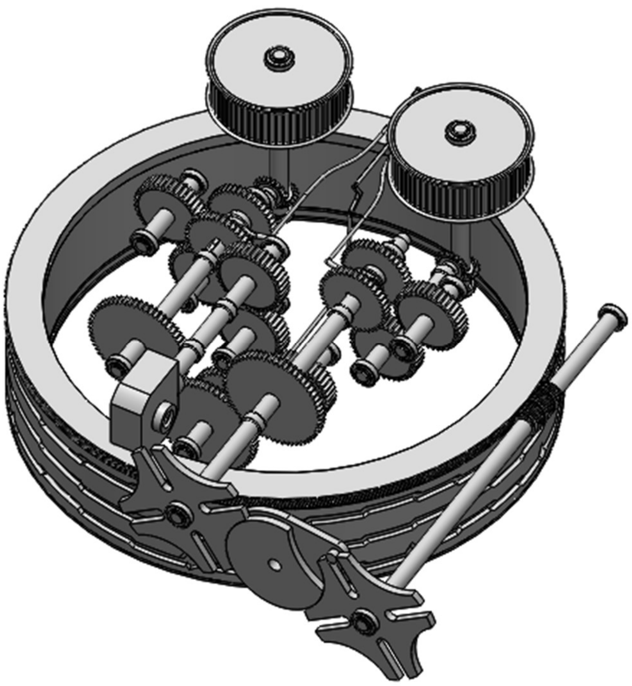


Figure 6. SolidWorks render of Geneva input, barrel cam mechanism, and movement transmission mechanism, first view.

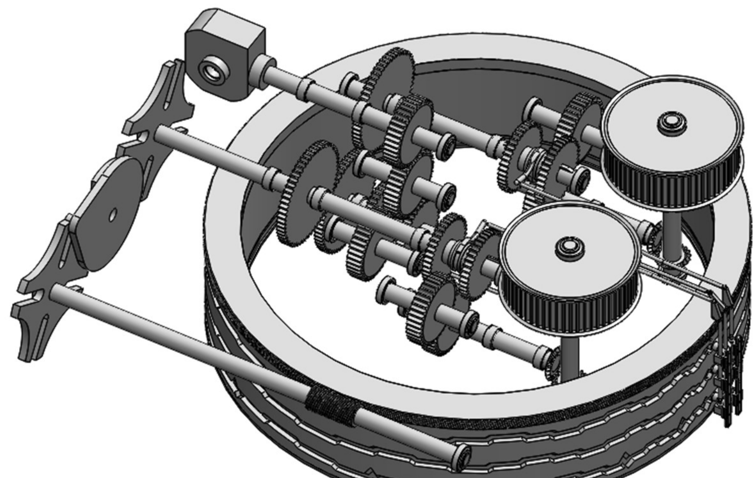


Figure 7. SolidWorks render of Geneva input, barrel cam mechanism, and movement transmission mechanism, second view.

The Geneva drive is connected to the shaft of the impeller and rotates continuously at a fixed speed. When the Geneva drive interacts with the four-slotted Geneva wheel to its left, there is a quantized rotation of the cylindrical cam in the clockwise direction from a top-down view. When the drive interacts with the four-slotted Geneva wheel located on its right, there is a quantized movement of the peltier cooler carrier or gantry wheels in the preprogrammed direction. Both the cylindrical cam counting system and the mechanically quantized movement procedure are described fully in the two following sections of the report.

6. Rotating Cylindrical Cam Mechanism

The complete rotating cylindrical cam mechanism and pushrod system is shown in Figure 8. The cylindrical cam has an outer diameter of 1500mm. The rotation of the cylindrical cam is controlled through the intermittent rotary motion of the Geneva wheel, driven by the continuous input rotation of the Geneva drive. The Geneva wheel is fitted with four slots and, as such, will make a one-quarter turn for every full rotation of the Geneva drive. The cylindrical cam will rotate $1/361^{th}$ of a complete circle for every one-quarter turn of the Geneva wheel until the cams have completed a full rotation. As can be seen in *Figure #*, when considering the profile of one of the cylindrical cams, the path traversed by that cam involves the cam following a track in one of three positions: the cam is either following a middle position, following a higher position by passing through an incline, or following a lower position by passing through a decline. The three tracks on the cylindrical cam mechanism are used to sequence the Y, XZ, and XZ_2 mechanism motions.

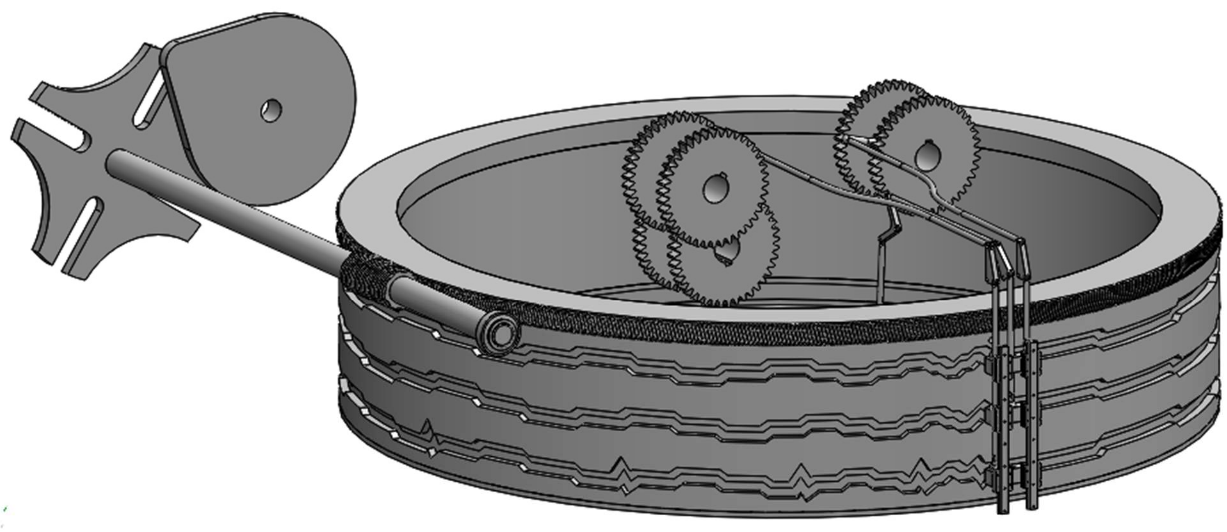


Figure 8. SolidWorks rendering of the rotating barrel cam mechanism, cam tracks, and cam followers connecting to shifting forks.

Figure 9 below unwraps the cylindrical and shows the cam follower tracks in a plan view, projected onto the horizontal plane. As seen in the figure, three separate cam tracks are cut into the cylindrical cam. The bottom cam track controls the XZ_1 mechanisms and motion; the middle cam track

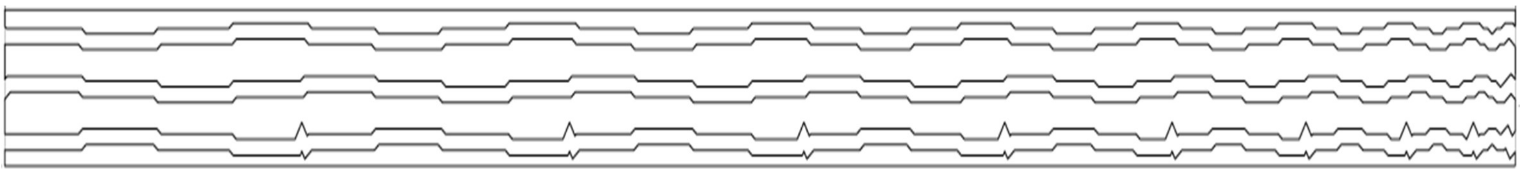


Figure 9. Unwrapped view of the barrel cam follower tracks programming XZ_1, XZ_2, and Y motion.

controls the Y mechanisms and motion; the top track guides the XZ_2 mechanisms and motion. Each independent track is created mathematically to map and control the movement of the machine to build the ice pyramid from start to finish in successively smaller perimeter squares. The mathematical model of each cam track was done in an Excel spreadsheet and the output table, Table 1, is included in Appendix A at the end of the report. Figure 10 takes the Excel outputs and illustrates the three cam tracks as a flat pattern layout before they are wrapped around the cylindrical.

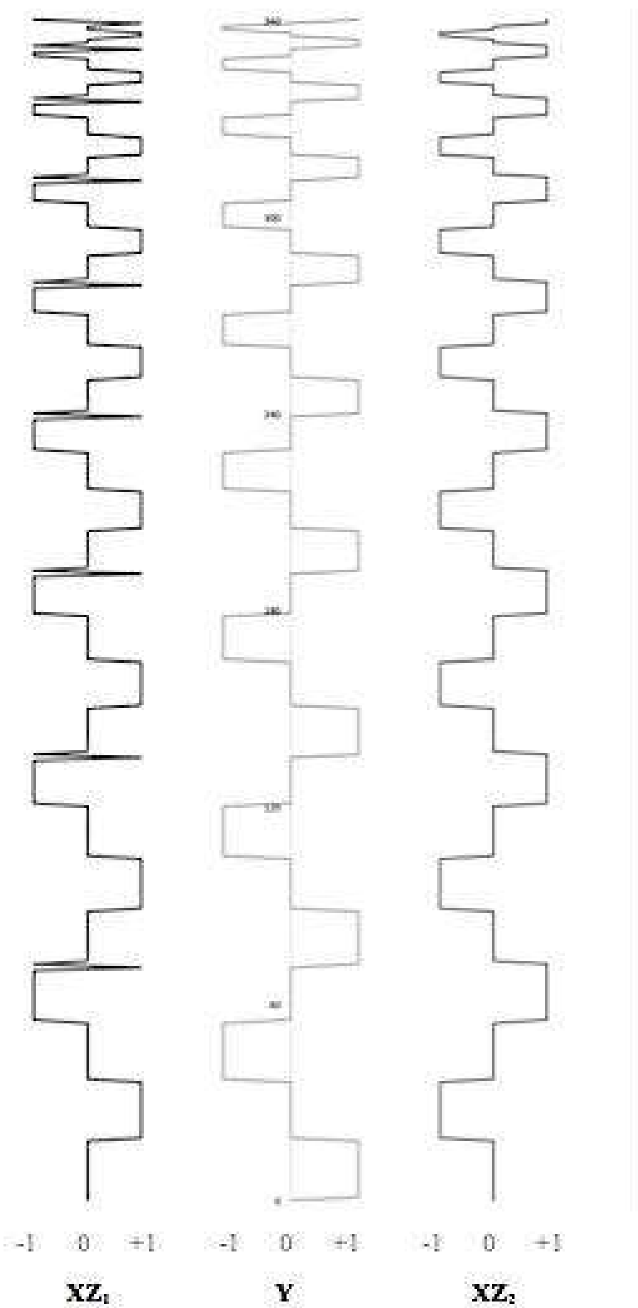


Figure 10. Calculated flat pattern layout of barrel cam tracks.

7. Transmission for Controlled Movement

An overview of the movement controlling mechanism is shown in Figure 11. The cylindrical cam mechanism this prototype employs is analogous to that of a shifting mechanism for a dual clutch transmission. As the cylindrical cam rotates and the cam followers move along the three different tracks, these movements engage and translate three different gear sets, associated to different movements of the machine. As a result, the movement shifting mechanism can be engaged and disengaged by the rotation of the cylindrical cam and subsequent translation of the three cam followers along their respective tracks.

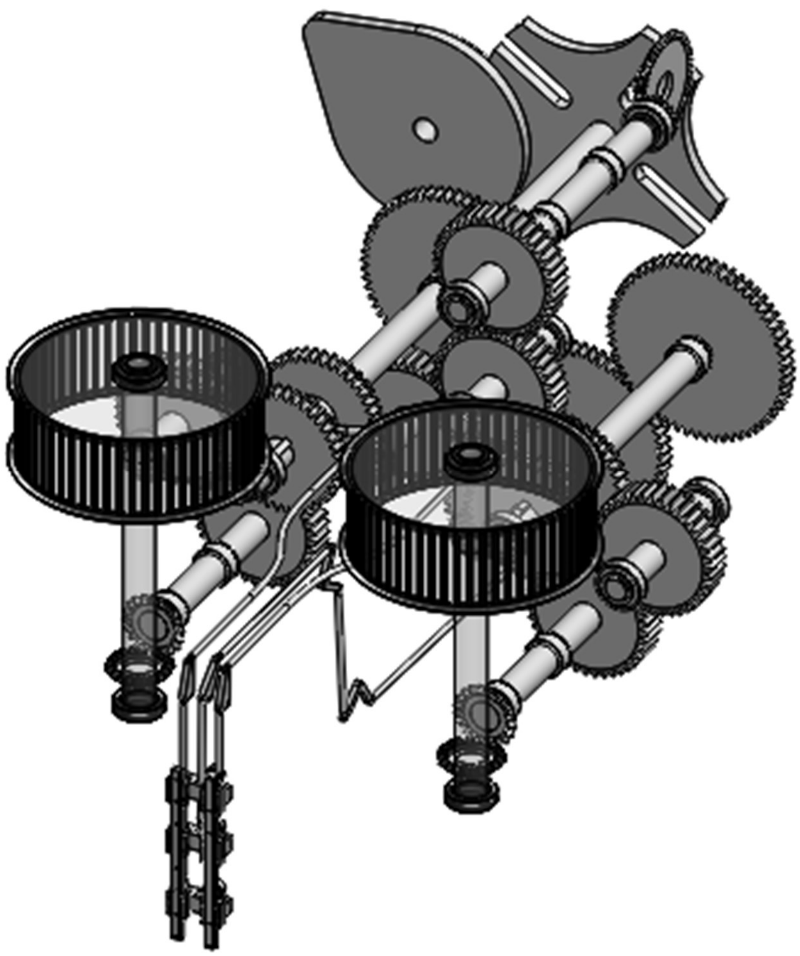


Figure 11. Transmission mechanism for XZ_1, XZ_2, and Y motions

An enlarged view of the cam follower region in Figure 12 gives insight into the characteristics of the mechanism and how it operates. Connecting rods extend from the cam followers and are guided by a linear bearing to add stability to the connecting rods. In this region, movement of the cam followers along the track will move these connecting rods vertically, upward and downward. A bellcrank linkage is attached to the end of these vertical rod segments and changes the motion of the connecting rods by

90 degrees. This means that the initial vertical movement of the connecting rods is changed to a horizontal movement. The applied horizontal movement connects to a shifting fork body that pushes and pulls the input gear mechanism, which controls the different motions of the prototype.

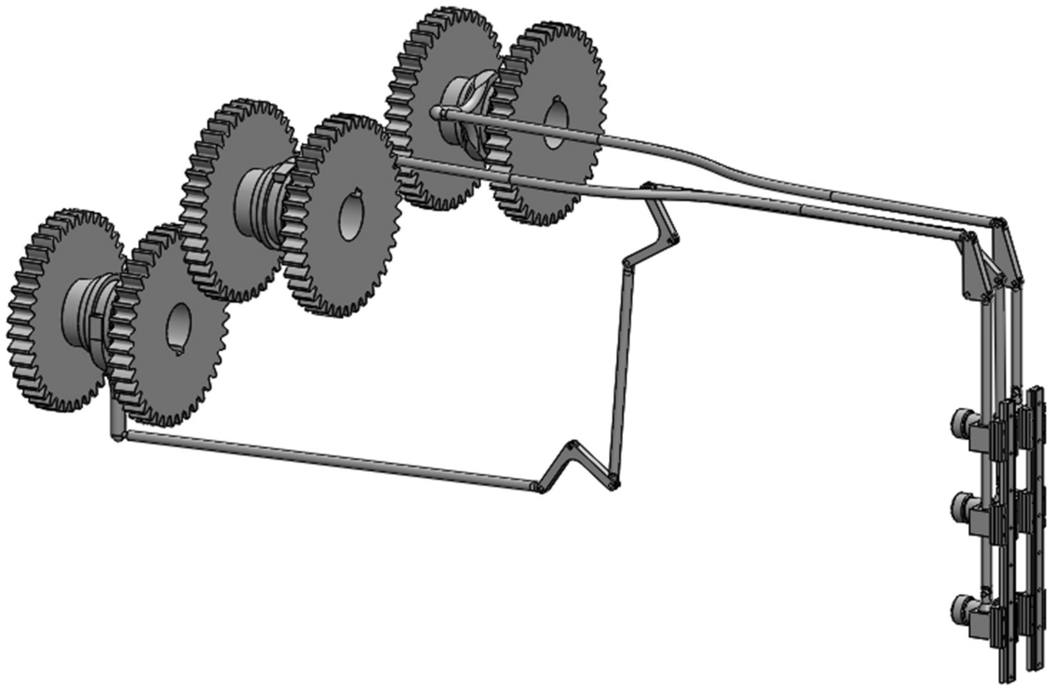


Figure 12. Enlarged SolidWorks rendering of cam follower and shifting gear mechanism.

Figure 13 below illustrates the complete interaction between the cylindrical cam timing mechanism and the transmission mechanism for movement. The cylindrical cam and the transmission controlling the pre-programmed movement of the prototype have been colour-coded in this figure to better recognize the different interactions that take place within the gearbox to control different movements. Shifting forks are connected to the dual input gear mechanism analogous to a clutch. From the motion of the cam follower along its mathematically programmed track, the connecting rod and shifting fork setup is capable of moving the input clutch to activate the scheduled forward, neutral, or reverse direction movement of the gearbox mechanism. In other words, the timing mechanism of the cylindrical cam controls the input clutches to ensure the appropriate motions will be performed, while the transmission is what actually applies the force for movement in the allowed direction, predetermined by the cylindrical cam.

This also explains why two separate Geneva wheels are employed in the design, each intermittently controlling a separate feature. First, the yellow Geneva wheel rotates the cylindrical cam

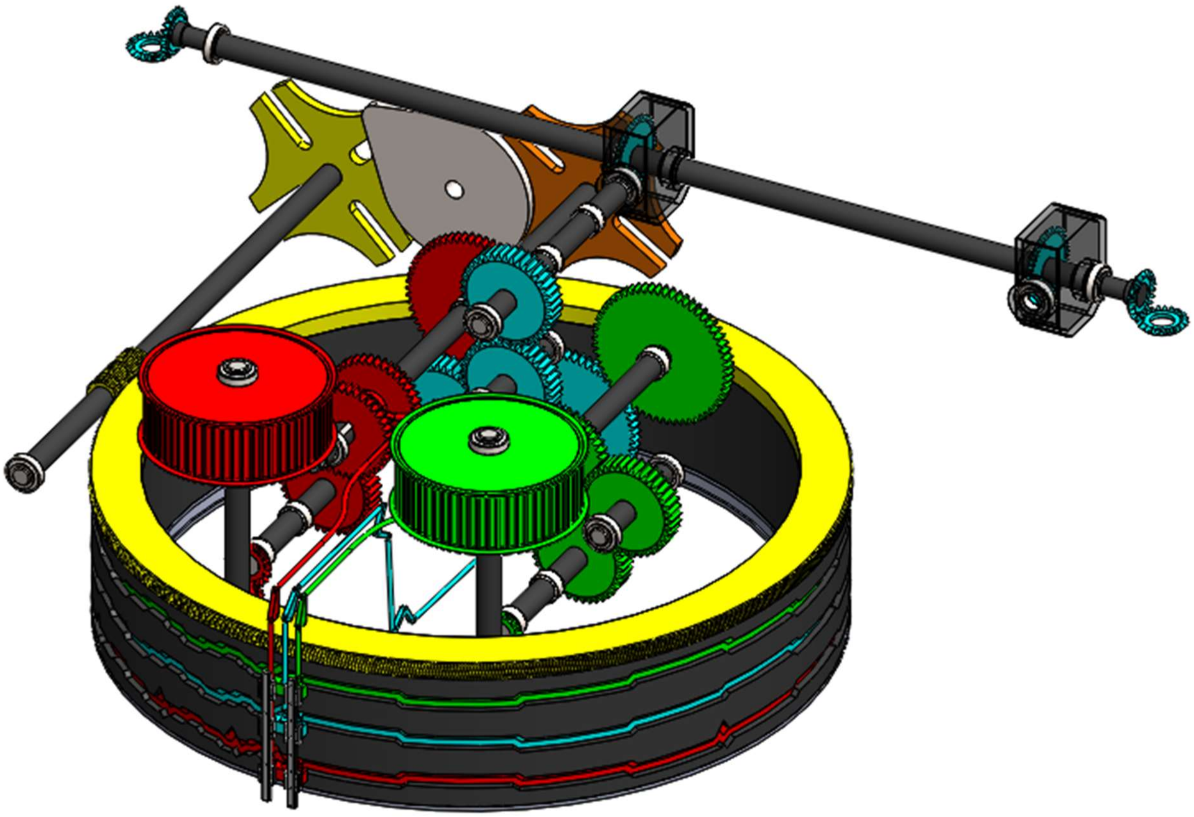


Figure 1 SEQ Figure * ARABIC 3. Colour-coded SolidWorks rendering of the barrel cam and transmission.

for a brief moment and the cam followers activate or deactivate the appropriate clutches in the transmission, which are presently stationary. Then, the orange Geneva wheel spins and there is an appropriate movement in a certain direction, now that a certain clutch combination has been activated or deactivated. Keeping in mind the colour-code, Figure 13 also allows for a clear identification of each separate movement system: the yellow represents the cylindrical cam timing mechanism; the red components are part of the XZ_1 movement system; the green components are part of the XZ_2 movement system; and the blue components are part of the Y movement system. The cam track mechanisms determining the XZ_1 and XZ_2 motions and the Y motion are discussed below, respectively.

8. XZ_1 and XZ_2 Motion

In the case of motion along the X and Z directions, a mechanism consisting of belts and pulleys is used. One of the possible motion sequences of the transmission is illustrated below in Figure 14. As is shown, two pulleys labelled XZ_1 and XZ_2 are attached to two different belts. Each of XZ_1 and XZ_2 pulley systems has their cam profiles, as previously referenced: the top cam track corresponds to XZ_2 and the bottom track corresponds to XZ_1. When both cams follow their respective higher track positions, indexed as '1', both XZ_1 and XZ_2 pulleys and belts turn clockwise. This will result in a counter clockwise torque being applied on the carriage gear that is placed between the belts and, as the figure illustrates, the peltier cooler box moves upwards in the Z–direction. When both cams for XZ_1 and XZ_2 follow the middle level of their respective cam track, which is indexed by '0', the X and Z motions are in the neutral position and are not engaged so there is no movement. When both cams follow their respective lower lines, indexed by '-1', both XZ_1 and XZ_2 pulleys and belts turn counter clockwise. This will result in a clockwise torque being applied on the carriage gear that's placed between the belts and as a result the Peltier Cooler moves downwards in the Z–direction. The telescoping feature of the peltier cooler box is simple yet effective, and allows for a prototype that can become smaller and easier to transport from one desired location to another.

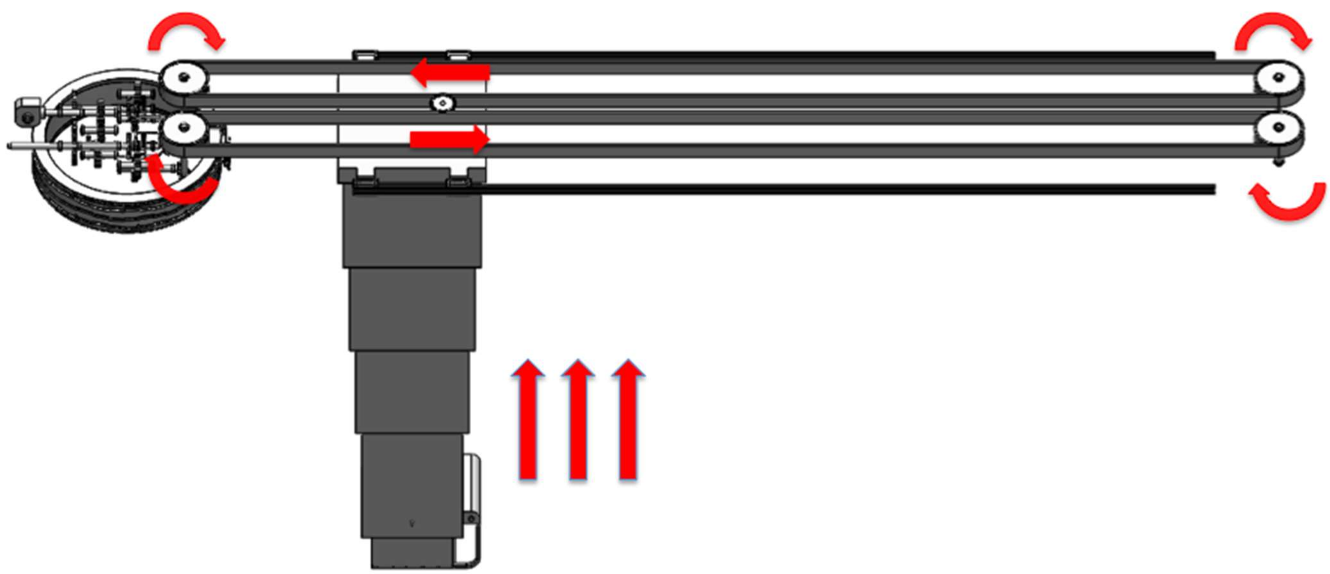


Figure 14. Motion Pattern of the telescoping peltier cooler box moving upward.

In addition to motion along the Z–direction, this mechanism is also used to allow for motion of the peltier cooler box carriage in the X–direction. When the cam corresponding to the XZ_1 belt and pulley mechanism follows its respective lower line on its path profile, indexed by '-1', and the XZ_2 belt and pulley mechanism follows its respective higher line on its path profile, indexed by '1', the XZ_1 and XZ_2 pulleys and belts rotate counter clockwise and clockwise respectively, resulting in the carriage gear and, by extension, the carriage moving to the left, which is taken to be the negative X-direction. When the cam corresponding to the XZ_1 belt and pulley mechanism follows its respective higher line on its path profile, indexed by '1', and the XZ_2 belt and pulley mechanism follows its respective lower line on its path profile, indexed by '-1', the XZ_1 and XZ_2 pulleys and belts rotate clockwise and counter clockwise respectively, resulting in the carriage gear and, by extension, the carriage moving to the right, which is taken to be the positive X–direction.

9. Y motion

The components used to control the Y motion of the machine connect to the four wheels of the gantry and are shown in Figure 15. Referring back to the cylindrical cam tracks, the middle cam track is designated for Y motion of the machine. When the cam is following the middle line, indexed by ‘0’ on the cam track, the Y motion is disengaged and the machine does not move along the Y direction. When the cam is following the higher line, indexed by ‘1’, the Y motion is engaged and the machine moves in the positive Y-direction which is chosen to be South of its initial start position. When the cam is following the lower line, indexed by ‘-1’, the Y motion is engaged and reversed so that the machine moves North of its initial start position. Appropriate motion is controlled in each independent wheel by using three differential clutch systems along the skeletal frame of the shafts.

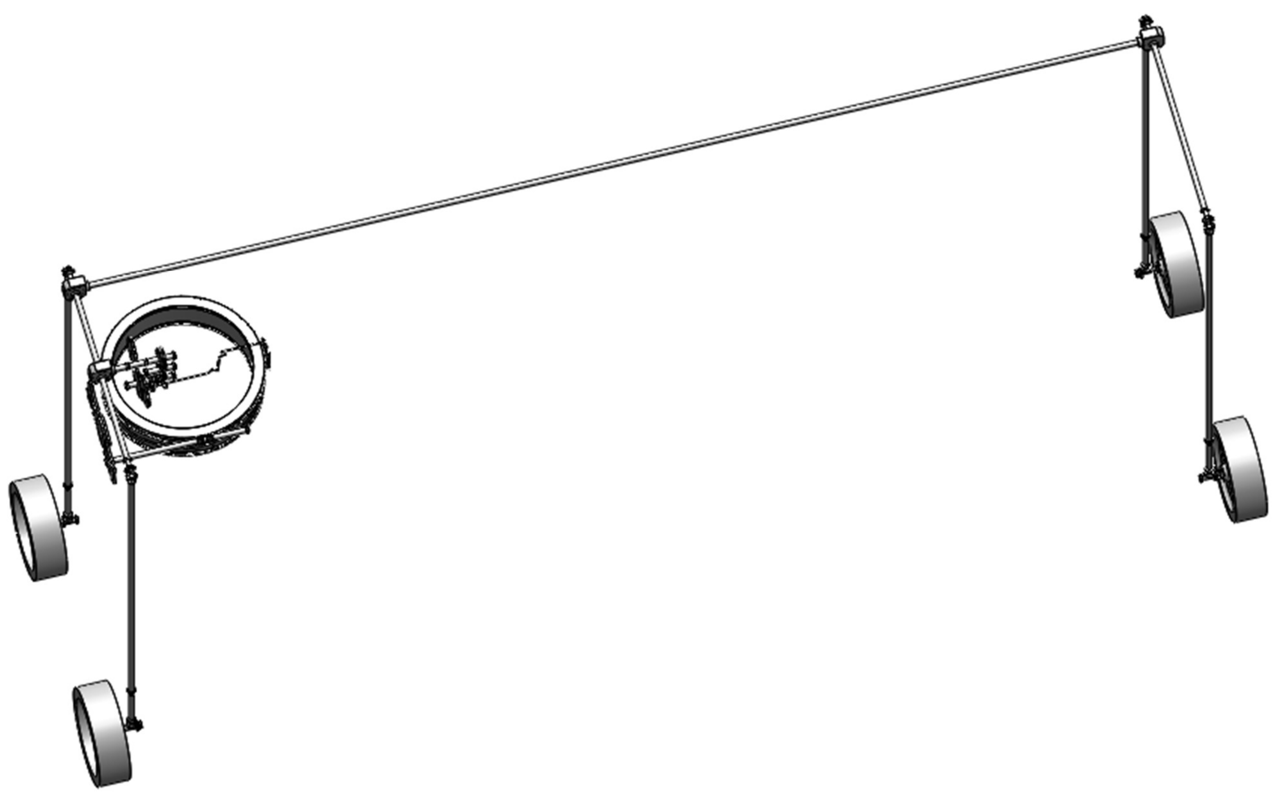


Figure 15. Components used for Y motion of the prototype.

10. Conclusion

The prototype offered as a solution for the tourists coming to the Capital region offers several advantages in its design and relative elegance. First of all, with the high demand of tourists coming to the Capital region in the winter, it is important to have a machine that will be reliable and will always build the correct structure. The mathematically programmed cylindrical cam this prototype uses guarantees that the ice blocks will be put down in their correct location, and can guarantee a consistent ice pyramid structure after each full use. Secondly, with the increase in global interest in sustainable and green energy use it is important that the Canadian Capital region lead by example. This prototype only uses one motor and uses the energy of the flowing water through the impeller to drive its main functions, which may be seen by the international community as an innovative and creative way to bring the ideas of green energy into the travel and tourism market.

The machine is also very easy to transport because of its collapsible legs, which allows for a safe and efficient transportation from one location to another on the back of a flatbed truck. The collapsed height of the structure meets highway requirements set in place by the Government of Ontario and would be safe to bring onto roadways. The ease of transportation is also important for tourists who request an ice pyramid to be built at a certain location.

Finally, this prototype may have implications that extend beyond simply creating a 10-block by 10-block perimeter base square. As the cylindrical cam tracks program the movement of the machine and subsequent placement of the ice blocks, this suggests that other cylindrical cams with different sizes and tracks be created and made to build a pyramid of different dimensions. Although this has not been tested by the company, being able to substitute out one cylindrical cam track for another can allow for pyramids of different sizes to be built. This has important financial implications that could increase the revenue brought in by this prototype, by being able to scale the price of the ice pyramid lodge with the number of blocks or perimeter squares constructed.

References

Baldor Motor Image:

http://www.baldor.com/brands/baldor-reliance/products/motors/ac-motors/general-purpose/single-phase-open-motors

Linear Guide for Cam Followers (Rail + Carriage):

https://grabcad.com/library/cpc-mr-15ml-1

Miniature Rail Guides for The Carriage:

http://www.pbclinear.com/Mini-Rail-Miniature-Linear-Guide

One-Way Check Valve:

https://grabcad.com/library/herose-check-valve-05416-1012-0004_sw0001-40-1

Appendix A: Excel Calculations for Programmed Movement

Table SEQ Table * ARABIC 1. Excel Calculations for Programmed Movement

Index Position (deg.)	Index distance	"X Indexer"	"Z Indexer"	"Y Indexer"	(XZ)_1 Indexer	(XZ)_2 Indexer
0	0	0	0	0	0	0
1	1.027851109	0	0	1	0	0
2	2.055702218	0	0	1	0	0
3	3.083553328	0	0	1	0	0
4	4.111404437	0	0	1	0	0
5	5.139255546	0	0	1	0	0
6	6.167106655	0	0	1	0	0
7	7.194957764	0	0	1	0	0
8	8.222808874	0	0	1	0	0
9	9.250659983	0	0	1	0	0
10	10.27851109	0	0	1	0	0
11	11.3063622	0	0	1	0	0
12	12.33421331	0	0	1	0	0
13	13.36206442	0	0	1	0	0
14	14.38991553	0	0	1	0	0
15	15.41776664	0	0	1	0	0
16	16.44561775	0	0	1	0	0
17	17.47346886	0	0	1	0	0
18	18.50131997	0	0	1	0	0
19	19.52917107	1	0	0	0.787401575	-0.787401575
20	20.55702218	1	0	0	0.787401575	-0.787401575
21	21.58487329	1	0	0	0.787401575	-0.787401575
22	22.6127244	1	0	0	0.787401575	-0.787401575
23	23.64057551	1	0	0	0.787401575	-0.787401575
24	24.66842662	1	0	0	0.787401575	-0.787401575
25	25.69627773	1	0	0	0.787401575	-0.787401575
26	26.72412884	1	0	0	0.787401575	-0.787401575
27	27.75197995	1	0	0	0.787401575	-0.787401575
28	28.77983106	1	0	0	0.787401575	-0.787401575
29	29.80768217	1	0	0	0.787401575	-0.787401575
30	30.83553328	1	0	0	0.787401575	-0.787401575
31	31.86338439	1	0	0	0.787401575	-0.787401575
32	32.89123549	1	0	0	0.787401575	-0.787401575
33	33.9190866	1	0	0	0.787401575	-0.787401575
34	34.94693771	1	0	0	0.787401575	-0.787401575
35	35.97478882	1	0	0	0.787401575	-0.787401575
36	37.00263993	1	0	0	0.787401575	-0.787401575
37	38.03049104	0	0	-1	0	0

38	39.05834215	0	0	-1	0	0
39	40.08619326	0	0	-1	0	0
40	41.11404437	0	0	-1	0	0
41	42.14189548	0	0	-1	0	0
42	43.16974659	0	0	-1	0	0
43	44.1975977	0	0	-1	0	0
44	45.22544881	0	0	-1	0	0
45	46.25329991	0	0	-1	0	0
46	47.28115102	0	0	-1	0	0
47	48.30900213	0	0	-1	0	0
48	49.33685324	0	0	-1	0	0
49	50.36470435	0	0	-1	0	0
50	51.39255546	0	0	-1	0	0
51	52.42040657	0	0	-1	0	0
52	53.44825768	0	0	-1	0	0
53	54.47610879	0	0	-1	0	0
54	55.5039599	0	0	-1	0	0
55	56.53181101	-1	0	0	-0.787401575	0.787401575
56	57.55966212	-1	0	0	-0.787401575	0.787401575
57	58.58751322	-1	0	0	-0.787401575	0.787401575
58	59.61536433	-1	0	0	-0.787401575	0.787401575
59	60.64321544	-1	0	0	-0.787401575	0.787401575
60	61.67106655	-1	0	0	-0.787401575	0.787401575
61	62.69891766	-1	0	0	-0.787401575	0.787401575
62	63.72676877	-1	0	0	-0.787401575	0.787401575
63	64.75461988	-1	0	0	-0.787401575	0.787401575
64	65.78247099	-1	0	0	-0.787401575	0.787401575
65	66.8103221	-1	0	0	-0.787401575	0.787401575
66	67.83817321	-1	0	0	-0.787401575	0.787401575
67	68.86602432	-1	0	0	-0.787401575	0.787401575
68	69.89387543	-1	0	0	-0.787401575	0.787401575
69	70.92172654	-1	0	0	-0.787401575	0.787401575
70	71.94957764	-1	0	0	-0.787401575	0.787401575
71	72.97742875	0	1	0	0.787401575	0.787401575
72	74.00527986	-1	0	1	-0.787401575	0.787401575
73	75.03313097	0	0	1	0	0
74	76.06098208	0	0	1	0	0
75	77.08883319	0	0	1	0	0
76	78.1166843	0	0	1	0	0
77	79.14453541	0	0	1	0	0
78	80.17238652	0	0	1	0	0
79	81.20023763	0	0	1	0	0
80	82.22808874	0	0	1	0	0

81	83.25593985	0	0	1	0	0
82	84.28379096	0	0	1	0	0
83	85.31164206	0	0	1	0	0
84	86.33949317	0	0	1	0	0
85	87.36734428	0	0	1	0	0
86	88.39519539	0	0	1	0	0
87	89.4230465	0	0	1	0	0
88	90.45089761	0	0	1	0	0
89	91.47874872	1	0	0	0.787401575	-0.787401575
90	92.50659983	1	0	0	0.787401575	-0.787401575
91	93.53445094	1	0	0	0.787401575	-0.787401575
92	94.56230205	1	0	0	0.787401575	-0.787401575
93	95.59015316	1	0	0	0.787401575	-0.787401575
94	96.61800427	1	0	0	0.787401575	-0.787401575
95	97.64585537	1	0	0	0.787401575	-0.787401575
96	98.67370648	1	0	0	0.787401575	-0.787401575
97	99.70155759	1	0	0	0.787401575	-0.787401575
98	100.7294087	1	0	0	0.787401575	-0.787401575
99	101.7572598	1	0	0	0.787401575	-0.787401575
100	102.7851109	1	0	0	0.787401575	-0.787401575
101	103.812962	1	0	0	0.787401575	-0.787401575
102	104.8408131	1	0	0	0.787401575	-0.787401575
103	105.8686642	1	0	0	0.787401575	-0.787401575
104	106.8965154	1	0	0	0.787401575	-0.787401575
105	107.9243665	0	0	-1	0	0
106	108.9522176	0	0	-1	0	0
107	109.9800687	0	0	-1	0	0
108	111.0079198	0	0	-1	0	0
109	112.0357709	0	0	-1	0	0
110	113.063622	0	0	-1	0	0
111	114.0914731	0	0	-1	0	0
112	115.1193242	0	0	-1	0	0
113	116.1471753	0	0	-1	0	0
114	117.1750264	0	0	-1	0	0
115	118.2028776	0	0	-1	0	0
116	119.2307287	0	0	-1	0	0
117	120.2585798	0	0	-1	0	0
118	121.2864309	0	0	-1	0	0
119	122.314282	0	0	-1	0	0
120	123.3421331	0	0	-1	0	0
121	124.3699842	-1	0	0	-0.787401575	0.787401575
122	125.3978353	-1	0	0	-0.787401575	0.787401575
123	126.4256864	-1	0	0	-0.787401575	0.787401575

124	127.4535375	-1	0	0	-0.787401575	0.787401575
125	128.4813887	-1	0	0	-0.787401575	0.787401575
126	129.5092398	-1	0	0	-0.787401575	0.787401575
127	130.5370909	-1	0	0	-0.787401575	0.787401575
128	131.564942	-1	0	0	-0.787401575	0.787401575
129	132.5927931	-1	0	0	-0.787401575	0.787401575
130	133.6206442	-1	0	0	-0.787401575	0.787401575
131	134.6484953	-1	0	0	-0.787401575	0.787401575
132	135.6763464	-1	0	0	-0.787401575	0.787401575
133	136.7041975	-1	0	0	-0.787401575	0.787401575
134	137.7320486	-1	0	0	-0.787401575	0.787401575
135	138.7598997	0	1	0	0.787401575	0.787401575
136	139.7877509	-1	0	1	-0.787401575	0.787401575
137	140.815602	0	0	1	0	0
138	141.8434531	0	0	1	0	0
139	142.8713042	0	0	1	0	0
140	143.8991553	0	0	1	0	0
141	144.9270064	0	0	1	0	0
142	145.9548575	0	0	1	0	0
143	146.9827086	0	0	1	0	0
144	148.0105597	0	0	1	0	0
145	149.0384108	0	0	1	0	0
146	150.0662619	0	0	1	0	0
147	151.0941131	0	0	1	0	0
148	152.1219642	0	0	1	0	0
149	153.1498153	0	0	1	0	0
150	154.1776664	0	0	1	0	0
151	155.2055175	1	0	0	0.787401575	-0.787401575
152	156.2333686	1	0	0	0.787401575	-0.787401575
153	157.2612197	1	0	0	0.787401575	-0.787401575
154	158.2890708	1	0	0	0.787401575	-0.787401575
155	159.3169219	1	0	0	0.787401575	-0.787401575
156	160.344773	1	0	0	0.787401575	-0.787401575
157	161.3726241	1	0	0	0.787401575	-0.787401575
158	162.4004753	1	0	0	0.787401575	-0.787401575
159	163.4283264	1	0	0	0.787401575	-0.787401575
160	164.4561775	1	0	0	0.787401575	-0.787401575
161	165.4840286	1	0	0	0.787401575	-0.787401575
162	166.5118797	1	0	0	0.787401575	-0.787401575
163	167.5397308	1	0	0	0.787401575	-0.787401575
164	168.5675819	1	0	0	0.787401575	-0.787401575
165	169.595433	0	0	-1	0	0
166	170.6232841	0	0	-1	0	0

167	171.6511352	0	0	-1	0	0
168	172.6789863	0	0	-1	0	0
169	173.7068375	0	0	-1	0	0
170	174.7346886	0	0	-1	0	0
171	175.7625397	0	0	-1	0	0
172	176.7903908	0	0	-1	0	0
173	177.8182419	0	0	-1	0	0
174	178.846093	0	0	-1	0	0
175	179.8739441	0	0	-1	0	0
176	180.9017952	0	0	-1	0	0
177	181.9296463	0	0	-1	0	0
178	182.9574974	0	0	-1	0	0
179	183.9853485	-1	0	0	-0.787401575	0.787401575
180	185.0131997	-1	0	0	-0.787401575	0.787401575
181	186.0410508	-1	0	0	-0.787401575	0.787401575
182	187.0689019	-1	0	0	-0.787401575	0.787401575
183	188.096753	-1	0	0	-0.787401575	0.787401575
184	189.1246041	-1	0	0	-0.787401575	0.787401575
185	190.1524552	-1	0	0	-0.787401575	0.787401575
186	191.1803063	-1	0	0	-0.787401575	0.787401575
187	192.2081574	-1	0	0	-0.787401575	0.787401575
188	193.2360085	-1	0	0	-0.787401575	0.787401575
189	194.2638596	-1	0	0	-0.787401575	0.787401575
190	195.2917107	-1	0	0	-0.787401575	0.787401575
191	196.3195619	0	1	0	0.787401575	0.787401575
192	197.347413	-1	0	1	-0.787401575	0.787401575
193	198.3752641	0	0	1	0	0
194	199.4031152	0	0	1	0	0
195	200.4309663	0	0	1	0	0
196	201.4588174	0	0	1	0	0
197	202.4866685	0	0	1	0	0
198	203.5145196	0	0	1	0	0
199	204.5423707	0	0	1	0	0
200	205.5702218	0	0	1	0	0
201	206.598073	0	0	1	0	0
202	207.6259241	0	0	1	0	0
203	208.6537752	0	0	1	0	0
204	209.6816263	0	0	1	0	0
205	210.7094774	1	0	0	0.787401575	-0.787401575
206	211.7373285	1	0	0	0.787401575	-0.787401575
207	212.7651796	1	0	0	0.787401575	-0.787401575
208	213.7930307	1	0	0	0.787401575	-0.787401575
209	214.8208818	1	0	0	0.787401575	-0.787401575

210	215.8487329	1	0	0	0.787401575	-0.787401575
211	216.876584	1	0	0	0.787401575	-0.787401575
212	217.9044352	1	0	0	0.787401575	-0.787401575
213	218.9322863	1	0	0	0.787401575	-0.787401575
214	219.9601374	1	0	0	0.787401575	-0.787401575
215	220.9879885	1	0	0	0.787401575	-0.787401575
216	222.0158396	1	0	0	0.787401575	-0.787401575
217	223.0436907	0	0	-1	0	0
218	224.0715418	0	0	-1	0	0
219	225.0993929	0	0	-1	0	0
220	226.127244	0	0	-1	0	0
221	227.1550951	0	0	-1	0	0
222	228.1829462	0	0	-1	0	0
223	229.2107974	0	0	-1	0	0
224	230.2386485	0	0	-1	0	0
225	231.2664996	0	0	-1	0	0
226	232.2943507	0	0	-1	0	0
227	233.3222018	0	0	-1	0	0
228	234.3500529	0	0	-1	0	0
229	235.377904	-1	0	0	-0.787401575	0.787401575
230	236.4057551	-1	0	0	-0.787401575	0.787401575
231	237.4336062	-1	0	0	-0.787401575	0.787401575
232	238.4614573	-1	0	0	-0.787401575	0.787401575
233	239.4893084	-1	0	0	-0.787401575	0.787401575
234	240.5171596	-1	0	0	-0.787401575	0.787401575
235	241.5450107	-1	0	0	-0.787401575	0.787401575
236	242.5728618	-1	0	0	-0.787401575	0.787401575
237	243.6007129	-1	0	0	-0.787401575	0.787401575
238	244.628564	-1	0	0	-0.787401575	0.787401575
239	245.6564151	0	1	0	0.787401575	0.787401575
240	246.6842662	-1	0	1	-0.787401575	0.787401575
241	247.7121173	0	0	1	0	0
242	248.7399684	0	0	1	0	0
243	249.7678195	0	0	1	0	0
244	250.7956706	0	0	1	0	0
245	251.8235218	0	0	1	0	0
246	252.8513729	0	0	1	0	0
247	253.879224	0	0	1	0	0
248	254.9070751	0	0	1	0	0
249	255.9349262	0	0	1	0	0
250	256.9627773	0	0	1	0	0
251	257.9906284	1	0	0	0.787401575	-0.787401575
252	259.0184795	1	0	0	0.787401575	-0.787401575

253	260.0463306	1	0	0	0.787401575	-0.787401575
254	261.0741817	1	0	0	0.787401575	-0.787401575
255	262.1020328	1	0	0	0.787401575	-0.787401575
256	263.129884	1	0	0	0.787401575	-0.787401575
257	264.1577351	1	0	0	0.787401575	-0.787401575
258	265.1855862	1	0	0	0.787401575	-0.787401575
259	266.2134373	1	0	0	0.787401575	-0.787401575
260	267.2412884	1	0	0	0.787401575	-0.787401575
261	268.2691395	0	0	-1	0	0
262	269.2969906	0	0	-1	0	0
263	270.3248417	0	0	-1	0	0
264	271.3526928	0	0	-1	0	0
265	272.3805439	0	0	-1	0	0
266	273.408395	0	0	-1	0	0
267	274.4362462	0	0	-1	0	0
268	275.4640973	0	0	-1	0	0
269	276.4919484	0	0	-1	0	0
270	277.5197995	0	0	-1	0	0
271	278.5476506	-1	0	0	-0.787401575	0.787401575
272	279.5755017	-1	0	0	-0.787401575	0.787401575
273	280.6033528	-1	0	0	-0.787401575	0.787401575
274	281.6312039	-1	0	0	-0.787401575	0.787401575
275	282.659055	-1	0	0	-0.787401575	0.787401575
276	283.6869061	-1	0	0	-0.787401575	0.787401575
277	284.7147573	-1	0	0	-0.787401575	0.787401575
278	285.7426084	-1	0	0	-0.787401575	0.787401575
279	286.7704595	0	1	0	0.787401575	0.787401575
280	287.7983106	-1	0	1	-0.787401575	0.787401575
281	288.8261617	0	0	1	0	0
282	289.8540128	0	0	1	0	0
283	290.8818639	0	0	1	0	0
284	291.909715	0	0	1	0	0
285	292.9375661	0	0	1	0	0
286	293.9654172	0	0	1	0	0
287	294.9932683	0	0	1	0	0
288	296.0211195	0	0	1	0	0
289	297.0489706	1	0	0	0.787401575	-0.787401575
290	298.0768217	1	0	0	0.787401575	-0.787401575
291	299.1046728	1	0	0	0.787401575	-0.787401575
292	300.1325239	1	0	0	0.787401575	-0.787401575
293	301.160375	1	0	0	0.787401575	-0.787401575
294	302.1882261	1	0	0	0.787401575	-0.787401575
295	303.2160772	1	0	0	0.787401575	-0.787401575

296	304.2439283	1	0	0	0.787401575	-0.787401575
297	305.2717794	0	0	-1	0	0
298	306.2996305	0	0	-1	0	0
299	307.3274817	0	0	-1	0	0
300	308.3553328	0	0	-1	0	0
301	309.3831839	0	0	-1	0	0
302	310.411035	0	0	-1	0	0
303	311.4388861	0	0	-1	0	0
304	312.4667372	0	0	-1	0	0
305	313.4945883	-1	0	0	-0.787401575	0.787401575
306	314.5224394	-1	0	0	-0.787401575	0.787401575
307	315.5502905	-1	0	0	-0.787401575	0.787401575
308	316.5781416	-1	0	0	-0.787401575	0.787401575
309	317.6059927	-1	0	0	-0.787401575	0.787401575
310	318.6338439	-1	0	0	-0.787401575	0.787401575
311	319.661695	0	1	0	0.787401575	0.787401575
312	320.6895461	-1	0	1	-0.787401575	0.787401575
313	321.7173972	0	0	1	0	0
314	322.7452483	0	0	1	0	0
315	323.7730994	0	0	1	0	0
316	324.8009505	0	0	1	0	0
317	325.8288016	0	0	1	0	0
318	326.8566527	0	0	1	0	0
319	327.8845038	1	0	0	0.787401575	-0.787401575
320	328.9123549	1	0	0	0.787401575	-0.787401575
321	329.9402061	1	0	0	0.787401575	-0.787401575
322	330.9680572	1	0	0	0.787401575	-0.787401575
323	331.9959083	1	0	0	0.787401575	-0.787401575
324	333.0237594	1	0	0	0.787401575	-0.787401575
325	334.0516105	0	0	-1	0	0
326	335.0794616	0	0	-1	0	0
327	336.1073127	0	0	-1	0	0
328	337.1351638	0	0	-1	0	0
329	338.1630149	0	0	-1	0	0
330	339.190866	0	0	-1	0	0
331	340.2187171	-1	0	0	-0.787401575	0.787401575
332	341.2465683	-1	0	0	-0.787401575	0.787401575
333	342.2744194	-1	0	0	-0.787401575	0.787401575
334	343.3022705	-1	0	0	-0.787401575	0.787401575
335	344.3301216	0	1	0	0.787401575	0.787401575
336	345.3579727	-1	0	1	-0.787401575	0.787401575
337	346.3858238	0	0	1	0	0
338	347.4136749	0	0	1	0	0

339	348.441526	0	0	1	0	0
340	349.4693771	0	0	1	0	0
341	350.4972282	1	0	0	0.787401575	-0.787401575
342	351.5250793	1	0	0	0.787401575	-0.787401575
343	352.5529305	1	0	0	0.787401575	-0.787401575
344	353.5807816	1	0	0	0.787401575	-0.787401575
345	354.6086327	0	0	-1	0	0
346	355.6364838	0	0	-1	0	0
347	356.6643349	0	0	-1	0	0
348	357.692186	0	0	-1	0	0
349	358.7200371	-1	0	0	-0.787401575	0.787401575
350	359.7478882	-1	0	0	-0.787401575	0.787401575
351	360.7757393	0	1	0	0.787401575	0.787401575
352	361.8035904	-1	0	1	-0.787401575	0.787401575
353	362.8314416	0	0	1	0	0
354	363.8592927	0	0	1	0	0
355	364.8871438	1	0	0	0.787401575	-0.787401575
356	365.9149949	1	0	0	0.787401575	-0.787401575
357	366.942846	0	0	-1	0	0
358	367.9706971	0	0	-1	0	0
359	368.9985482	0	1	0	0.787401575	0.787401575
360	370.0263993	-1	0	1	-0.787401575	0.787401575

Appendix B: Methodology Class Work

B.1. Mandate, Criteria, and Restrictions

The mandate consists in designing a machine that will build ice lodges to accommodate tourists coming to the capital city. The machine must be able to build ice lodges at any location requested by the tourists. Ice lodges will be square igloos with a general shape of a pyramid. Ice blocks will measure 60cm by 60cm by 30cm and the machine must place these blocks in successive layers. Each layer will consist of a perimeter square to create a lodging with an empty, hollow interior. The base of the pyramid lodge should consist of a 10 x 10 block perimeter square laid on the ground, with each successive layer containing a perimeter square with 4 fewer blocks. An optional block may be placed at the top of the pyramid. The machine must build the lodges automatically without human intervention except for initially starting and stopping the machine. One ice block will be made every 30 seconds in a peltier cooler. The machine must receive the block from the cooler and lay them in the required shape. The machine may only build the lodge from the outside. Loads on the lodge must be minimized as it is being built. The machine operates on electricity from a generator and so all mechanical power must be supplied by three electric motors or less. The machine may not use any electric controllers with the exception of contact limit switches. Motions of the machine laying down ice blocks must be purely mechanical. Simplicity, reliability, and elegance of the machine is paramount.

Criterion and Restrictions

Below is a list of the restrictions and criteria for the machine. Restrictions are listed numerically, while criteria are listed alphabetically. The absolute weighing of each operational characteristic is located in Figure 1.

Restrictions

1. No parts of the machine may remain inside the pyramid upon completion.
2. All motions required to lay down ice blocks into the required pyramidal shape must be created through purely mechanical means.
3. Machine cannot utilize any electrical controllers - only limit switches.
4. Machine must construct lodgings automatically without human intervention, with the exception of initially positioning, starting and stopping the machine.
5. Machine must automatically receive ice blocks from a peltier cooling unit.
6. Peltier cooling unit must consist of a 5 or 6 sided box with interior dimensions equal to the dimensions of the ice block, with 4 sides consisting of peltier cooling plates, and with a bottom side that slides or hinges open to release the ice block when it has completed freezing.

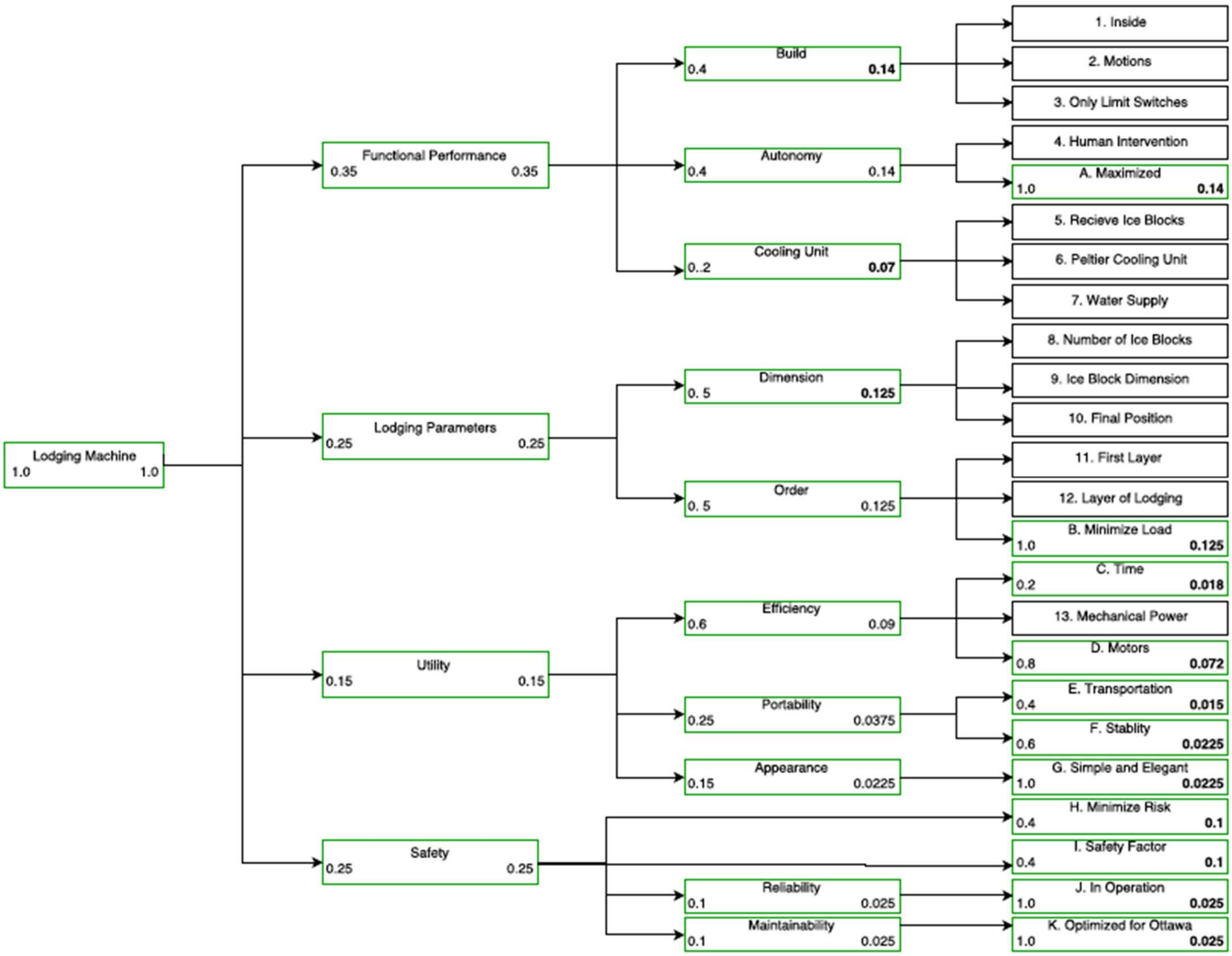
7. Water supply to the cooling unit must be automatically closed using a single valve build when the bottom side of the cooling unit is opened; water supply is reopened when the bottom of the cooling unit is closed.
8. Pyramid lodgings must have no less than 180 blocks; no more than 181 while conforming to a square based pyramidal shape.
9. Each ice block must have dimensions of 60cm x 60cm x 30cm.
10. Each ice block must be laid in its final position such that a 60cm x 60cm side is facing down.
11. First layer of pyramid lodging should consist of a 10 x 10 block perimeter square laid on the ground, with each successive layer containing a perimeter square with 4 fewer blocks.
12. Each layer of pyramid lodging must be completed before ice blocks for subsequent layers may be laid.
13. All mechanical power must be supplied by three electric motors or less.

Criteria

A. Autonomy must be maximized.
B. Minimize the load being applied directly on the pyramid lodging during the building process.
C. Machine must build the pyramid in a reasonable amount of time (~90 minutes suggested).
D. Minimize number of electric motors used; while 3 is the maximum allowable, fewer is better.
E. Machine must be easy to transport from one location to another.
F. Machine should remain stable while in operation.
G. Solution must be designed as simple and elegant as possible.
H. Appropriate safety features on the machine should be implemented to minimize risk to the operator and area surrounding the pyramid lodging.
I. Machine should have a safety factor greater than the expected load created by the ice blocks.
J. Machine should be as reliable as possible while in operation.
K. Machine should be optimized for performance in Ottawa winter weather conditions.

Hierarchical Structure of Operational Characteristics

The diagram below illustrates the hierarchical structure of the criteria and restrictions for the mandate. Restrictions are illustrated in black boxes with the number value corresponding to the restriction list above. Similarly, criteria are listed in green boxes with a letter value corresponding to the list in the previous section of the mandate. Absolute weights of the different criterion have been determined to evaluate possible solutions and guide decision.


Lodging Machine
1.0
1.0
Functional Performance
0.35
0.35
Lodging Parameters
0.25
0.25
Utility
0.15
0.15
Safety
0.25
0.25
Build
0.4
0.14
Autonomy
0.4
0.14
Cooling Unit
0. 2
0.07
Dimension
0. 5
0.125
Order
0. 5
0.125
Efficiency
0.6
0.09
Portability
0.25
0.0375
Appearance
0.15
0.0225
Reliability
0.1
0.025
Maintainability
0.1
0.025
1. Inside
2. Motions
3. Only Limit Switches
4. Human Intervention
A. Maximized
1.0
0.14
5. Recieve Ice Blocks
6. Peltier Cooling Unit
7. Water Supply
8. Number of Ice Blocks
9. Ice Block Dimension
10. Final Position
11. First Layer
12. Layer of Lodging
B. Minimize Load
1.0
0.125
C. Time
0.2
0.018
13. Mechanical Power
D. Motors
0.8
0.072
E. Transportation
0.4
0.015
F. Stablity
0.6
0.0225
G. Simple and Elegant
1.0
0.0225
H. Minimize Risk
0.4
0.1
I. Safety Factor
0.4
0.1
J. In Operation
1.0
0.025
K. Optimized for Ottawa
1.0
0.025

B.2. Generation of Solutions

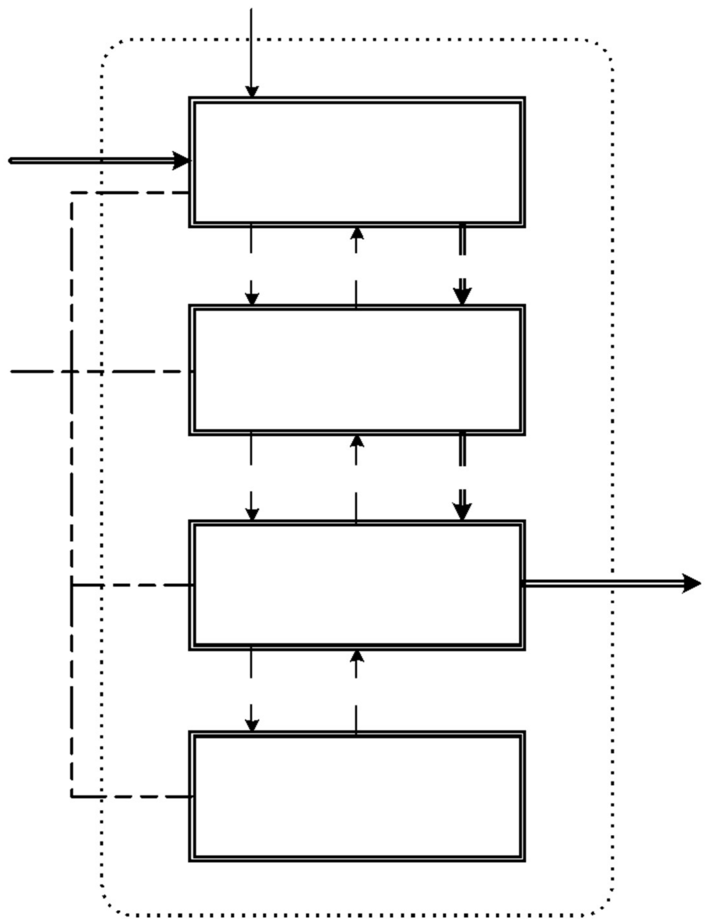


Figure 4: Machine Functional Analysis Chart

S_1: Operator turns on machine.

Execute F_1

S_2: Ice block created. Execute F_2

S_3: Block retrieved. Repeat F_1

S_4: Block retrieved. Execute F_3

S_5: Block placed. Repeat F_2

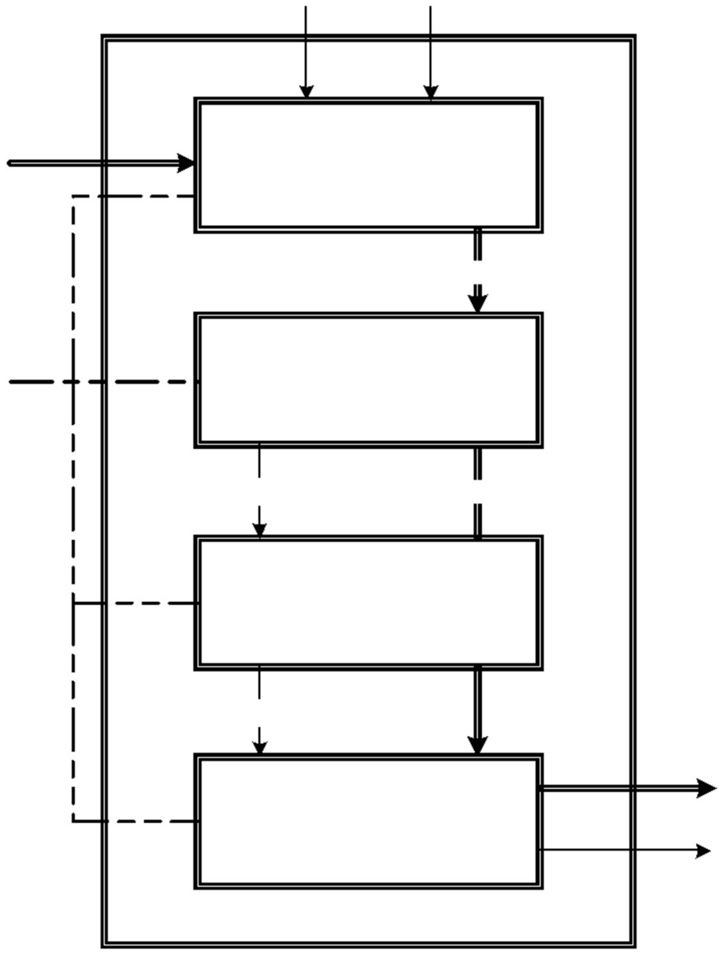


Figure 5: F_1 Functional Analysis Chart

S_1: Operator turns on machine. Execute $F_{1.1}$

S_2: Ice block created. Execute F_2

S_3: Block retrieved. Execute $F_{1.1}$

U: Cooler full. Execute F

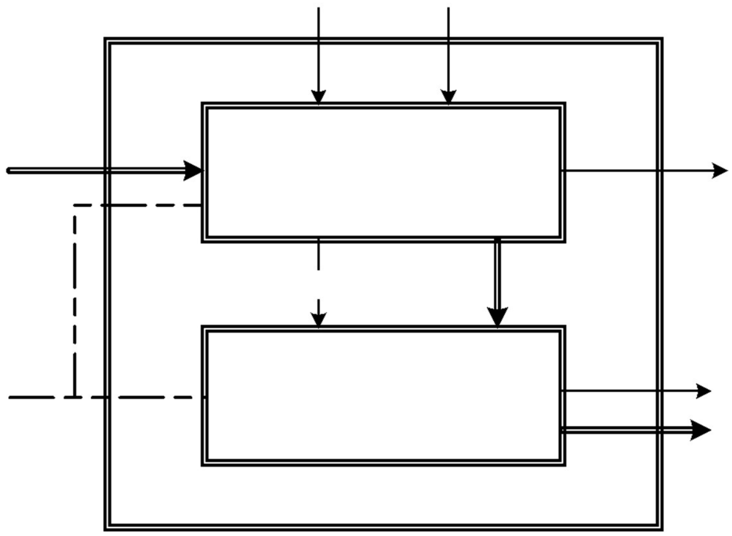


Figure 6: F_3 Functional Analysis Chart

S_2: Ice block created. Execute F_2

S_3: Block retrieved. Execute $F_{1.1}$

S_4: Block retrieved. Execute F_3

S_5: Block placed. Repeat F_2

BRAINSTORMING

Basic Function F1: Create Ice Block

A. “Float ball” similar to style showed in Figure A.1. Supply from valve is cut when the Peltier cooler box is full of water.

B. To avoid water spillage, need a “clamp” or “pin” of some sort to hold float ball up when bottom of cooler is open and ice block is being removed.

C. Limit switches to open and close valve when filling up cooler. Similar Figure A.2 which shows limit switches used to position a box.

D. Electric pump should be at bottom, below water source. Good design for conserving energy.

E. Position Peltier cooler on machine can give a 3D printing style approach.

F. Timer for every 30 seconds when another ice block is ready.

Basic Function F2: Retrieve Ice Block

A. Sliding bottom door? Hinged door? What type of door is best to limit and control movement of ice block?
B. Worm gear along one side → guided track on another side → Input of rotation = bottom door slides out.
C. Ice Blocks in predetermined positions known by machine.
D. Machine 'scoops' ice block up like a spatula.
E. Machine 'clamps' ice block on both sides.
F. Machine pushes ice block out of box with arm

Basic Function F3: Place Ice Block

A. Ice block positioned at location with known dimensions.
B. Limit switch to signal when ice block has been placed / machine is not holding ice block.
C. Rotating arm which travels from retrieval position to placement position.
D. Ice block is on platform which is then raised and moves to target location.

Basic Function F4: Reposition Machine

A. Limit switches used to reposition machine to location of next block placement.
B. Complete bottom layer perimeter before moving onto next perimeter layer.
C. Linear Actuator? Good for creating motion in a straight line as opposed to the circular motion from a conventional electric motor.
D. Gantry style setup, similar to Figure A.3
E. Guide machine like a 3D printer using XYZ screw gears, as seen in Figure A.4
F. Mechanical counting mechanism counts down from 9-1 repeatedly. Every time four cycles are completed, the highest value (9 initially) gets decreased by 1. This informs correct placement of blocks.

COMBINATION TABLE

Below, three different concepts are shown in combination tables, as illustrated in Table 1, 2, and 3. A brief explanation is provided about each concept from each combination table.

Table 2: Combination table for concept 1.

Functions		Solutions: A	B	C	D	E	F
1	Create Ice Block	“Float Ball”	“Clamp / pin”	“Limit switch to open and close”	“Electric Pump”	“Position on machine”	“Timer”
2	Retrieve Ice Block	Sliding or hinged door	“Worm gear”	“Ice blocks in predetermined position”	“Scoops ice block up”	“Clamps ice block”	“Pushes block with arm”
3	Place Ice Block	“Known dimensions”	“Limit switch”	“Rotating arm”	“Platform”	----	----
4	Reposition Machine	“Limit switches to reposition”	“Complete bottom layer”	“Linear actuator”	“Gantry style setup”	“3D printer”	“Mechanical counting mechanism”

Concept 1: This first concept resembles the functioning of a 3D printer. The peltier cooler is positioned on the machine, which places the ice blocks of known dimensions in predetermined positions using XYZ screw gears to appropriately determine the position and placement of each ice block. Similar concept to a 3D printer, which is above the surface and builds from the bottom upwards.

Table 3: Combination table for concept 2.

Functions		Solutions: A	B	C	D	E	F
1	Create Ice Block	“Float Ball”	“Clamp / pin”	“Limit switch to open and close”	“Electric Pump”	“Position on machine”	“Timer”

2	Retrieve Ice Block	Sliding or hinged door	“Worm gear”	“Ice blocks in predetermined position”	“Scoops ice block up”	“Clamps ice block”	“Pushes block with arm”
3	Place Ice Block	“Known dimensions”	“Limit switch”	“Rotating arm”	“Platform”	----	----
4	Reposition Machine	“Limit switches to reposition”	“Complete bottom layer”	“Linear actuator”	“Gantry style setup”	“3D printer”	“Mechanical counting mechanism”

Concept 2: This concept is built almost entirely by using limit switches to determine when to start and stop various events of the lodge building sequence. By creating and developing a system of limit switches that work together, the process of building the ice lodge could be accomplished. A mechanical counting mechanism can be used to inform correct placement of each ice block and the end of the building process. The counter counts down from 9 to 1 repeatedly and the highest value of 9 is decreased by 1 every time four cycles are completed.

Table 4: Combination table for concept 3.

Functions / **Solutions**		A	B	C	D	E	F
1	Create Ice Block	"Float Ball"	"Clamp / pin"	"Limit switch to open and close"	"Electric Pump"	"Position on machine"	"Timer"
2	Retrieve Ice Block	Sliding or hinged door	"Worm gear"	"Ice blocks in predetermined position"	"Scoops ice block up"	"Clamps ice block"	"Pushes block with arm"
3	Place Ice Block	"Known dimensions"	"Limit switch"	"Rotating arm"	"Platform"	----	----
4	Reposition Machine	"Limit switches to reposition"	"Complete bottom layer"	"Linear actuator"	"Gantry style setup"	"3D printer"	"Mechanical counting mechanism"

Concept 3: This concept can be interpreted like a robotic arm that has been programmed to perform a task. In this case, however, the process is entirely mechanical. The ice block formation is controlled by a float ball similar to that of a toilet, which closes a valve when a certain threshold of water is obtained. Input of rotation to a worm gear that follows a track will open the bottom of the box and the ice block will be removed. The machine will pick up the block and, using a rotating arm, will place the block at the desired position. This can be accomplished in different ways, but applying a Gantry style setup may make the process more efficient.

B.3. Solution and Preparation

Decisional Analysis

Table 1: Decisional analysis of complete solutions from Mandate M2.

Criteria	Weighting	Evaluations			Weightings X Evaluations		
		Complete Solutions			Complete Solutions		
		S1	S2	S3	S1	S2	S3
A	0.17	5	8	6	0.85	1.36	1.02
B	0.16	5	8	7	0.8	1.28	1.12
C	0.05	8	6	6	0.4	0.3	0.3
D	0.075	4	9	7	0.3	0.675	0.525
E	0.055	6	5	5	0.33	0.275	0.275
F	0.055	5	6	7	0.275	0.33	0.385
G	0.055	7	8	7	0.385	0.44	0.385
H	0.13	7	7	6	0.91	0.91	0.78
I	0.13	6	8	7	0.78	1.04	0.91
J	0.06	8	9	7	0.48	0.54	0.42
K	0.06	9	7	8	0.54	0.42	0.48
					6.05	**7.57**	**6.6**

The sum of the products of the criteria weightings and evaluation of solutions are listed in Table 1 above. From the table, the second complete solution S2 scored the highest. This design offers several advantages. Solution 2 conforms to the restriction that the machine is purely mechanical. Not only this, but the design is fairly simple since it will rely on limit switches and a sophisticated counting mechanism (Geneva wheel) will be used for placement of each ice block. This design will be able to successfully build the ice lodges while being very simple. It will not have a large number of parts and will be easy to set up and transport from one location to another.

Realization Strategy

Assignment of design leadership for basic solutions:

- F1 Create Ice Block: Jason Killen
- F2 Retrieve Ice Block: Jeromy Denk
- F3 Place Block: Yousuf Elmamlouk
- F4 Reposition Machine: Evan Ruston

Leadership Assignment: Jason Killen will be the team leader. He will be in charge of management, be the reference person on information and production on SolidWorks.

Realization strategies for each team member are listed in the ensuing tables below. Each team member has been assigned responsibility for one function of the overall design of the machine. The strategy tables below serve as guidelines for each team member and deadlines listed below are approximations, which may change with the scope of the project. While the project deadline is Monday, April 3, note that the realization strategies below aim to have the project completed one week in advance, by March 27. This extra week is considered the "safety net" and will be used to make any small adjustments, if necessary.

Table 2: Realization strategy for Jason - F1 Objectives and deadlines.

Realization Strategy - Jason Killen		
1	Research Peltier coolers: function, general design.	17/02/2017
2	*Reading Week:* Formalize idea, draw design, present to group upon return from reading week.	24/02/2017
3	Present final drawing to group, make any adjustments if necessary.	26/02/2017
4	Begin SolidWorks design of F1.	27/02/2017
5	Show progress of SolidWorks design to the team; make any changes to design if the team deems it necessary.	04/03/2017
6	Meet with group to examine each member's progress on the design / SolidWorks; make adjustments to the schedule or redistribute work for deliverable dates if necessary.	04/03/2017
7	Provisional SolidWorks design of F1 completed (to be shown to the team).	11/03/2017
8	Show provisional F1 design to the team and make any necessary modifications.	12/03/2017
9	Final SolidWorks design of F1 is complete.	16/03/2017
10	Begin technical report writing for design of machine and F1.	17/03/2017
11	Assembly of all functional parts into the complete machine design.	19/03/2017

12	Make any adjustments to provisional machine design, finalize SolidWorks of the machine.	21/03/2017
13	Finalize technical drawing(s) on SolidWorks, technical report, and oral presentation.	25/03/2017
14	Project completion date:	**27/03/2017**
15	Review of technical report, assembly drawings, practice oral presentation.	01/04/2017
16	Technical report, assembly drawings, and presentation due:	**03/04/2017**

Table 3: Realization strategy for Jeromy - F2 Objectives and deadlines.

Realization Strategy - Jeromy Denk		
1	Research block extraction mechanisms	17/02/2017
2	Formalize block extraction mechanism design	
3	Create initial block extraction mechanism SolidWorks design	24/02/2017
4	Show progress of SolidWorks design to the team; make any changes to design if the team deems it necessary	04/03/2017
5	Meet with group to examine each member's progress on the design / SolidWorks; make adjustments to the schedule or redistribute work for deliverable dates if necessary	04/03/2017
6	Show provisional F2 design to the team and make any necessary modifications.	12/03/2017
7	Finalize block extraction SolidWorks design	
8	Begin technical write-up for F2 for final report	
9	Project completion date:	**27/03/2017**
10	Review of technical report, assembly drawings, practice oral presentation.	01/04/2017
11	Technical report, assembly drawings, and presentation due:	**03/04/2017**

Table 4: Realization strategy for Youssef - F3 Objectives and deadlines.

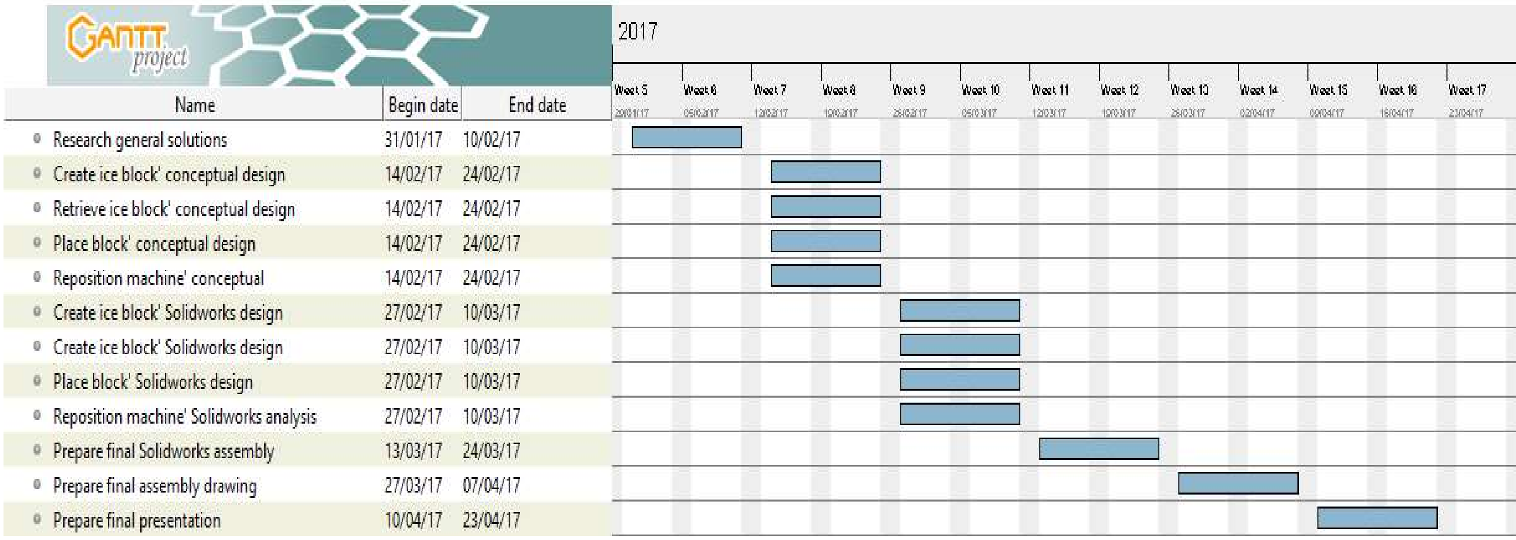
Realization Strategy - Youssef Elmamlouk		
1	Research mechanisms for F3 (Hydraulics, Linkages, etc.)	17/02/2017
2	*Reading Week:* Continue research, simulate researched mechanisms on SolidWorks, present most feasible mechanism to group on return from Reading Week	24/02/2017
3	Present drawings of chosen mechanism for F3, make adjustments/corrections if necessary	26/02/2017
4	Begin final design of F3 on SolidWorks	27/02/2017
5	Show progress of SolidWorks design to the team; make any changes to design if the team deems it necessary	04/03/2017
6	Meet with group to examine each member's progress on the design / SolidWorks; make adjustments to the schedule or redistribute work for deliverable dates if necessary	04/03/2017
7	Show provisional F3 design to the team and make any necessary modifications.	12/03/2017
8	Create assembly drawings for F3 using SolidWorks	13/03/2017
9	Begin technical write-up for F3 for final report	16/03/2017
10	Integrate and assemble F3 with completed basic solutions	16/03/2017
11	Project completion date:	**27/03/2017**
12	Review of technical report, assembly drawings, practice oral presentation.	01/04/2017
13	Technical report, assembly drawings, and presentation due:	**03/04/2017**

Table 5: Realization strategy for Evan - F4 Objectives and deadlines.

Realization Strategy - Evan Ruston		
1	Research mechanical counters	27/02/2017
2	Research clutchless shifting mechanisms	27/02/2017
3	Begin development of counting shaft with continuous rotating shaft and shifter	28/02/2017
4	Prepare completed shaft design without switches or shifters for presentation	04/03/2017
5	Meet with group to examine each member's progress on the design / SolidWorks; make adjustments to the schedule or redistribute work for deliverable dates if necessary	04/03/2017
6	Begin development of contact switches for shifters to change between counters	05/03/2017
7	Prepare functional model of shifting mechanism integrated with shafts	11/03/2017
8	Show provisional F4 design to the team and make any necessary modifications.	12/03/2017
9	Project completion date:	**27/03/2017**
10	Review of technical report, assembly drawings, practice oral presentation.	01/04/2017
11	Technical report, assembly drawings, and presentation due:	**03/04/2017**

Organizational Structure of Project Completion

Figure 1: Organizational structure of project completion, illustrated in a Gantt Chart.



Appendix C. Agenda and Minutes of Meetings

Note: For the first few meetings, the team thought that an agenda and minutes were the same thing, so this is why the minutes are only included.

Minutes for Meeting 1 of Design Team 6
Design Project: Lodge-Building Machine (25 January 2017)
At 16:30, Jason Killen's apartment

Present: J. Carroll, J. Denk, J. Killen, E. Ruston

Absent: None

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 1***

- E. Ruston requests an introductory period to get to know the other teammates.
- J. Carroll requests time for the team members to discuss their various strong and weak points in the field of drafting and design.
- J. Denk requests a temporary pause in the meeting when the pizza was delivered.

The minutes are approved, subject to the above modifications.

3. ***State of the design assignment***

- J. Denk divides up the work for the mandate + criteria and restrictions assignment.
- E. Ruston books conference room at the University of Ottawa library for weekly meetings.
- J. Carroll leads the discussion in identifying the difference between criteria and restriction.

4. ***Steps of mandate assignment***

All team members contributed to this work. Results appear in Appendix A of the report.

5. ***Additional items***

- J. Denk requests that each team member brainstorm rough ideas to begin the creative thought process before drafting and design. All team members support this notion.

6. ***Next meeting***

The next meeting will be held at the University of Ottawa at 16:30 on Wednesday, February 1, 2017.

Meeting was adjourned at 18:00.

Minutes Recorder: J. Killen Signature: ________________________

Minutes for Meeting 2 of Design Team 6
Design Project: Lodge-Building Machine (1 February 2017)
At 16:30, University of Ottawa MRT 403

Present: J. Denk, J. Killen, E. Ruston

Absent: J. Carroll

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 2***

- Evan informed the team of J. Carroll's health status and need to take the winter semester off school.
- J. Carroll's absence will be discussed with professor Robitaille next class.

The minutes are approved, subject to the above modifications.

3. ***State of the design assignment***

- Mandate assignment 2 on generation of solutions to be completed for next Tuesday.
- Team members took time to introduce their ideas and findings related to the project.
- Assignment M2 was discussed and tasks were assigned for each group member.
- J. Denk proposes mechanical counting system as a potential solution for placing the ice blocks.

4. ***Steps of mandate assignment***

All team members contributed to this work. The results of the Deliverable M2 will appear in the appendices of the final report.

5. ***Additional items***

- No additional items were discussed this week.

6. ***Next meeting***

The next meeting will be held in MRT 403 at 16:30 on Wednesday, February 8, 2017.

Meeting was adjourned at 18:00.

Minutes Recorder: J. Killen Signature: ________________________

Minutes for Meeting 3 of Design Team 6
Design Project: Lodge-Building Machine (11 February 2017)
At 14:30, University of Ottawa MRT 403

Present: J. Denk, J. Killen, E. Ruston, Y. Elmamlouk

Absent: J. Carroll

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 2***

- Y. Elmamlouk attended his first new meeting with his new team.
- J. Killen nominated himself as group leader.

The minutes are approved, subject to the above modifications.

3. ***State of the design assignment***

- Mandate assignment 3 on Decisional Analysis to be completed for next Tuesday.
- Team members were assigned a basic solution to undertake and design for the Lodge-Building Machine.
- Assignment M3 was discussed and tasks were assigned for each group member.
- J. Killen prepared a table to analyze the weightings of three possible solutions and to decide on the solution to pursue for the Lodge-Building Machine.

4. ***Steps of mandate assignment***

All team members contributed to this work. The results of the Deliverable M2 will appear in the appendices of the final report.

5. ***Additional items***

- No additional items were discussed this week.

6. ***Next meeting***

The next meeting will be held in SITE at 18:00 on Thursday, February 15, 2017.

Meeting was adjourned at 17:30.

Minutes Recorder: Y. Elmamlouk Signature: ________________________

Agenda for Meeting 4 of Design Team 6
Design Project: Lodge-Building Machine (15 February 2017)
At 16:30, University of Ottawa MRT 403

16:30 Meeting Begins – Greetings and topics to be discussed are mentioned.
- Time Allowed: 5 minutes

16:35 Revision of marks obtained on first two Mandate assignments: where mistakes were made; how to fix the mistakes; important things missed on the assignments.
- Time Allowed: 10 minutes

16:45 Revision of Mandate M3 – Agree upon division of tasks for designing the project; set realistic dates for finishing parts of the project; assign SolidWorks tasks to team members.
- Time Allowed: 30 minutes

17:15 Finalize tentative design concept of the project. Discuss alternative methods, concepts, theories, or ideas team members have come up with since last meeting.
- Time Allowed: 30 minutes

17:45 Review material covered in this meeting, discuss any questions or concerns group members may have.
- Time Allowed: 15 minutes

18:00 Meeting Adjourned

Minutes for Meeting 4 of Design Team 6
Design Project: Lodge-Building Machine (15 February 2017)
At 16:30, University of Ottawa MRT 403

Present: J. Denk, Y. Elmamlouk, J. Killen, E. Ruston

Absent: None

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 2***

- Mandate assignments were discussed and reviewed.
- Tentative final design of the project was finalized.
- New ideas to add to or change the currently accepted design were discussed. No changes were agreed upon or made to the tentative final design.
- SolidWorks tasks and deadline dates were assigned to group members.

The minutes are approved, subject to the above modifications.

3. ***State of the design assignment***

- The theoretical design of the project has been finalized and the ideas are being put into the design process through SolidWorks and through detailed engineering drawings.
- Due dates were discussed and tasks were assigned to each group member for completion.

4. ***Steps of mandate assignment***

All team members contributed to the Mandate M3 that was due this week. The results of the Deliverable M3 will appear in the appendices of the final report.

5. ***Additional items***

- No additional items were discussed this week.

6. ***Next meeting***

No meeting will be held on reading week. The next meeting will be held in MRT 403 at 16:30 on Wednesday March 1, 2017

Meeting was adjourned at 18:00.

Minutes Recorder: J. Killen Signature: ________________________

Agenda for Meeting 5 of Design Team 6
Design Project: Lodge-Building Machine (5 March 2017)
At 14:30, University of Ottawa MRT 405

14:30 Meeting Begins – Greetings and topics to be discussed are mentioned.
- Time Allowed: 5 minutes

14:35 Review of Mandate M3 conducted. Team review of solution. Concerns or ideas incited as a result of design research are discussed.
- Time Allowed: 1 hour

15:35 Revision of projected timeline conducted using Gantt chart.
- Time Allowed: 20 minutes

15:55 Review material covered in this meeting, discuss any questions or concerns group members may have.
- Time Allowed: 15 minutes

16:10 Meeting Adjourned

Minutes for Meeting 5 of Design Team 6
Design Project: Lodge-Building Machine (5 March 2017)
At 14:30, University of Ottawa MRT 405

Present: J. Denk, Y. Elmamlouk, J. Killen, E. Ruston

Absent: None

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 4***

The minutes are approved unanimously with no changes.

3. ***State of the design development***

- Peltier cooler release mechanism simplified
- Movement/timing algorithm confirmed
- Movement/timing mechanism developed
- Pros/con analysis of machine frame design conducted

All team members contributed to this work.

4. ***Additional items***

- No additional items were discussed this week.

5. ***Next meeting***

No meeting will be held on reading week. The next meeting will be held in MRT 406 at 16:30 on Sunday March 12th, 2017

Meeting was adjourned at 16:10

Minutes Recorder: J. Denk Signature: ________________________

Agenda for Meeting 6 of Design Team 6
Design Project: Lodge-Building Machine (12 March 2017)
At 14:30, University of Ottawa MRT 405

14:30 Meeting Begins – Greetings and topics to be discussed are mentioned.

- Time Allowed: 5 minutes

14:35 Review of material discussed with Dr. Robitaille during the informal meeting.

- Time Allowed: 10 minutes

14:45 Review of rough drawings prepared by the team members; brief and informal presentations of new ideas, designs, SolidWorks files.

- Time Allowed: 30 minutes

15:15 Discussion on ideas presented and decisions on what ideas will and will not be used in the final design project.

- Time Allowed: 20 minutes

15:35 Assignment of SolidWorks tasks to team members; deadlines are set for parts to be created and shared with the group

- Time Allowed: 15 minutes

15:50 Any remaining questions, problems, or concerns to be brought up and discussed. The time and date for next meeting are determined and scheduled.

- Time Allowed: 10 minutes

16:00 Meeting Adjourned.

Minutes for Meeting 6 of Design Team 6
Design Project: Lodge-Building Machine (12 March 2017)
At 14:30, University of Ottawa MRT 405

Present: J. Denk, Y. Elmamlouk, J. Killen, E. Ruston

Absent: None

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Minutes of meeting 6***

- The concept behind an impeller, its function, and how it can be used as an energy source was brought up by E. Ruston. The team agreed to incorporate it into the final design.
- The team approved a gantry style setup, suggested by J. Denk.
- Team drawings were reviewed and drawings by Y. Elmamlouk were unanimously favored.
- The peltier cooler system SolidWorks files by J. Killen were examined and minor modifications were addressed (fix dimensions; hinging door on bottom).
- SolidWorks assignments were given to each member: J. Denk and E. Ruston are to work on the counting mechanism and axial motion, while Y. Mamlouk and J. Killen are to finish the peltier cooler and gantry design. A soft due date was set as March 20, 2017.
- No further concerns or questions relating to the design project were brought up or discussed.

3. ***State of the design assignment***

- Obtained reassurance/confirmation that the counting mechanism design should work.
- Rough hand drawings have been completed; SolidWorks tasks have been assigned and are to begin this week.
- Final theoretical design has been determined – now to be created in SolidWorks.
- Technical report, drawings, and presentation to be submitted/presented are being casually researched and looked into.

4. ***Additional items***

- Y. Elmamlouk discusses forming a separate study group to study the lecture material from class.
- Technicalities of the oral presentation: exporting simulation movie files; coming prepared with multiple formats of presentation (PowerPoint, PDF, Google Slides, etc.) are discussed.
- Jason expressed interest in reviewing class drawings next week with the team to see where there can be improvement for future assignments.

5. ***Next meeting***

The next meeting is scheduled to be held in MRT 405 at 14:30 on Sunday March 19, 2017.

Meeting was adjourned at 16:00.

Minutes Recorder: E. Ruston Signature: ________________________

Agenda for Meeting 7 of Design Team 6
Design Project: Lodge-Building Machine (19 March 2017)
At 14:30, University of Ottawa MRT 405

14:30 Meeting Begins – Greetings and topics to be discussed are mentioned.
- Time Allowed: 5 minutes

14:35 Review of agenda and minutes taken during the last meeting. Modifications or additions are to be made, if any.
- Time Allowed: 10 minutes

14:45 Review of coursework D2 requirements. Brainstorming ideas; Selecting realistic gear ratios; Agreement on a solution; Assignment of tasks to team members.
- Time Allowed: 30 minutes

15:15 Discussion of problems faced with Geneva wheel counting mechanism: suggested alternatives and how they can be designed are discussed.
- Time Allowed: 45 minutes

16:00 Assignment of SolidWorks tasks to each team member with soft deadlines to be met.
- Time Allowed: 20 minutes

16:20 Any remaining questions, problems, or concerns to be brought up and discussed. The time and date for next meeting are determined and scheduled.
- Time Allowed: 10 minutes

16:30 Meeting Adjourned.

Minutes for Meeting 7 of Design Team 6
Design Project: Lodge-Building Machine (19 March 2017)
At 14:30, University of Ottawa MRT 405

Present: J. Denk, Y. Elmamlouk, J. Killen

Absent: E. Ruston

1. ***Approval of agenda***

The agenda was approved unanimously with no changes.

2. ***Approval of minutes from Meeting 6***

The minutes taken were approved unanimously with no changes.

3. ***Coursework D2***

- Gear specifications were selected: helical gears to reduce noise; worm gear with a high reduction ratio of approximately 20:1; gear reducer of 120:1 with perpendicular and intersecting rotating shaft axes.
- The definition of what defines a continuous shaft was discussed and determined, explained by J. Denk.
- Y. Elmamlouk agreed to do the drawing; J. Denk and J. Killen selected to work on the brief write-up to accompany the assignment.
- J. Killen is to do a final review of the completed assignment on Monday, March 21.

4. ***Problems and alternatives to the Geneva wheel mechanism***

- J. Denk addressed the inherent flaw in using 9 different sized Geneva wheels as a counting mechanism while only trying to use one driver.
- Solutions to the Geneva wheel counting mechanism were brainstormed, but there was no success.
- The team abandoned the Geneva counting mechanism in favor of a cylindrical phonograph that will act as a guide, reading x, y, and z-motions for the machine.
- The concept of the cylindrical phonograph and how it is used to control different directional motion was mapped out by J. Denk, Y. Elmamlouk, and J. Killen.

5. ***SolidWorks tasks***

- J. Denk is to design the cylindrical counting mechanism that also maps directional movement.
- J. Killen is to design the peltier cooler box, the damper (dashpot) mechanism, and the method of opening the bottom of the cooler box to drop the ice block.
- Y. Elmamlouk is to find and obtain open-sourced CAD files for single-phase motors, impellers, gears, pulleys, and any other things he finds that may be of use.
- E. Ruston is to design the frame of the gantry and pulley mechanisms.

6. ***Additional items***

- Evan had forewarned the group of his absence due to prior commitments. His absence from the meeting is accepted and excused. A copy of the agenda and minutes are to be provided to him by e-mail.
- No additional items, questions, concerns, or problems were brought up or discussed by the team.

7. ***Next meeting***

The next meeting is scheduled to be held in MRT 405 at 14:30 on Sunday March 26, 2017.

Meeting was adjourned at 16:30.

Minutes Recorder: Y. Elmamlouk Signature: ________________________