University of Ottawa - Faculty of Engineering
Department of Mechanical Engineering

MCG 2101 A: INTRODUCTION TO DESIGN
Pyramid Ice Lodging Builder

FINAL REPORT

TEAM 2

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Submitted to: Dr. François Robitaille

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1. Introduction

The purpose of this report is to detail the functions and capabilities of a machine used to build a pyramidal ice lodging without any human intervention. The pyramid is to have 180 blocks. Mechanical power is provided by three motors. The machine is to minimize load bearings, the number of mechanical components and the time required to build a lodging.

The machine that was designed uses ultra-efficient peltier coolers to form ice blocks that are then moved using a timing mechanism which initiates and stops the water supply, removes the block of ice from the cooler and pushes it to its next position. The ice blocks are moved with four telescopic barriers that use a pushing algorithm to fill each layer with the appropriate number of blocks. When a layer is filled pressure activated contact limit switch is activated which turns on a motor. This motor is attached to four power screws which the telescopic barrier is mounted on. The motor causes a rotation in the power screws which drives the telescopic barrier up by 30cm and in by 30cm to the base of the next layer.

The overall dimensions of this machine are a height of 703.3 cm , and a width and depth of 983.4 cm. Mechanical power is used in the forms of gears, bearings, shafts, belt drives and three motors. On the following page, **Figure 1.1** will show the full assembly of the machine. For the purposes of showing detail, some of the pieces have been made transparent in order to see the inner mechanisms.

This report will discuss in detail each mechanism, their parts, and their function. It will begin with the timing mechanism used to create each ice block and transmit them to the appropriate position. It will detail how the telescopic barriers will be used to form each layer and the gear interaction that are used in the block pushing algorithm. It will explain power screws will be used to guide the barriers in an upward and inward direction to the base on the following layer. Finally the report will conclude with another overview of this machine and will reiterate the machines benefits and capabilities.

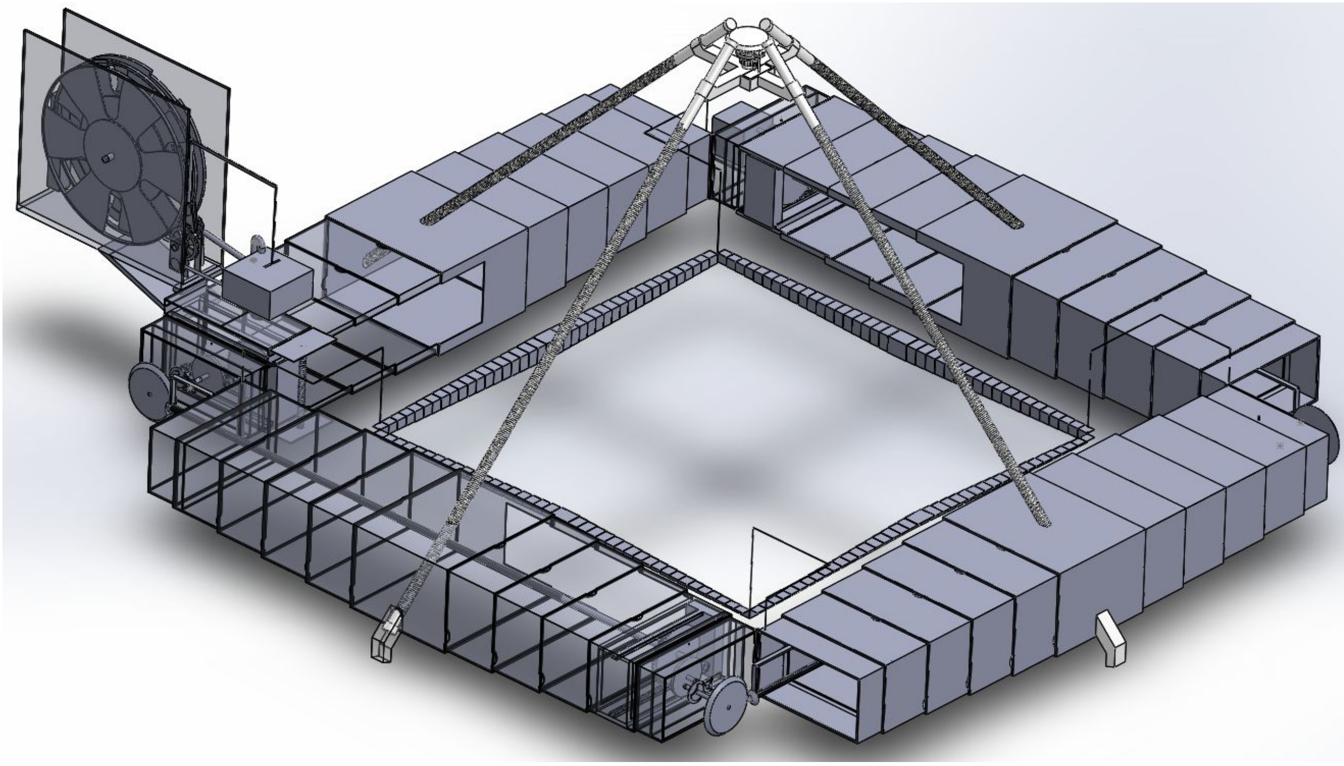

Figure 1.1 Isometric View of Full Assembly for Pyramid Ice Lodging Builder

2. Timing Mechanism

2.1 Cooler System

For the design to begin building the ice pyramid lodging, an ice block must be produced. The ice blocks will be made on-site by ultra-efficient Peltier coolers. The device responsible for making the ice blocks is a cooling box (part 1) measuring 60 cm high by 60 cm wide by 30 cm tall, where the four vertical sides of the box are thin ultra-efficient Peltier coolers. The coolers are powered by electricity using flexible wiring. A new block is frozen every 30 seconds and is ready for use 10 seconds later, meaning the total time to fill the cooler, freeze the block, and have it ready for use is 40 seconds. The water supply that is used for the ice blocks comes from a large barrel, located on site, that transports the water through a flexible pipe that inserts into the top of the cooler.

2.2 Timing System

As a block is frozen in 30 seconds and the total time from start to finish is 40 seconds, a timing mechanism is used to ensure precise timing of the different elements. In this design, the timing device is composed of one motor (part 44), a shaft (part 48) , three timing wheels, two pinions and two piston assemblies. By having these components, it can be ensured that a new ice block is frozen and placed into correct position for assembly of the pyramid.

2.2.1 Design of timing system

As mentioned previously, it takes 30 seconds to freeze the water into a usable ice block. The remaining 10 seconds are used to remove the ice block from the cooler and move it into the next position. A visual representation of the timing diagram of the ice block creator is shown in **Figure 2.1**.

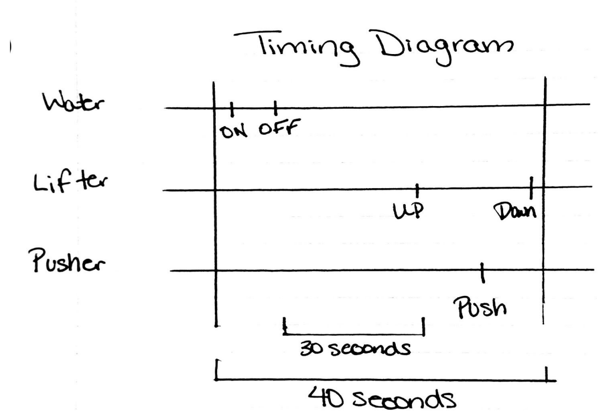

Figure 2.1 Timing diagram of cooler system

As seen from the **Figure 2.1**, a timing cycle of 40 seconds is used to control three different components: the water, the lifter and the pusher. The water controls the valve used to turn the water supply on and off, the Lifter refers to the mechanism lifting the cooler up and down, and the Pusher refers to mechanism pushing the ice block into the next position.

2.2.2 Gears

In order to put this timing diagram into practice, three large timing wheels and two small pistons were assembled on a connecting shaft. One wheel controls the water valve (part 45), the second wheel controls the piston raising and lowering the cooler box (part 46), and the last wheel controls the piston in charge of pushing the ice block off the bottom of the cooler to it's next position (part 47). The connecting shaft that the three gears are resting on is driven, via belt drive (part 53), by a motor, with an output speed of 1.5 rpm.

The water wheel is an 180 cm diameter wheel that acts as cam with a notch in it (**Figure 2.2**). When the beginning of the notch contacts the spring-loaded water switch that controls the flow of water into the cooler, it activates the switch. The opposite end of the notch returns the water switch to the off position. As the cooler fills up instantly with water, the process of flipping the switch on and off is brief.

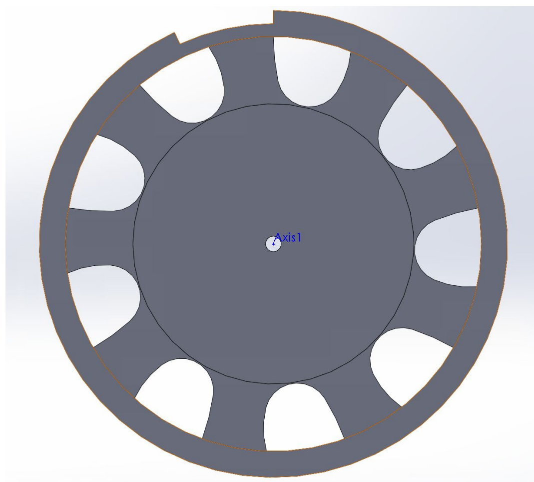

Figure 2.2 Water wheel Solidworks drawing

The next wheel on the shaft, located to left of the water wheel, is the lifter wheel. In this design, the cooler is built in such a way that the top is detachable from the bottom, meaning that the four sides and top are built as one piece and the bottom is in a fixed position. This wheel is 180 cm in diameter and has two sets of 15 partial teeth for a total of 30 teeth. The first set of 15 teeth start at 270° continuing until 285° and the next set of teeth starting at 345° and continue until 360°. To mesh with this wheel, a 15cm diameter pinion (part 43) that has 30 teeth all the way around is used (**Figure 2.3**).

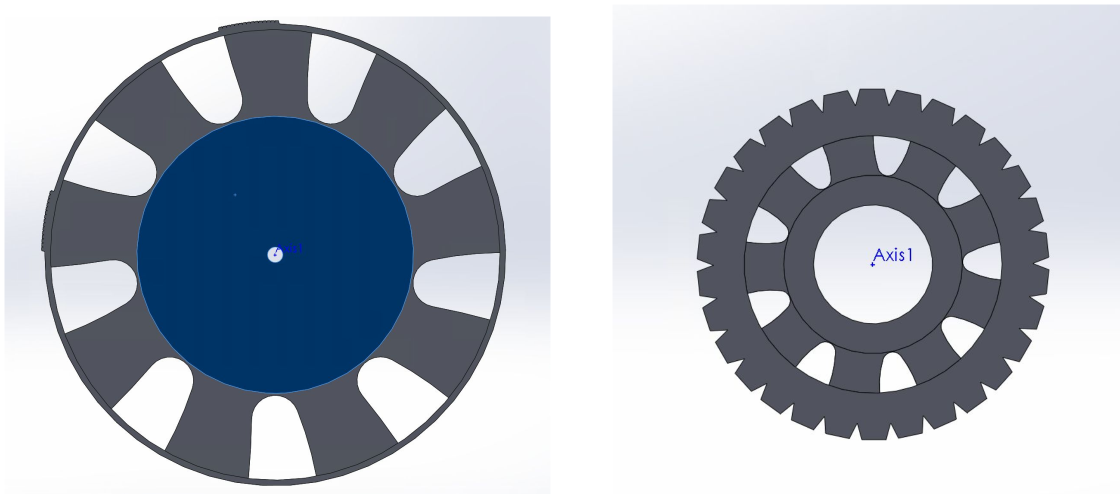

Figure 2.3 Lifter wheel and pinion Solidworks drawings

This pinion is attached to a piston assembly (part 2), which in turn raises and lowers the cooler box (**Figure 2.4**) When the teeth on the pinion mesh with the first set of teeth on the lifter wheel, a U-shaped bend that the cooler piston assembly is between allows the piston to lift the cooler up 30 cm. When the 15 teeth have meshed, a cam is used to hold the cooler box stationary 30 cm above its base. When the rest of the pinion teeth mesh with the second set of teeth on the lifter wheel, the cooler box is lowered into it’s original position. The teeth on the lifter wheel are arranged to allot a 30 seconds delay to freeze the ice block, and take two seconds the lift the cooler box and two seconds to place it back down, leaving six seconds for the last component in the timing system.

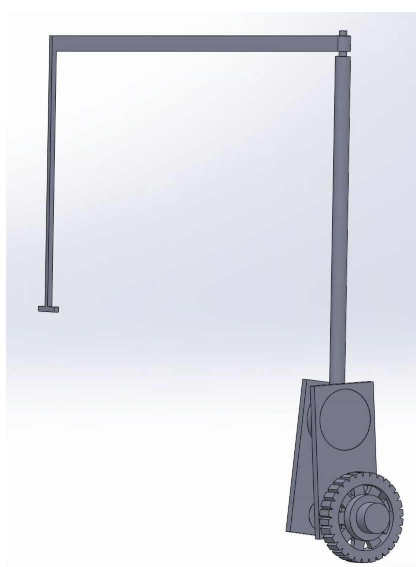

Figure 2.4 Lifter piston assembly in Solidworks

The last wheel on the shaft located to the left of the lifter wheel is the pusher wheel. The pusher wheel is 180 cm in diameter, and also has partial teeth. There are 60 teeth on the pusher wheel, starting from 285° on the wheel, and continuing until 345°, aligned with the lifter wheel (**Figure 2.5**). This alignment ensures that while the lifter assembly is in action, the pusher assembly is stationary and vice-versa.

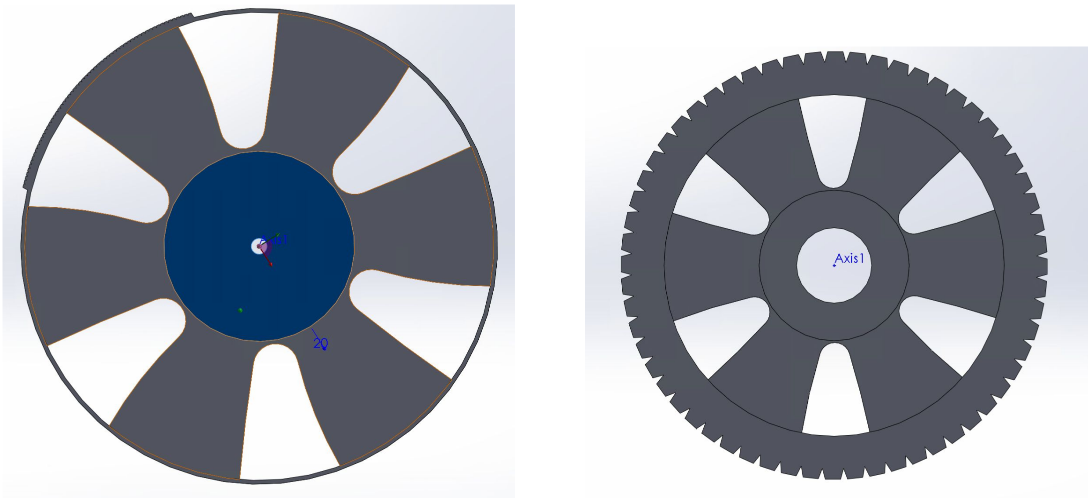

Figure 2.5 - Pusher wheel and pinion in Solidworks

The pusher wheel also meshes with a pusher pinion (part 41) with a diameter of 30 cm and 60 teeth around its circumference. When the pusher pinion meshes with the pusher wheel, a U-shaped bend allows the pusher piston (part 3) to extend 60cm and then retract to its original position during the six second pause between the lifter piston raising and lowering the cooler box, (**Figure 2.6**).

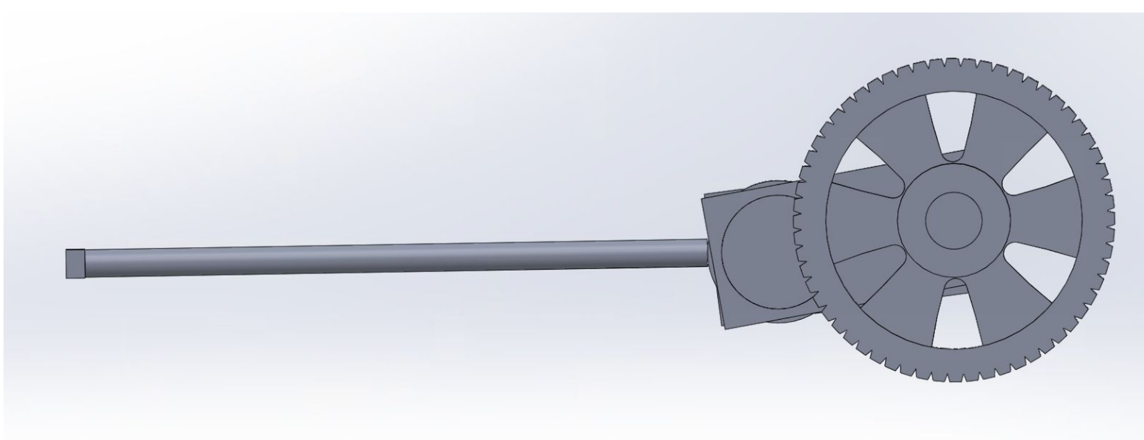

Figure 2.6 - Pusher piston assembly in Solidworks

As the dimensions of the ice block are 60 cm across, the timing system must be contained in a structure of no more than 60 cm width. In this design the timing system is contained in a 58 cm wide casing, determined by the width of the telescopic barrier that the timing system rests on, (**Figure 2.7**). This was obtained by making the 3 wheels, 5.2cm thick along the 58cm shaft. In between each wheel, there is a space of 10.2 cm. In this 10.2 cm space is where the assemblies for lifting and pushing pistons are found, which are 10.1 cm.

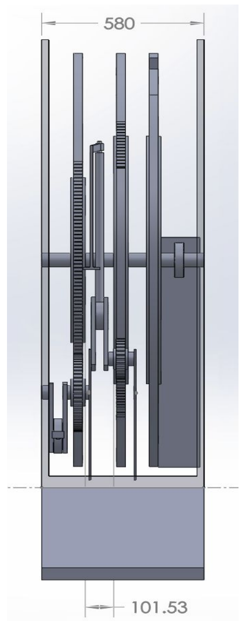

Figure 2.7 - Timing mechanism assembly in Solidworks

3. Antenna (Telescopic) Barriers

After the ice block has been produced, it is pushed by the pusher rod (part 3) onto the spring loaded plate (part 5) where the block descends to ground level as shown in **Figure 3.1**.

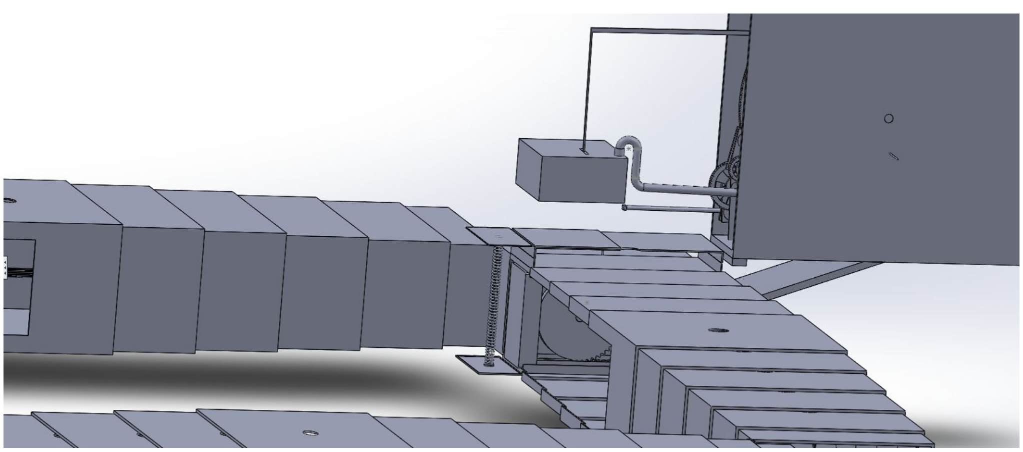

Figure 3.1 Starting position for block to be placed in a layer

The function of the four antenna barriers arranged in a square is to keep the ice blocks in a square perimeter as the layer is being built. **Figure 3.2** shows the overall length of one of these antenna barriers 6511.72 mm and there is an offset, (distance between the barrier face and the one of the side lengths of the square perimeter layer of ice blocks), of 310 mm to prevent the barrier from colliding with the completed layer of blocks below, when the four barriers ascend diagonally at 45 degrees via the power screws, which are explained in section 4. Each barrier also has a 100 mm diameter hole in the middle angled at 45 degrees for the power screw.

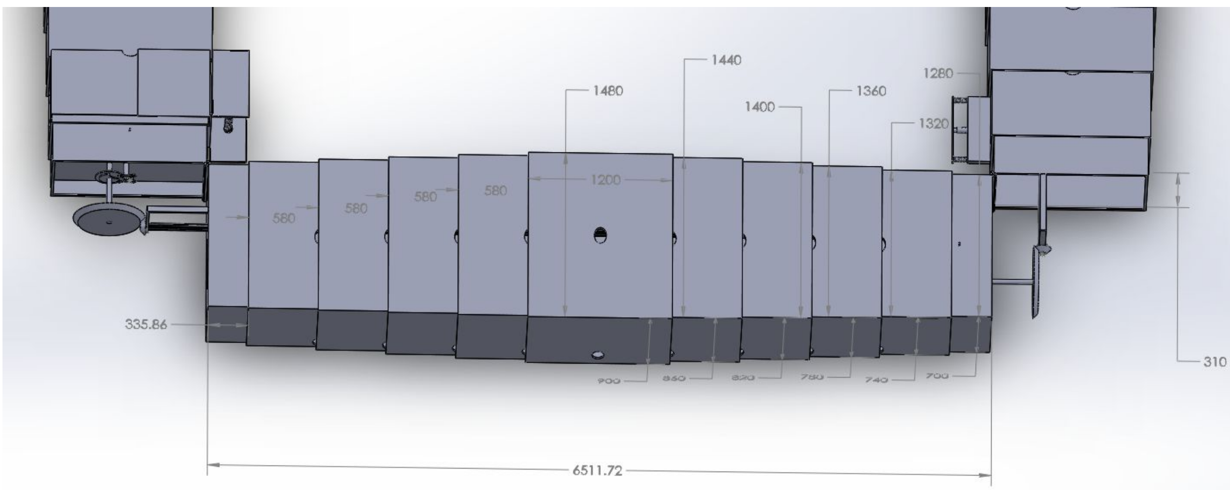

Figure 3.2 Overall dimensions of an antenna barrier

3.1 Mechanism to Accommodate the Cooler System and Timing Mechanism

As seen in **Figure 3.1**, the cooler and the timing mechanism are not resting directly along the casing for the pushing plate (part 34); they are raised by a flap that is 160 mm tall. **Figure 3.3** shows that 80 mm is the height of the sliders on the bottom of the flap for the cooler system and mechanism, preventing collision with the edges of the antenna barrier, as the barrier shrinks when higher layers are being built.

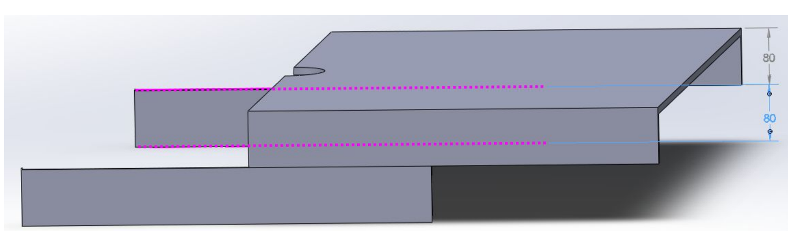

Figure 3.3 Flap with sliders to allow mechanisms to slide inward as the barrier shrinks

3.2 Mechanism Inside the Antenna Barriers that Arrange the Ice Blocks in Each Layer

After the ice block has been lowered via the spring loaded plate, it is now at its start position shown at position 4 in **Figure 3.4**. The mechanism operates with four sequential motions numbered 1, 2, 3 and 4. Each numbered motion refers to one cycle of the reciprocating rack and pinion (out of the antenna barrier toward the middle and then back inside the barrier) in **Figure 3.5**. At each corner of the of square formed by the antenna barriers, there is a Geneva wheel mechanism. The four Geneva wheels have four different starting positions with 1 touching the Geneva wheel, ready to rotate it by a quarter rotation counter-clockwise and 2,3 and 4 each 90 degrees behind each other (90 degrees more clockwise than the previous position) as shown in **Figure 3.6**. This set-up of the Geneva wheels allow for motions 1, 2, 3 and 4 to occur in order and for the blocks to be arranged along side length 4-3, side length 3-2, side length 2-1 and finally side length 1-4 which can be noticed in **Figure 3.4**.

As previously mentioned, it takes 40 seconds for an ice block to be produced and pushed to the spring loaded plate. It also takes an additional 3 seconds for the ice block meaning that motions 1, 2, 3 and 4 occur in 43 seconds. Therefore, the input motor speed would be such that the four sequential motions occur within 43 seconds.

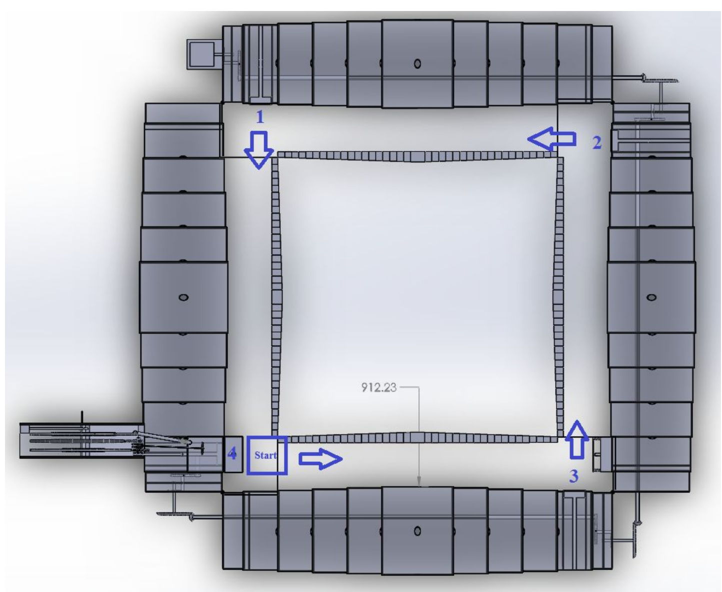

Figure 3.4 Arrangement of blocks in a layer

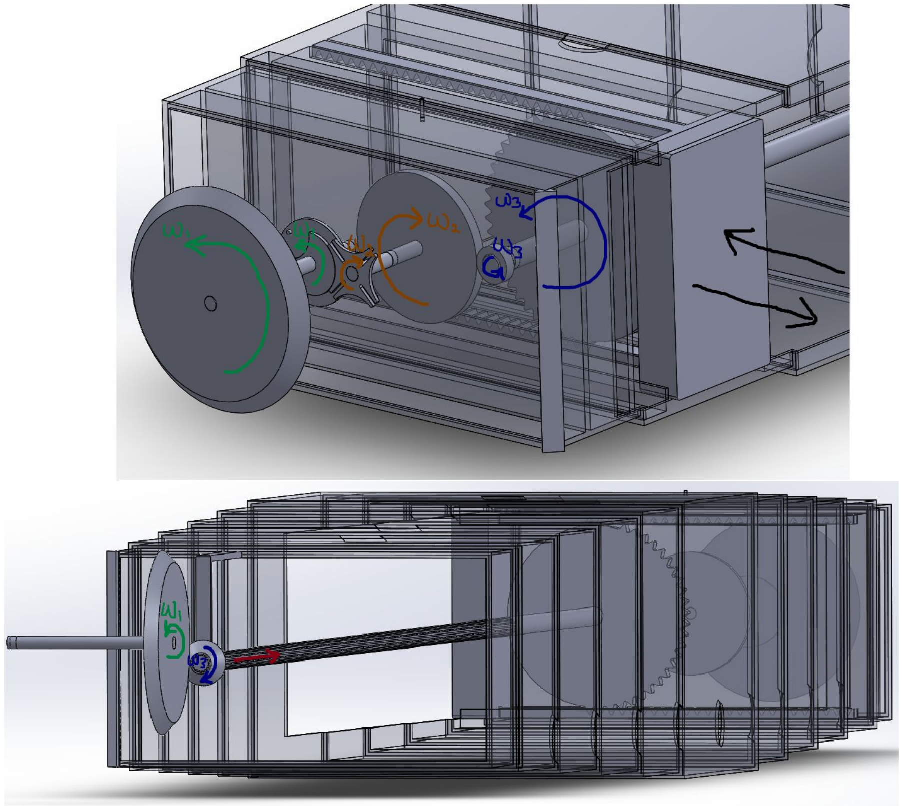

Figure 3.5 Reciprocating rack and pinion mechanism

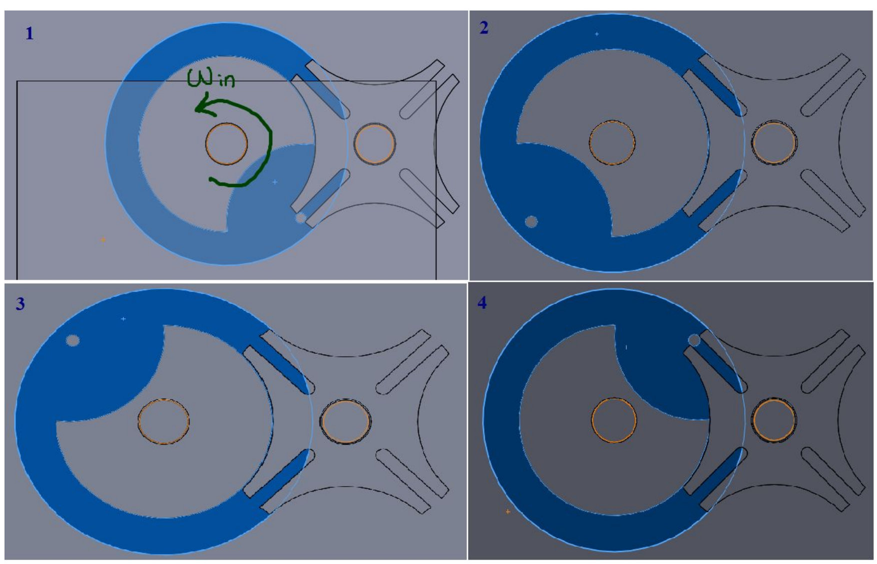

Figure 3.6 Arrangement of Geneva wheels at the four corners of the square formed by the antenna barriers

The internal mechanism of the antenna barriers work by having an input rotation at a speed of omega in. Demonstrated by **Figure 3.6**, there is an outline showing an electrical motor in front of the Geneva wheels mechanism. In **Figure 3.5**, there is first a bevel gear with 60 teeth and a helix angle of 10 degrees that rotates counterclockwise at omega 1 which is equal to omega in; hence, this bevel gear can also be thought of the motor input. Next, the Geneva wheel and the spur gear (64 teeth) on the same shaft rotates at omega 2 equal to omega 1. There is then a speed acceleration of 4 times (speed ratio of ¼) since the spur gear counterclockwise at omega 2 has 16 teeth. When the smaller spur gear rotates, the teeth of the partial pinion gear (part 8) begin to mesh with the lower teeth of the rack (with a pusher plate at the end) (part 35) to bring part 35 outward toward the middle; after half of a rotation of the smaller spur gear, part 8 meshes with the top teeth of the rack to bring part 35 back inside the barrier. It is important for one to note that part 35 moves toward the middle by 910 mm as opposed to 600 mm to account for the offset of 310 mm. At the end of the splined shaft (part 33), there is a bevel gear with 15 teeth and a helix angle of 10 that meshes with the larger aforementioned bevel gear for a speed reduction of 4 times (speed ratio) in order to transmit torque to the adjacent antenna barrier.

At the corner of each barrier, there is a contact plate to allow for contact forces between the barriers to shrink them as they are being raised to higher layers by the power screw (explained in section 4). The lubricated slider ring and bearing (part 36) acts to counteract the axial and radial forces generated by the meshing bevel gears and to slide part 37 along the splined shaft when the barriers shrink as shown in **Figure 3.5**. Also, the splined shaft allows for large torques to be transmitted along the antenna barriers.

In addition, there are three cylindrical roller bearings to withstand the axial and radial loads caused by the meshing gears [3].

3.3 Contact Limit Switch of Antenna Barrier

The last block to be placed is at position 4 displayed in **Figure 3.4**. This block fills side length 4-3, so when part 35 tries to push this side length of blocks, it compresses the spring of the contact limit switch (part 38) near position 3 in **Figure 3.4**. Then, the contact limit switch, which is wired to the motor (part 9), turns off the motor for the barrier. The motors used for the cooler system and timing mechanism then also turn off. The motor to rotate the power screws turns on.

3.4 Bracing Arm

In order to keep the ice blocks from falling into the middle of the pyramid while being pushed, a mechanism was required to brace the blocks and guide them in the proper position. The brace would have to shrink in accordance with the telescopic barrier, therefore the same telescopic design was used for the bracing arm (part 19). To not interfere with the pushing plates and block movement, the width of the centre member was 17.5 cm and gradually decreased by 4 mm for each member on each side. The bracing arm was connected to the outermost member of the telescopic barrer by a long rod that extrudes from the leftmost member. This connection would allow the bracing arm to shrink in the same increments as the telescopic barrier. **Figure 3.7** demonstrates an isometric view of the assembly of the bracing arm.

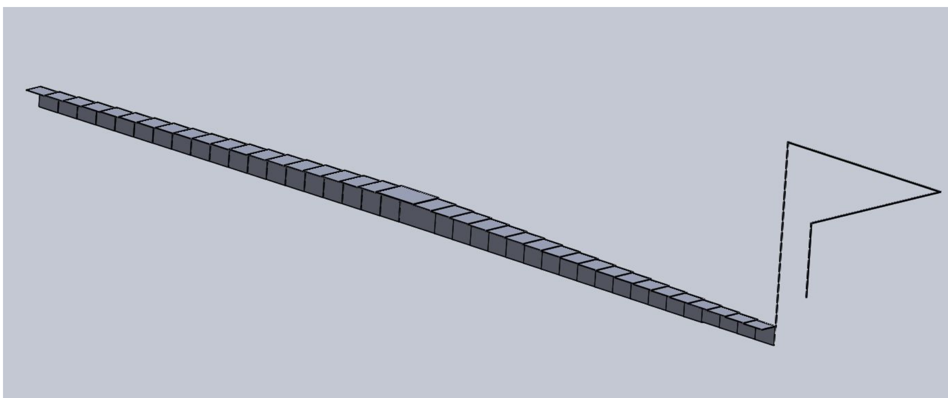

Figure 3.7 Isometric view of the bracing arm

4. Frame

The frame of the machine is formed by 4 power screws (part 49) which are angled at 45 degrees. The screw is composed of three section lengths. The total length of the screw is 643.4cm and the diameter is 10 cm. The smooth length at the bottom is 23 cm, the length contains the thread is 479 cm and the thread has 150 revolutions. **Figure 4.1** shows the power screw with a bevel gear on its top.

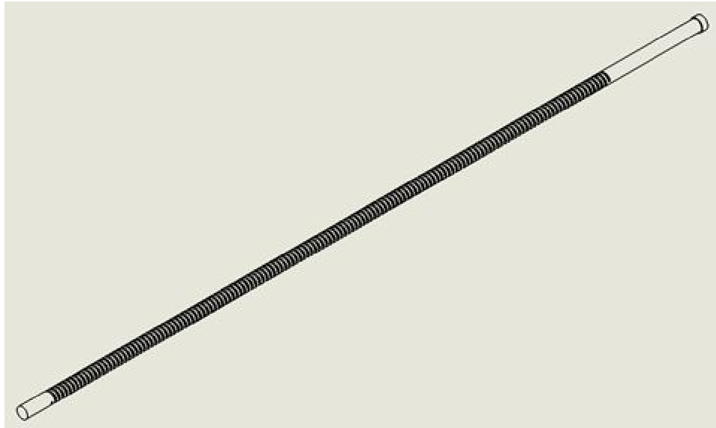

Figure 4.1. Power screw with bevel gear

Since the screw needs to be fixed to the ground, the four feet (supports) (part 50). Also, each foot has bearing for eliminating the torque of the power screw. The four feet are all triangular at the bottom so that they can be hammered into the ground. The pitch length of the thread on the screw is 3.2cm and each 15 revolves of the screw will lift the case up one layer. The top smooth length (part10) of the power screw is 91.23 cm. This length has to be smooth because it will prevent the case from going up after the nine layers of the ice blocks are all built. And at the top of the power screw, there are teeth on the surface with a face width of 5cm and a diameter of 11.54 cm. In order to make it steady at the top, the frame support (part 13) is designed to connect these power screws at the top smooth section, (**Figure 4.2**). In the center of the cross, there is an empty cylinder with 10 cm diameter and 10 cm deep hole, is designed to put the central shaft in order to transmit the power from the motor to the four power screws. A 30 cm by 10 cm 8 cm square slot is designed on the frame support to place the motor (part15).

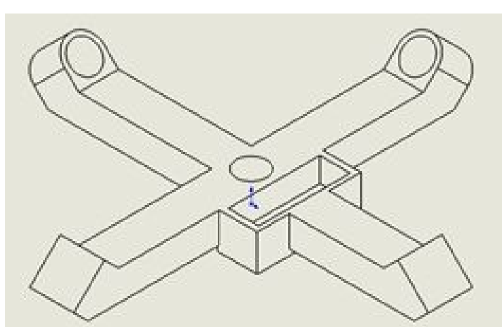

Figure 4.2 Frame Support

The central shaft is composed of 3 parts, (**Figure 4.3**). The bottom gear is the spur gear (part 12) that connects with the motor, it has module of 1 and diameter of 15 cm. In the middle of the shaft, there is a Geneva wheel (part 16) that stops the motor on the cross connection every 15 revolutions of the power screw, and four revolutions of the central shaft. At the top part of the central screw, a bevel gear with an angle of 45 degrees, meshes with the bevel gear at the top of the power screw.

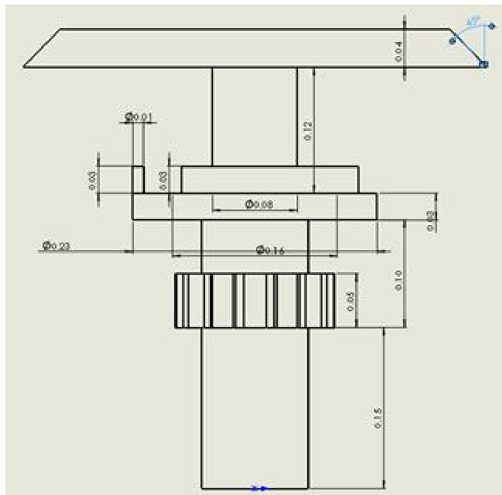

Figure 4.3 Central shaft with Geneva wheel, bevel gear and meshing gear of motor

A motor box (part 15) will be put in the square slot of the cross connection. On the motor box, there are three shafts (**Figure 4.4**). The first has a gear that connects with the motor and meshes with the central shaft's bottom gear to provide the power to the central shaft. The middle shaft is used for putting another part of the Geneva wheel in order to mesh with the Geneva wheel on the central shaft. On this part of the Geneva wheel, there is a little rod with diameter of 0.3 cm, that extends out one cm at the bottom surface of the Geneva wheel in order to touch the switch (part 17) that is found on the third shaft, once the Geneva wheel has made one revolution. The switch on the third shaft is composed of spring, and if nothing is touching it, the motor is on. Once the rod bends the switch, the power on the motor for the power screws turns off and the motors for the timing mechanism and the antenna barriers turn on.

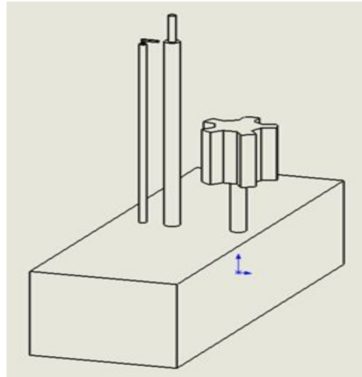

Figure 4.4 Motor Box

5. Summary and Conclusion

In summary, the machine created to build the pyramidal ice lodging is composed of three major mechanisms that have many moving parts to achieve their respective goals.

The timing mechanism uses a series of partial gears meshing with pinions that achieve the motions of water supply control, removing the top of the cooler and pushing the block onto the spring loaded plate. The partial gears allow for continuous sequential motions.

The telescopic barriers use rack and pinions to power pushing plates. The pushing plates execute sequential motions from the input of a geneva wheel timing system. The spline shaft allows the barrier to shrink in size as it is driven up the frame.

Pressure activated contact limit switches behind the pushing plates activate the motor in the frame. This motor causes the four power screws in which the telescopic barrier is mounted to rotate. The rotation of the power screws drive the barrier upward on the screws to the base of the next layer.

This machine is optimal because it fulfils the criteria that require a minimal amount of load bearing, mechanical parts and time to complete the building of a lodging. The timing mechanism that creates the blocks of ice and the barriers pushing system is very efficient. The ice blocks are always being moved and no time or resources are wasted.

Overall, the pyramid ice lodging builder meets the requirements of the given mandate. The machine acts without human intervention, with the exception of being turned on and off through a contact limit switch. The final result of this machine in action is an empty 180 block pyramidal ice lodging.

List of References

[1] Robitaille, Francois. “Gears 1”. Introduction to Design 2017. Lecture.

[2] Robitaille, Francois. “Gears 2”. Introduction to Design 2017. Lecture.

[3] Robitaille, Francois. “Bearings and Bushings”. Introduction to Design 2017. Lecture.

[4] T. (2011, May 18). Rotation to translation mechanism 2. Retrieved April 04, 2017, from https://www.youtube.com/watch?v=kOyRtiDRZ_o

[5] I. (2015, October 20). Vex Mechanisms - Period 3 Lead Screw. Retrieved April 04, 2017, from https://www.youtube.com/watch?v=VyMHNJr-VcA

[6] C. (2013, November 01). Power screw. Retrieved April 04, 2017, from

[7] E. (2014, January 31). Understanding a Microswitch. Retrieved April 04, 2017, from http://www.youtube.com/watch?v=q6nP1FjxAMU

[8] www.davall.co.uk/media/2570/multi%20driven1.jpg

APPENDIX A: Course Work

A.1: Collection of Agendas and Minutes

Agenda for Meeting 1 of Team 2
Location: SITE
Date and Time: January 26, 2017 at 5:30pm

1. Determine which project to choose
2. Create Google Doc to complete mandate one
3. Start criteria and restrictions tree
4. Additional items

Minutes for Meeting 1 of Team 2

Location: SITE

Date and Time: January 26, 2017 at 5:30pm

Present: Michael, Katherine, Mackenzie, Leilei, Utu
Absent: None

1. *Determine which project to choose*

- Read over the mandates for each potential project
- Advantages and disadvantages for each were discussed
- Voted for which project to complete
- Unanimously decided on the mechanical project

2. *Create Google Doc for completing mandate one*

- Google document was created and shared with all group members

3. *Start criteria and restrictions tree*

- Read over the project outline as a group and made a list of all criteria and restrictions

4. *Additional Items*

- Agreed to work individually on defining the mandate over the weekend
- Planned to meet again on Monday to review the completed mandate

Meeting ended: 6:40pm

Agenda for Meeting 2 of Team 2
Location: SITE
Date and Time: February 2, 2017 at 5:30pm

Agenda:

1. Create document for Methodology 2 (M2)
2. Figure out the different basic functions
3. Brainstorm solutions for basic functions
4. Group together brainstormed ideas to build four complete solutions containing solutions for basic functions

Minutes for Meeting 2 of Team 2

Location: SITE

Date and Time: February 2, 2017 at 5:30pm

Present: Katherine, Mackenzie, Leilei, Utu and Michael
Absent: None

1. *Create document for M2*

- Mackenzie created document for second coursework
- Mackenzie shared document to other team members

2. *Breakdown into basic functions*

- Katie recorded our ideas for basic functions of design
- Michael created flow charts containing basic functions
- From the basic functions, the group put these functions in chronological order

3. *Brainstorming solutions for basic functions*

- The group then listed many ideas for how each of the basic functions could work, from the simpler ideas to the more creative and complex ideas.

4. *Group generating complete solutions*

- The group was able to group together a few of the brainstorming ideas to come up with solutions and put them into a readable table.
- Michael commented on the rationale for each complete solution

Meeting ended: 8:15pm

Agenda for Meeting 3 of Team 2

Location: SITE

Date and Time: February 9, 2017 at 3:30pm

Agenda:

1. Review feedback from Methodology 1 (M1)
2. Rate solutions with criteria
3. Breakdown basic functions to each team member
4. Each team member responsible for creating their respective deadlines chart

The agenda has been approved by all team members.

Minutes for Meeting 3 of Team 2

Location: SITE

Date and Time: February 9, 2017 at 3:30pm

Minutes:

Present: Katherine, Mackenzie, Leilei, Utu and Michael

Absent: None

1. *Review feedback from M1*

- It was noticed that most of the criteria in the chart were actually restrictions.
- Mackenzie emailed Miriam asking if it was necessary to redo the chart.
- Team worked together to find more criteria for the new chart if necessary
- New weightings were calculated

2. *Rate solutions with criteria*

- Team worked together to visualize each solution and rate each solution for how well it satisfies each criterion

3. *Breakdown basic functions to each team member*

- Michael: Placing and stacking blocks (with help from Utu)

- Utu: Opening and closing the bottom of the cooler
- Leilei: Movement of block to the appropriate position
- Katherine: Time 30 seconds to freeze the block
- Mackenzie: Stopping the water supply

4. *Each team member responsible for creating their respective deadlines chart*

- Mackenzie will calculate the weightings for the new criteria and restrictions
- Each team member will create their own deadlines chart and collaborate with the other members to adjust dates and construct a Gantt Chart

Meeting ended: 8:20pm

Agenda for Meeting 5 of Team 2

Location: SITE

Date and Time: February 27, 2017 at 4:00pm

Agenda:

1. Review progress from reading week
2. Address current design problems
3. Brainstorm solutions for problems

The agenda has been approved by all team members.

Minutes for Meeting 5 of Team 2

Location: SITE

Date and Time: February 27, 2017 at 4:00pm

Minutes:

Present: Katherine, Mackenzie, Leilei, Utu and Michael

Absent: None

1. *Review progress from reading week*
- Both Mackenzie and Katie worked on preparing dimensions for the belt drive
- Leilei discussed progress with the block pushing arm

2. *Address current design problems*
- Corner of last block of layer acting as an obstacle for new block to go to next layer
- How will the belt drive system be supported/stabilized?
- How will the barriers shrink suddenly?
- How will the barriers move inside by 30cm for each layer?

3. *Brainstorming solutions for problems*
- Options for changing the angle of the belt drive to accommodate for the corner obstacle
- Each team member will do research to come up with additional possible solutions for next meeting, scheduled for Thursday at 5:30pm.

Meeting ended: 5:00pm

Agenda for Meeting 6 of Team 2

Location: SITE

Date and Time: March 6, 2017 at 4:15pm

Agenda:

1. Approve previous meetings minutes
2. Evaluate if motions obey laws of physics
3. Discuss problems with smoothness of block motion (corner of exterior ice block of previous layer blocking inclined motion of block inclined motion of block, sudden shrinking of barriers)
4. Find simpler mechanisms to accomplish the same motion.

The agenda has been approved by all team members.

Minutes for Meeting 6 of Team 2

Location: SITE

Date and Time: March 6, 2017 at 4:15pm

<u>Minutes:</u>

Present: Katherine, Mackenzie, Leilei and Michael

Absent: Utu

1. *<u>Approve previous meetings minutes</u>*

- The minutes for the previous meeting was reviewed and approved

2. *<u>Evaluate if motions obey laws of physics</u>*

- Discussed Hooke's Law for the springs
- Came to the realization that our solution for removing the block from the box is flawed and a new solution needs to be found

3. *<u>Discuss problems with smoothness of block motion</u>*

- Ramp and conveyor belt idea was put on hold, group decided to look for an alternative method of moving blocks to starting position

4. *<u>Find simpler mechanisms to accomplish the same motion</u>*

- Katherine came up with an alternative method of moving the blocks to the starting position, involving a pushing arm.

Meeting ended: 5:00pm

*Note: Later this evening (March 6) we were informed that our team member Utu had dropped the course.

Agenda for Meeting 7 of Team 2

Location: SITE

Date and Time: March 13, 2017 at 4:15pm

<u>Agenda:</u>

1. Approve previous meetings minutes
2. Michael will explain design idea for barrier shrinkage
3. Katie and Mackenzie must come up with solution for ice block transmission

The agenda has been approved by all team members.

Minutes for Meeting 7 of Team 2

Location: SITE

Date and Time: March 13, 2017 at 4:15pm

<u>Minutes:</u>

Present: Katherine, Mackenzie, Leilei and Michael

Absent: None

1. *<u>Approve previous meetings minutes</u>*

- The minutes for the previous meeting was reviewed and approved

2. *<u>Michael will explain design idea for barrier shrinkage</u>*

- Michael went through each component of his idea
- He showed drawings he prepared to further demonstrate his ideas

3. *<u>Katie and Mackenzie must come up with solution for ice block transmission</u>*

- Planned out time diagram and came up with a prototype to demonstrate how to move the block.

Meeting ended: 5:50pm

Agenda for Meeting 8 of Team 2

Location: SITE

Date and Time: March 23, 2017 at 4:15pm

<u>**Agenda:**</u>

1. Approve previous meetings minutes
2. Over the weekend, each team member agreed to work on their respective solidworks parts.
3. Team 2 agreed that we will meet on Monday to start assembling the ice block machine.
4. Team 2 also agreed to meet on google slides on the weekend and create the small presentation for Week 11.

The agenda has been approved by all team members.

Minutes for Meeting 8 of Team 2

Location: SITE

Date and Time: March 20, 2017 at 4:15pm

<u>**Minutes:**</u>

Present: Katherine, Mackenzie, Leilei and Michael

Absent: None

1. <u>*Approve previous meetings minutes*</u>

- The minutes for the previous meeting was reviewed and approved

2. <u>*Over the weekend, each team member agreed to work on their respective solidworks parts*</u>

- Each team member had started their solidworks pieces over the weekend and we showed each other what we had done over the weekend.

3. <u>Team 2 agreed that we will meet on Monday to start assembling the ice block machine.</u>

- Since each team member had a starting point in solidworks, and some pieces were assembled with each other.
- By starting the assembly, we were able to confirm dimension of the different pieces.

4. <u>Team 2 also agreed to meet on google slides on the weekend and create the small presentation for Week 11.</u>

- The small presentation slides were finished over the weekend, and were practiced to present at meeting.

The agenda has been approved by all team members

The minutes have been approved by all team members

Meeting ended: 8:00pm

A.2: Definition of Mandate

A machine is to be designed so it constructs a pyramidal lodging from ice blocks, with the following dimensions; 60cm x 60cm x 30cm.

The bottom-most layer will measure 10 blocks by 10 blocks, laid side by side, for a total of 36 blocks (10+10+8+8). The next layer will measure 9 blocks by 9 blocks, for a total of 32 blocks (9+9+7+7), and will lie on top of the bottom-most layer. This pattern will continue until the last closed square, measuring 2 blocks by 2 blocks. It is the design team's choice if they want to place one final block on the top of the pyramid, meaning the lodging will either consist of 180 or 181 blocks. The pyramid must remain empty on the inside, and therefore the lodging must be built from the outside.

The device must run with no human intervention, other than starting the machine to begin the process, and stopping the machine when it is finished. The lodging builder operates on electricity from a generator. Mechanical power may be generated by at most three motors. There can also be no electric controller to operate the device, only contact limit switches.

The ice blocks are made on-site using ultra-efficient Peltier coolers. Water is pumped into the cooler by means of a flexible pipe, coming out from the top. A new ice block is ready every 30 seconds, and the bottom of the cooler must slide or hinge open to let go of the ice blocks when frozen. The water supply must be stopped automatically by a single valve built on the pipe when the bottom of the cooler is opened, and must reopen, allowing water flow, when the bottom of the cooler is closed. Since a block is ready every 30 seconds, the time to build the lodging is roughly 90 minutes.

A.3: Criteria and Restrictions

In **Table A.3.1**, the criteria are shown in green and the restrictions are shown in red.

Table A.3.1. Criteria and Restrictions and the Absolute Weights of the Criteria

	Absolute Weighing
1. Pyramid base 10x10, with each successive layer decreasing by one block per side length.	
2. Machine's ability to withstand cold temperatures must be maximized.	0.048
3. Machine must remain on the outside of the pyramid.	
4. Minimize the time to build the lodging.	0.072
5. Minimize the load bearings on the structure.	0.06
6. Minimize the number of mechanical components.	0.06
7. Ice blocks are created to measure 60cm x 60cm x 30cm.	
8. Pyramid must be 180 or 181 blocks.	
9. Machine must be as small as possible.	0.16
10. Machine must run on electricity from a generator.	
11. Maximum 3 motors.	
12. Machine must be as energy efficient as possible.	0.21
13. Minimize number of motors.	0.09
14. Machine must operate with any human intervention.	
15. Must use contact limit switches.	
16. Cannot use any electronic controller.	
17. Only one ice making box.	
18. Takes 30 seconds for each block to form.	
19.Block must drop from the bottom of the cooler.	

20. Water supply must be cut before the block is dropped.	
21. Minimize the chance of collisions between blocks.	0.3

Hierarchical Tree - Assignment of Importance to Each Criterion

Figure A.3.1 displays what defines the criteria and restrictions on the right and what justifies the criteria on the right. In each box, the relative weightings are the leftmore numbers and the absolute weightings are the rightmost numbers.

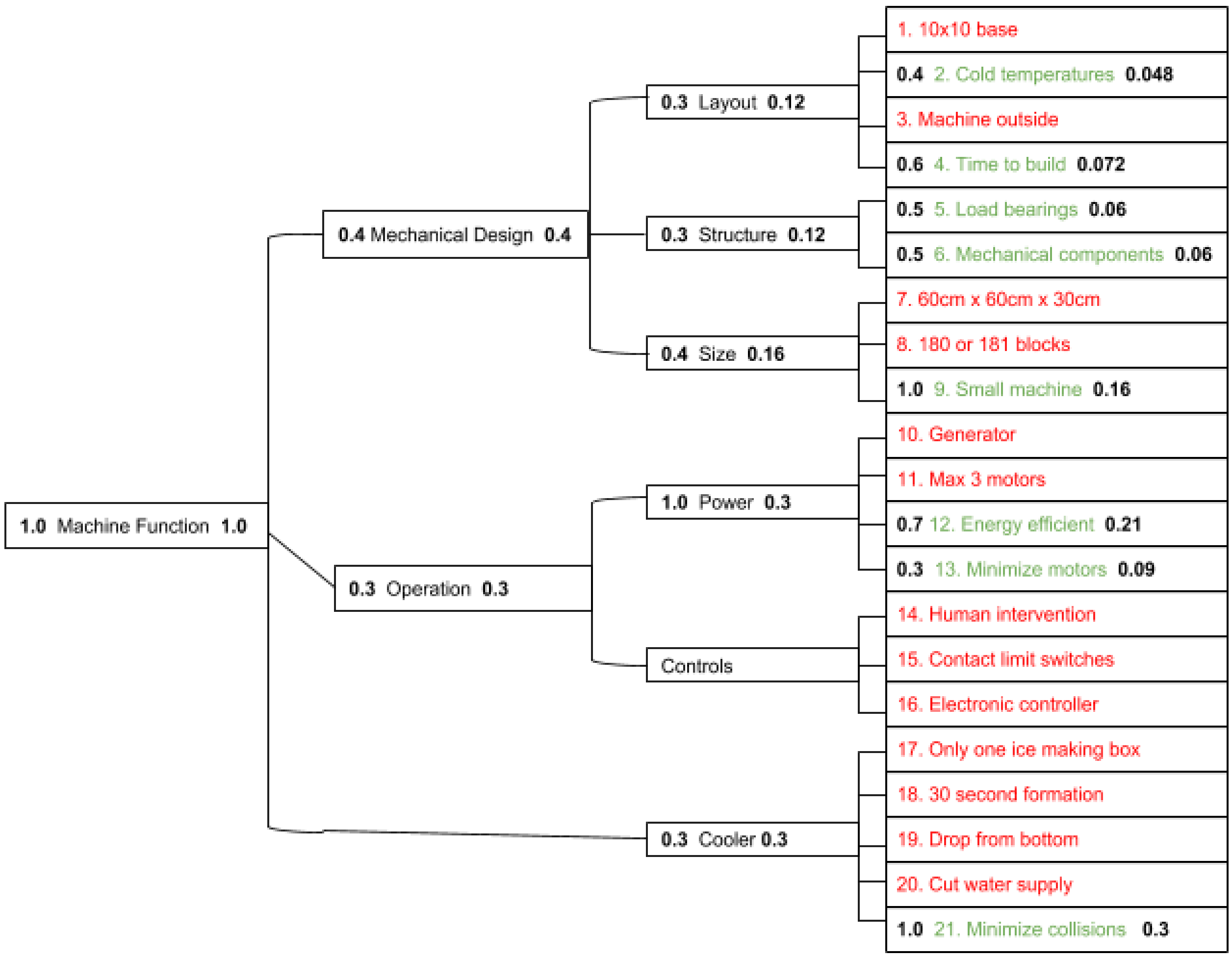

Figure A.3.1. Tree diagram breaking down the machine's function into criteria to which are assigned different levels of importance

A.4 Generation of Solutions

1. Functional Analysis - Basic Functions

STARTING STEP: Turning the machine ON
Open bottom of cooler
Stop water pipe when cooler bottom is open
Start water flow when cooler bottom is closed
Time to freeze ice block; 30 seconds
Placing ice blocks (position)
Stacking the blocks
FINAL STEP: turning machine off

General Breakdown of basic functions:

1. (Starting with closed box) Start water supply -> Once filled, stop water supply and open bottom of box -> Release ice block -> Close bottom of cooler -> Start water supply
2. Placing blocks: remove block from cooler -> move into position -> continue until underlayer is completed
3. Stacking the blocks: wait until underlayer is completed -> start new layer on top

This analysis is general, so a more specific analysis follows with detailed flow charts.

Functional Analysis - Detailed Charts

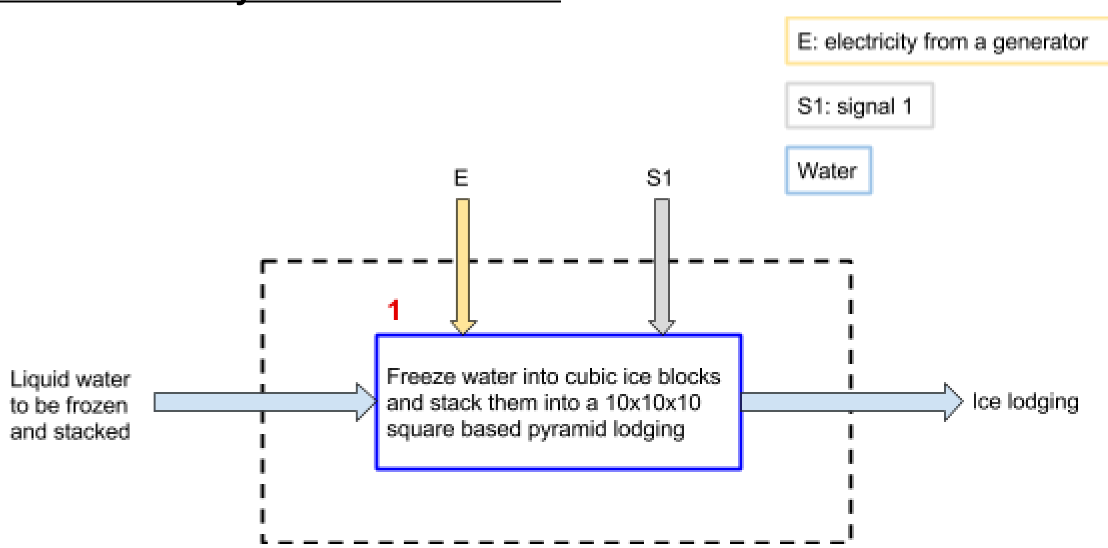

Figure A.4.1 Block diagram for Functional Analysis, part 1

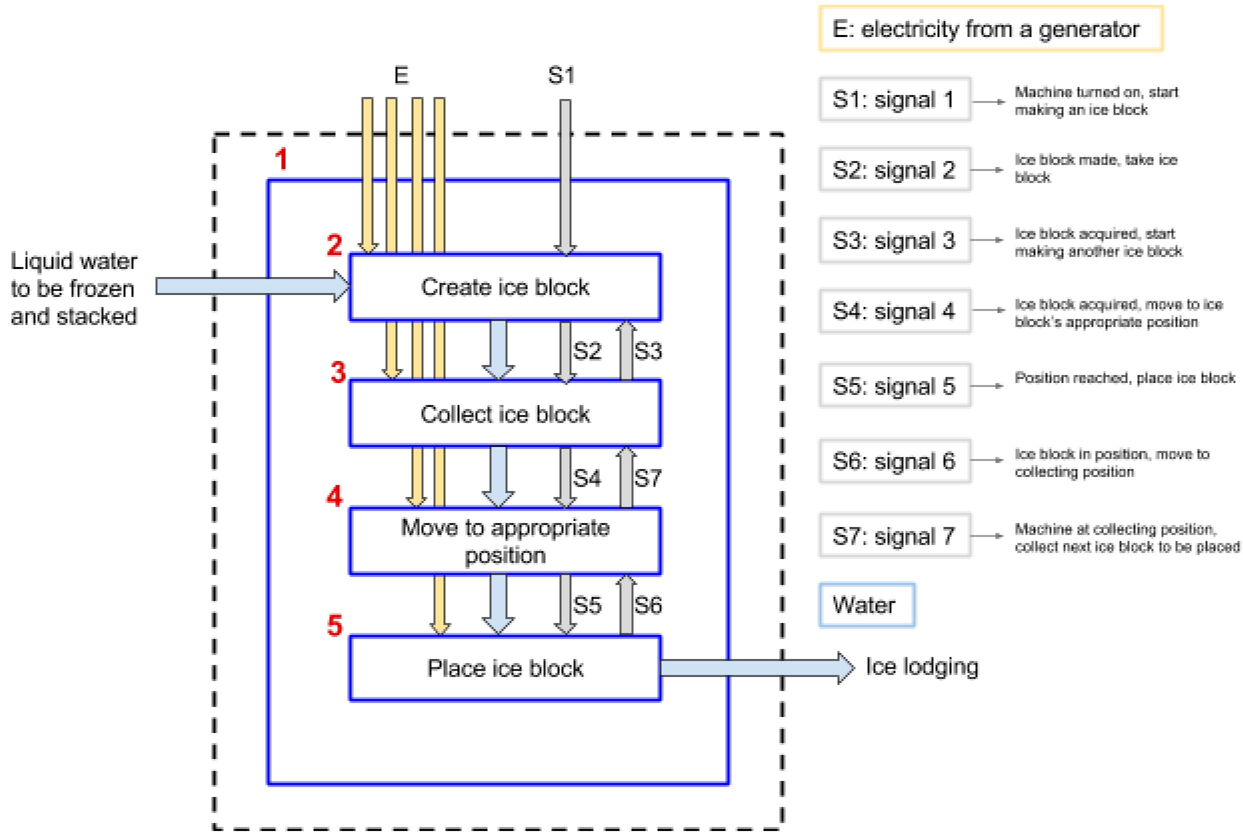

Figure A.4.2 Block diagram for Functional Analysis, part 2

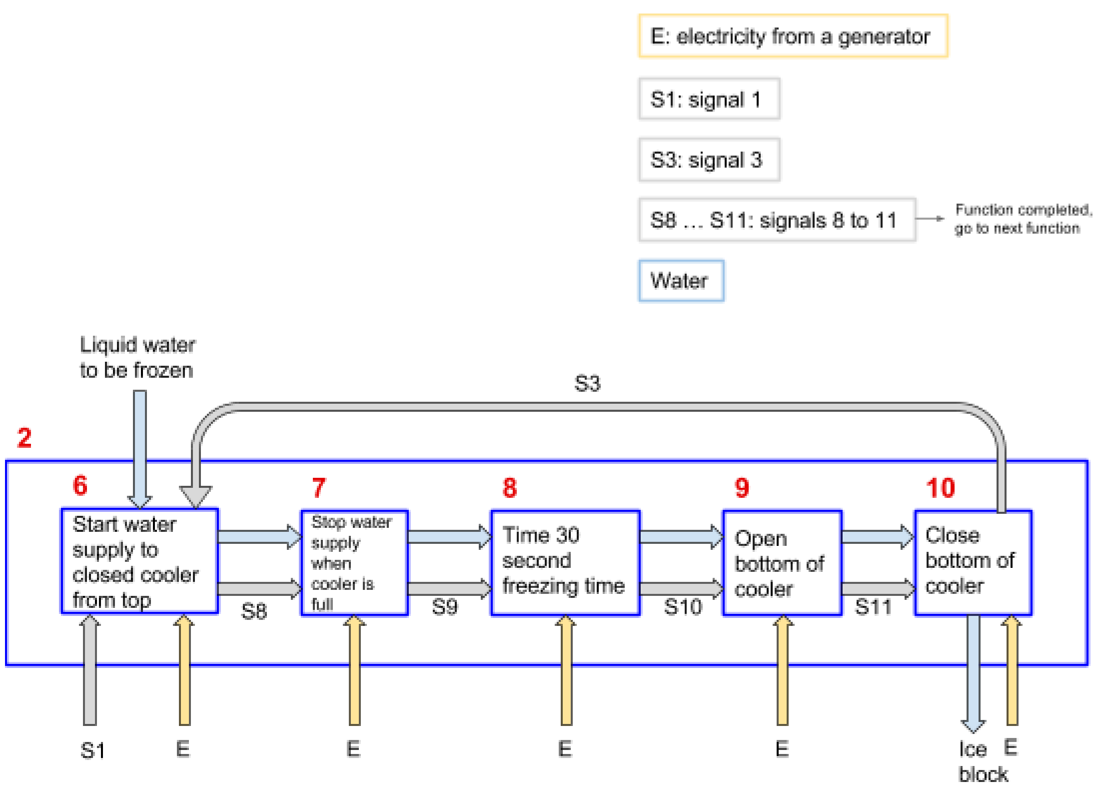

Figure A.4.3 Block diagram for Functional Analysis, part 3

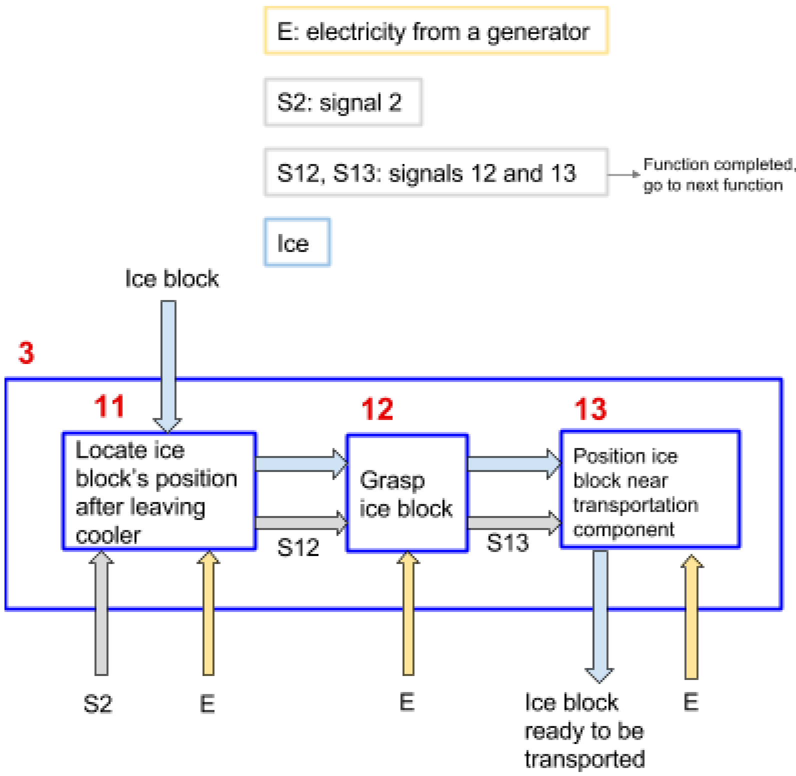

Figure A.4.4 Block diagram for Functional Analysis, part 4

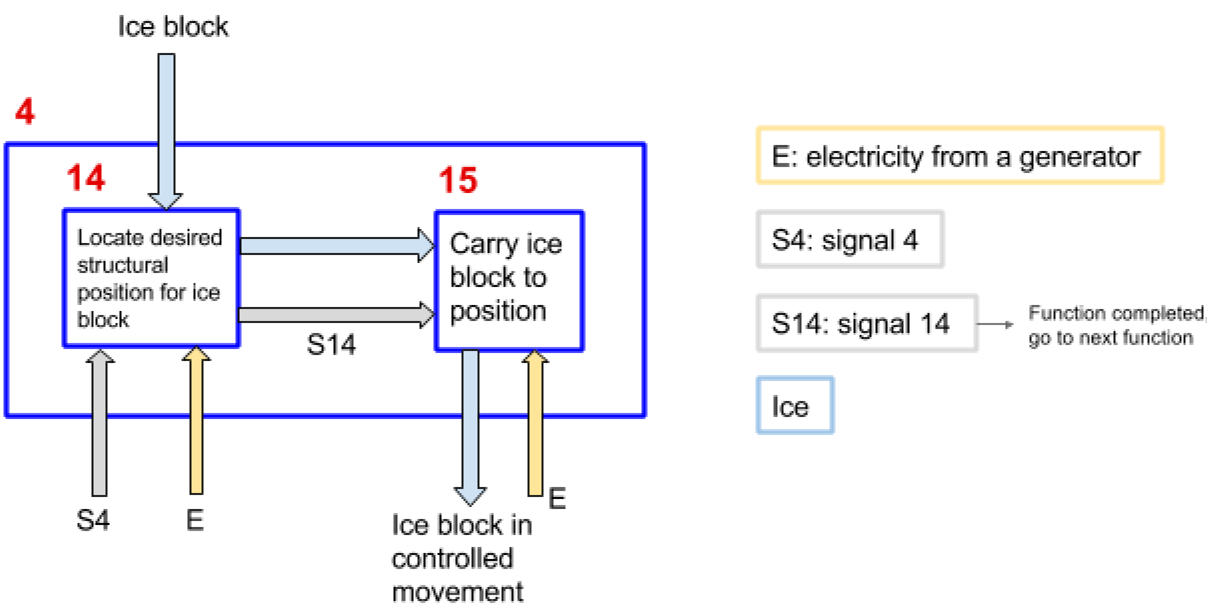

Figure A.4.5 Block diagram for Functional Analysis, part 5

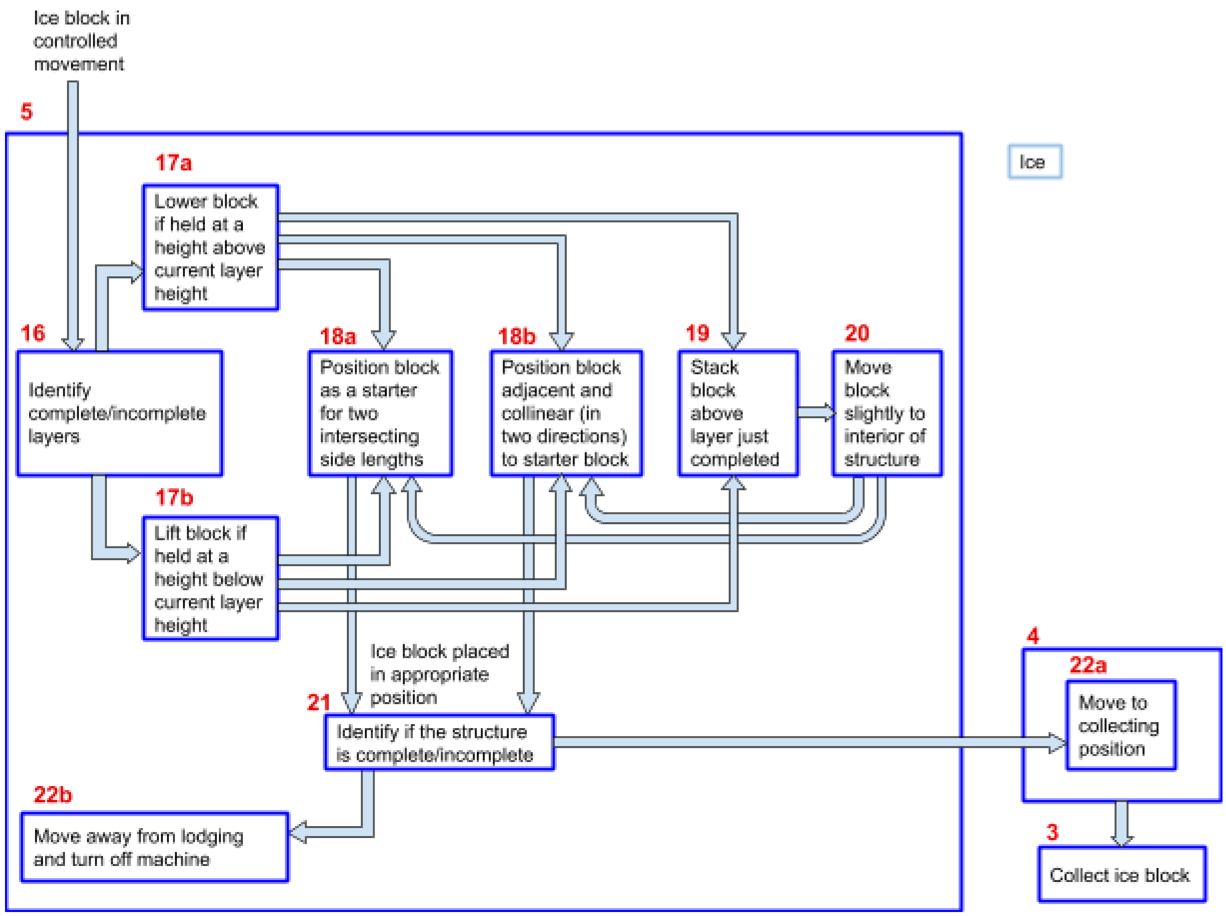

Figure A.4.6 Block diagram for Functional Analysis, part 6

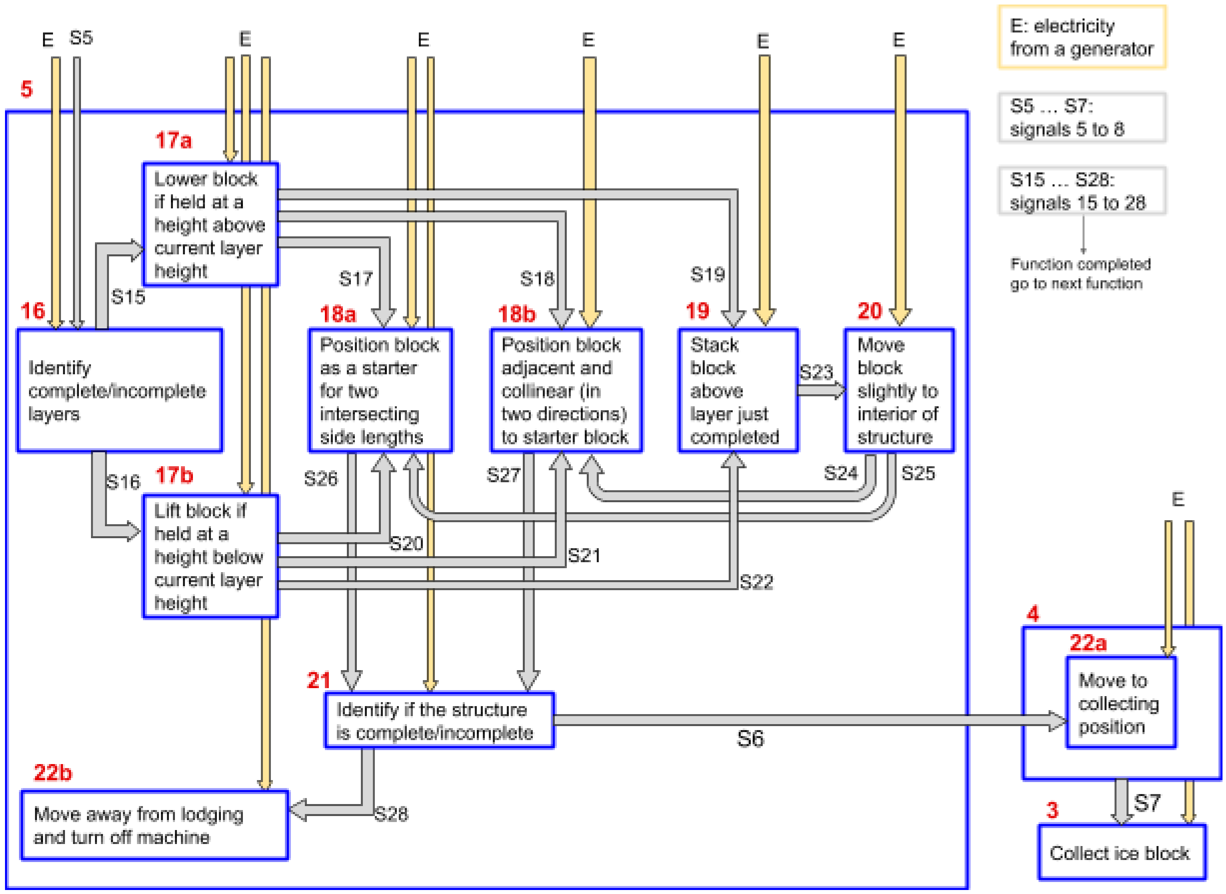

Figure A.4.7 Block diagram for Functional Analysis, part 7

Two flow charts for function five have been made since it would be much to difficult to fit the ice, signals and energy on one diagram. For clarification, a ***or*** b occurs depending on the circumstance.

2. Brainstorming - Solutions to Basic Functions

Open and close bottom of cooler:
- Open at certain weight
- Linkages to open and close
- Hinges to open and close
- Rollers to slide open and close
- sensor to open and close

Stopping water supply when cooler bottom is open:
- Linkage attached to sliding door and water supply panel (when door open, water off and vice versa)
- Sensor to recognize when bottom of cooler is open
- Cam and rocker arm that opens a valve to fill the cooler and closes the valve for 30 seconds

Time to freeze block; 30 seconds:
- Claw that drops ice block will send signal in the form of pulley system that takes 30 seconds to reach and close the cooler
- Block is dropped from cooler when sensor in the claw signals that the previous block has been placed, assuming process takes 30+ seconds
- Ramp conveyor belt rotating at constant speed such that component will go up and down the ramp in 30 seconds

Placing blocks:
- Slide blocks into position
- Use punching arm (piston) to move into position
- Using a pulley system
- Digging a channel for the blocks to fit in
- Rubik's cube rotation
- Robotic arm to drop the blocks
- Cooler attached to the top of the machine frame (stationary)
- Cooler attached to the top of the machine frame (moving along the frame)
- Extendable and retractable claw with gear trains and stationary gears at the pivot points
- Ramp with 10 square slots
- Barrier system (one on every level) placed at all corners, to push and align the ice blocks, and when layer is finished, springs attached to barrier system are compressed.

Stacking the blocks:
- Layer by layer
- Drop block into same corner position and use arm to push until layer is full, and when block can no longer go into corner position, the machine will begin the next layer

- Elevator pistons

Table A.4.1 Combination of Solutions

3. Combination

<u>Basic Function</u>	**Complete Solution 1**	**Complete Solution 2**	**Complete Solution 3**	**Complete Solution 4**
Open and close bottom of cooler (Utu)	Rollers to slide open and close bottom	Rollers to slide open and close bottom	Linkage connected to bottom of cooler and water supply	Hinge connected to side and bottom faces to open/close door by rotation
Stop water supply (Mackenzie)	Linkage attached to to sliding door and water supply panel (when door open, water off and vice-versa)	Sensor at top of box that stops supply immediately after water reaches the top	Linkage rotating to shut panel within water pipe	Cam and rocker arm closing valve to stop water flow
Time 30 seconds to freeze block (Katie)	Claw that drops ice block will send signal in the form of pulley system that takes 30 seconds to reach and open the cooler	Block is dropped from box when sensor in the claw signals that the previous block has been placed, assuming process takes 30+ seconds	Ramp conveyor belt rotating at constant speed cooler-opening component will go up and down the ramp in 30 seconds	Same as in Solution 3
Move block to appropriate position (Leilei)	Using a pulley system	Cooler attached to the top of the machine frame (both cooler and frame are stationary), Moved by a claw that picks up the block	Horizontal conveyor belt for blocks to drop on to	Same as in Solution 3
Placing and stacking blocks (Michael +	Elevator pistons	Extendable and retractable claw that opens and closes when its	Angled conveyor belt with square slots that	Same as in Solution 3

Utu)		gears rotate around a pivot point	remain open for incomplete layers	

Complete Solution 1 mainly relies on vertical motion which is why the pulley systems and elevator pistons were combined; the claw is used to pick up the ice block that will likely end up on the ground after the bottom of the cooler slides open. **Complete Solution 2** suggests the machine doesn't move very much, so an extendable and retractable claw and a sensored cooler attached to the machine will reduce the machine's displacement. **Complete Solution 3 and 4** work with a conveyor belt which is ideal to combine the latter three basic functions using the following methods: timing at a constant velocity, moving blocks and raising blocks to be placed.

A.5 Decision Analysis

Decisional Analysis

The complete solutions 1 through 4 are given ratings out of 10 (0 being the worst and 10 being the best) of how well each basic solution within each complete solution fulfills each criteria. For each complete solution, an absolute rating was given by multiplying each weight with each rating out of ten and then adding them up.

Table A.5.1 Solutions Evaluations

Table 2*:* Evaluation of the Complete Solutions

Criteria	Weight (W)	Complete Solution 1 (S1)	Complete Solution 2 (S2)	Complete Solution 3 (S3)	Complete Solution 4 (S4)	S1x W	S2x W	S3x W	S4x W
2	0.048	8	8	8	8	0.384	0.384	0.384	0.384
4	0.072	6	4	7	7	0.432	0.288	0.504	0.504

5	0.06	9	3	10	10	0.54	0.18	0.6	0.6
6	0.06	6	4	7	8	0.36	0.24	0.42	0.48
9	0.16	7	5	6	6	1.12	0.8	0.96	0.96
12	0.21	8	4	6	6	1.68	0.84	1.26	1.26
13	0.09	7	7	5	5	0.63	0.63	0.45	0.45
21	0.3	6	10	7	7	1.8	3	2.1	2.1
					Total:	**6.346**	**5.522**	**6.678**	**6.738**

Since **Complete Solution 4** has the highest absolute rating, it is the solution that will be retained.

<u>Preparation to Design - Equal Distribution of the Workload Among the Team Members</u>

As shown in **Table 3**, the workload in building the machine has been distributed by assigning each team member an approximately equal amount of solutions to basic functions. The basic functions come from the flowcharts in Methodology 2 (M2).

Table A.5.2 Complete Solutions

Table 3. Complete Solution 4 - Assignment of Basic Solutions to Team Members

Basic Function	**Basic Solution**	**Team Member**
Start water supply to closed cooler from top	Belt drives starts when contact switch is turned on, and guiding hand hits handle	Mackenzie
Stop water supply when	When guiding hand moves past handle, water supply is cut off	Mackenzie

cooler is full		
Time 30 second freezing time	The belt drives move with constant speed along with the guiding had, in order for block to freeze in time	Mackenzie
Open bottom of cooler	Guiding hand moves up rods connected to the bottom of the cooler, which is detachable from the cooler	Katherine
Close bottom of cooler	Guiding hand pushes the ice block off the bottom of the cooler, which releases the pressure, and causes spring loaded bottom of cooler to spring back up to the cooler	Katherine
Locate where ice block's position after leaving cooler	Ice block is pushed by the guiding hand, until it reaches the first available hole for layer one.	Mackenzie
Locate desired structural position for ice block	Ice block travels along belt drives to placement position	Katherine
Identify complete/incomplete layers	Incompleted rows allow piston to push ice block in perimeter of layer and completed rows do not allow ice blocks to be pushed in layer (pushed above to next layer instead)	Katherine
Lower block if held at height above current layer height	Blocks start on ground	Leilei
Lift block if held at height below current layer height	Previous layer blocks and slanted surface will force ice blocks to next layer	Leilei
Position block as a starter for two intersecting side lengths	Fixed position for each block to be transferred to (next blocks will push first blocks)	Leilei
Position block adjacent and collinear (in two directions) to starter block	Pistons will push ice blocks along barriers	Leilei

Stack block above layer just completed	Bars between two belt drives will guide blocks to appropriate layers (if a layer is full, last block in layer will prevent next block to enter the specific layer and block will move above bar leading to next layer)	Michael
Move block slightly to interior of structure	Four barriers, two of which have pistons retract (barriers constructed similar to how an antenna is constructed)	Michael
Identify if the structure is complete/incomplete	Person looks at pyramid and knows when to turn off machine	Michael
Move to collecting position	Transmission runs in a cycle (next block would already be at starting position for layer pushing the previous blocks to end of row in layer)	Michael
Move away from lodging and turn off machine	Person turns off machine and moves it away	Michael
Idealize entire frame structure	Determine optimal positions for components of the machine, and how to optimize the entire structure.	Utu

Preparation to Design - Realization Strategies and Deadlines

Tables 4-8 demonstrate the key deadlines for tasks, divided between team members. **Table 9** lays out the dates for which key pieces of information are to be exchanged.

Table A.5.3: Realization Strategy Table for Mackenzie

	REALIZATION STRATEGY - MACKENZIE	**Completion Date:**
1	Identify belt drive dimensions.	02/18/17
2	Determine angle required for belt to line up with pyramid.	02/19/17
3	Determine dimensions of gears needed for belt drive.	02/20/17
4	Determine shape and size of guiding hand.	02/22/17
5	Determine how guiding hand is connected to belt drive and	02/23/17

	interacts with the system.	
6	Identify placement of water supply handle.	02/24/17
7	Determine how the water supply handle is activated.	02/27/17
8	Identify interaction between guided arm and water supply.	03/03/17
9	Identify constant speed for belt drives to be moving at.	03/04/17
10	Determine placement and type of motor to use for the belt drive.	03/06/17

Table A.5.4: Realization Strategy Table for Katherine

	REALIZATION STRATEGY - KATHERINE	**Completion Date:**
1	Confirm with professor if our method for releasing the block is acceptable.	02/14/17
2	Ensure blocks are not falling at a high enough distance to break.	02/19/17
3	Identify slot placement for blocks to fall through.	02/21/17
4	Determine the dimensions of compressible arm and platform that transfers ice block from belt.	02/23/17
5	Determine the type of spring required for pushing down bottom of box.	02/25/17
6	Determine how the bottom of the cooler is sealed after block has been delivered to the belt drives.	02/27/17
7	Obtain information from Utu on the dimensions of the frame	03/15/17
8	Determine how the cooler is connected to the frame.	03/17/17
9	Determine how belt drives and guiding hand interact with the block placement system.	03/13/17
10	Determine placement of contact limit switch to activate machine.	03/06/17

Table A.5.5: Realization Strategy Table for Leilei

	REALIZATION STRATEGY - LEILEI	**Completion**

		Date:
1	Confirm with the professor if position barriers are allowed at each layer.	02/14/17
2	Obtain information for the dimensions of the mechanism containing the belt drives from Mackenzie.	02/20/17
3	Determine the dimensions of stationary and moving barriers.	02/28/17
4	Figure out appropriate piston dimensions.	03/02/17
5	Find the appropriate length of the spring attached to the barrier pistons.	03/03/17
6	Figure out the most compatible type of straight line generator linkages (in terms of volume taken) which connected to the overall frame.	03/06/17
7	Find the dimensions for these linkages.	03/08/17
8	Determine how to connect the placing barriers to the linkages attached to the frame.	03/09/17
9	Determine how to raise the four barriers to the next layer (clarification - the stationary barriers will be horizontally stationary and not vertically stationary and the moving barriers will be moving horizontally and vertically).	03/13/17
10	Concoct mechanical components that would raise panels to stabilize blocks at starter position.	03/14/17

Table A.5.6: Realization Strategy Table for Michael

	REALIZATION STRATEGY - MICHAEL	**Completion Date:**
1	Evaluate the smoothness of the block motion over previous block layer and adjust the adjust the motion with a smooth slanted surface if needed.	02/20/17
2	Evaluate if the ice blocks will collide or be overly compressed.	02/22/17
3	Evaluate if the piston is moving 60cm each time a block is pushed.	02/25/17
4	Find the locations to implement the gear trains.	02/27/17
5	Determine the number and size of gears needed.	03/02/17

6	Choose a rotation speed for each input gear in each gear train.	03/05/17
7	Figure out the smallest possible size for the four barriers that control the motion of the ice blocks being placed.	03/08/17
8	Concoct mechanical components to ensure the alternating motion of the rods attached to the frame (one motion to push the block in the x direction and another to push it in the y direction).	03/10/17
9	Implement a mechanism to ensure the simultaneous shortening of the barriers.	03/15/17
10	Ensure all the components interact with each in the appropriate manner.	03/20/17

Table A.5.7: Realization Strategy Table for Utu

	REALIZATION STRATEGY - UTU	**Completion Date:**
1	Collect dimensions from all teammates for the dimensions of all basic components.	03/13/17
2	Determine optimal area of frame.	03/15/17
3	Determine placement of cooler box.	03/17/17
4	Determine placement of water supply.	03/17/17
5	Determine connection with belt drive.	03/19/17
6	Determine placement of block placement system.	03/21/17
7	Optimize component placements.	03/23/17
8	Optimize frame design.	03/24/17
9	Finalize frame design.	03/26/17
10	Identify how the machine will shut off with contact limit switch	03/27/17

Table A.5.8: Outline for dates by which information must be exchanged

Information Exchange Deadlines

Name:	**Information Required:**	**Obtained From:**	**Obtained By:**

Katherin e	Confirm if method to release block is acceptable	Professor	02/14/17
Leilei	Confirm if barriers are allowed at each level.	Professor	02/14/17
Katherin e	Dimensions of the frame.	Utu	02/20/17
Leilei	Belt drive dimensions	Mackenzie	03/13/17
Utu	Dimensions of all components	All	03/15/17
Michael	Ensure all components interact with each other in the appropriate manner.	All	03/20/17

<u>Gantt Deadlines Chart</u>

In **Figure A.5.1**, a Gantt chart is used in order to illustrate the major tasks to be completed and their deadlines. It also shows who will take a leadership role during each task.

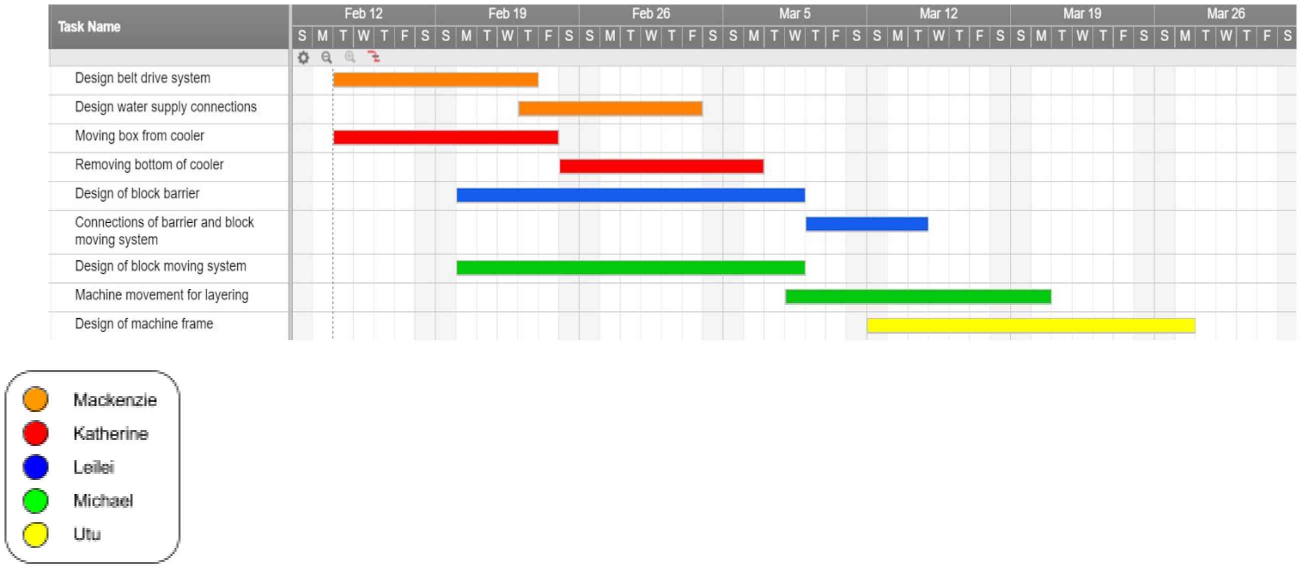

Figure A.5.1 Gantt chart illustrating deadlines for specific tasks and the leader responsible for them

APPENDIX B: Hand Drawings

B.1: Collection of hand drawn pictures and calculations

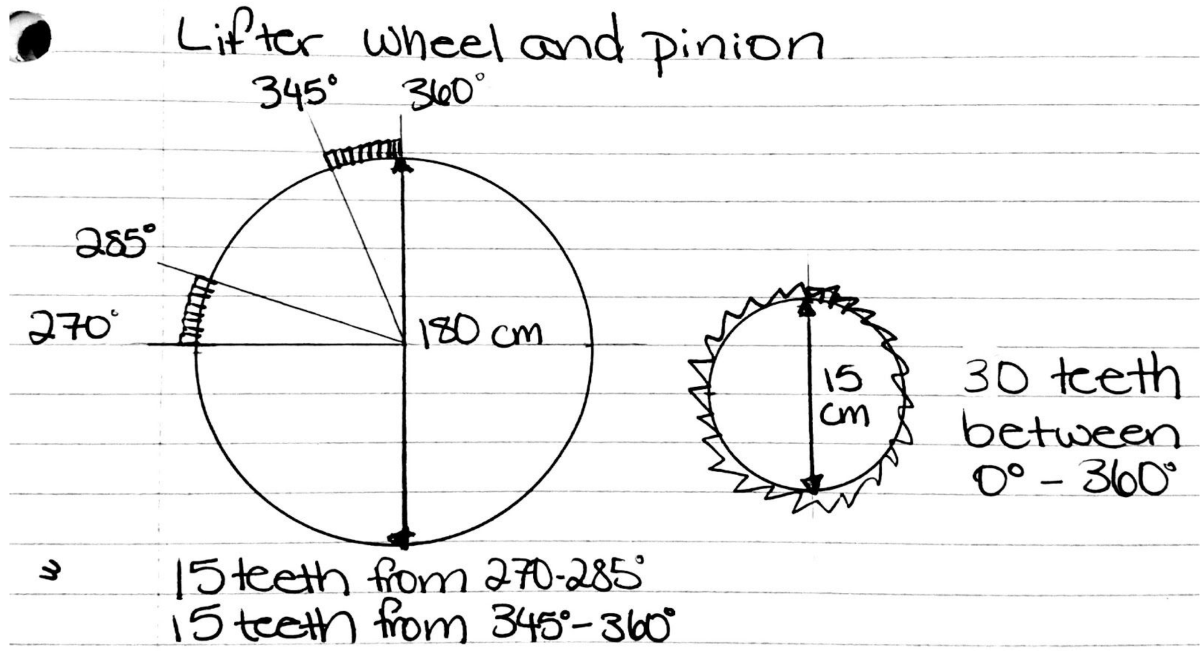

Figure B.1 Lifter wheel and pinion drawing

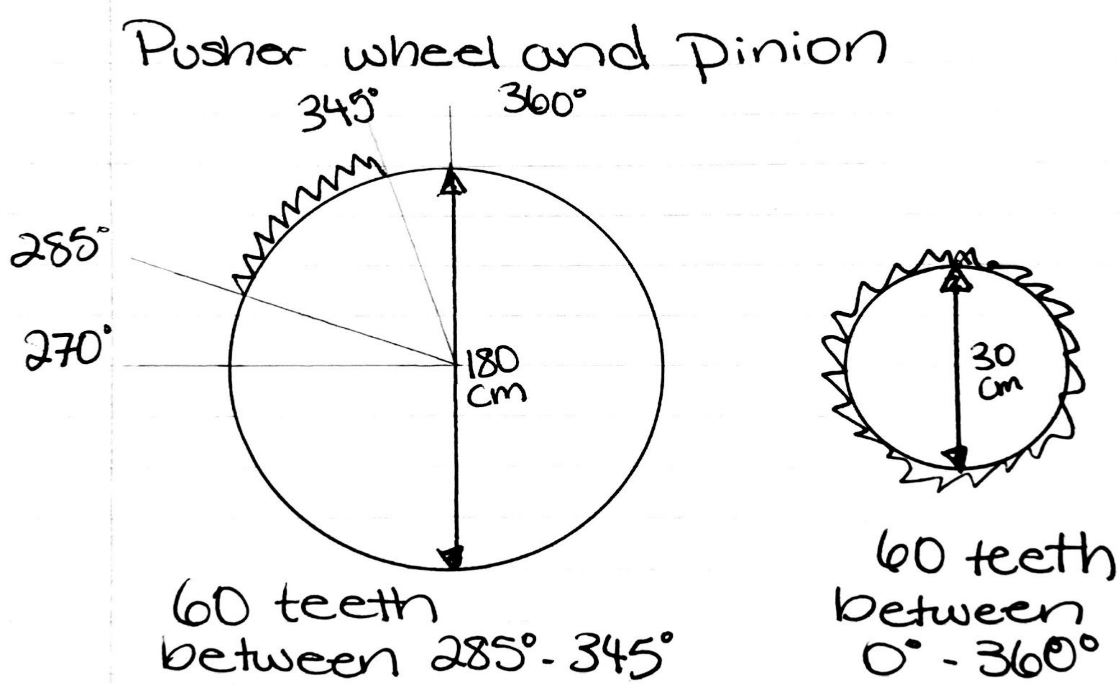

Figure B.2 - Pusher wheel and pinion drawing