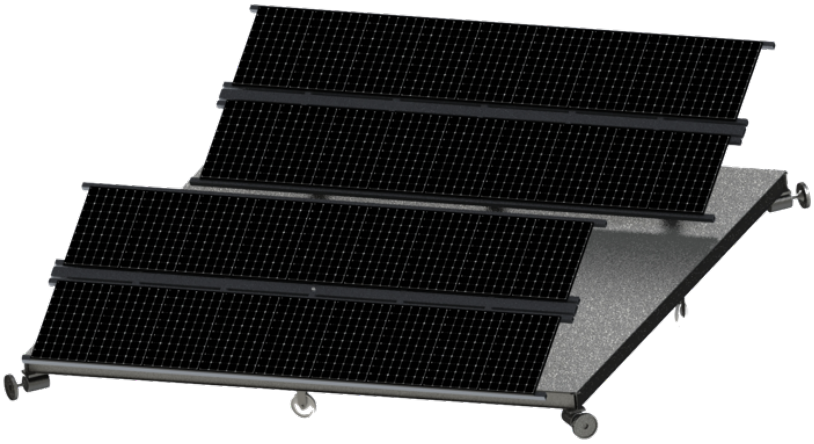
School of Engineering
Integrated Design Project 2

Detail Design - Mechanical
2019/20



Group: M14
Helios Wheel

Date of submission: 27th March 2020

Authors

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STATEMENT OF CONTRIBUTION

Name	Student ID	Contribution in their own words	Contribution level agreed with group with respect to the group average. (high/normal/low/none)
King Fong	1916879	Group Coordinator Compiled report Torque requirements calculations Presentation recording 3D printing building Parts of PDS Recording mentor meetings	High
Emma Howard	1896525	AR research Presentation recording Section 1/2 write up Preparing presentation Report editing	Normal
Liam Man	1780396	CAD drawings and rendering Solar panel CAD Sun path research Angle of tilt calculations Meeting log AR implementation	Normal
James Wilkins	1902868	Gearbox design CAD Gearbox calculations Sensor research Hydraulics system research	Normal
Ryan Bianchi	1945847	CAD drawings and renderings Concept drawings Material selection Solar panel selection	Normal
Ollie McCall	1935854	Compiling report Maintenance research Logging meetings Material and component selection Concept designs Product design specification	Normal

Section 1 – Concept design

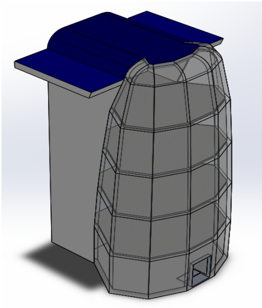


Figure 1: Mumbai, India

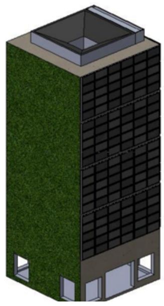


Figure 2: Shanghai, China

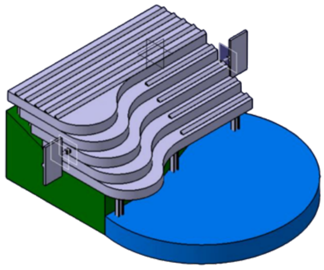


Figure 3: Toronto, Canada

Figure 4: Cairo, Egypt

Figures 1-4 shows the Model and Location of the vertical farm designs from Semester 1. The location of the Semester 2 farm was decided by ranking: the number of hours of sunlight, cost, and suitability for hydroponics. Cairo was the found to be the most suitable location with low labour costs, 9 hours of sunshine on average, and the country has no regulations against solar panels with a tracking function.

Our concept design is a mobile solar tracking array mounted upon the top of a tall vertical farm structure. The purpose of this is to have a source of renewable energy which will be used to power systems within our farm. The solar panels have been adapted as they have been placed on a turntable that has the ability to rotate in order to face the sun as it moves throughout the day to maximise the time it's exposed to solar radiation and therefore they will be in an optimal position to increase their energy output. The array will be based on a single axis quad motor-powered turntable, like those used to turn buses. It was decided to be located on the roof to decrease the impact of potential obstruction by other buildings or other low altitude objects and to avoid interfering with the operation of the farm below it. The turntable will need to use several gears to be able to support the movement of a large mass at slow speeds which will be required to stop and start at certain intervals in order to track the sun throughout the day.

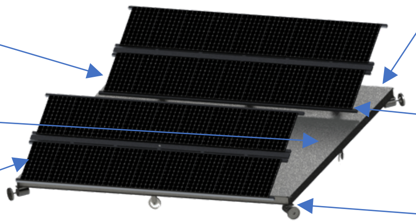


Figure 5: Single axis rotating solar tracker

To decide which building was suitable for our design we compared our first semester models and assessed the suitability of the buildings in terms of being able to support a heavy load, if they have a large surface area on the roof, if the area has high exposure to solar radiation and which designs were more appealing and creative. The vertical farm that was chosen is a simple skyscraper style structure with a large flat roof which will be sufficiently spacious to have the array mounted while still leaving space for maintenance staff to operate. It will be located in Cairo, an ideal location due to the high amount of sunlight received by the area. The design has 5 floors therefore it is at an adequate height to avoid any obstructions from other buildings. On the other hand, we used different parts of everyone's concept designs to make the building be original and to have flair, for example, designs for external features such as the doors and windows were combined to make it look appealing.

Section 2 – Concept design model

The aim of our design is to produce renewable, clean energy for our vertical farm and therefore we decided to create a system consisting of solar panels. We decided to place the solar panels on the roof of our farm to prevent any obstruction that could occur if the panels were placed on the side of the building. We chose to place solar panels slanted at an angle associated with the optimum position to absorb solar radiation which improves the production of energy by 30%. Also, our design has been adapted with a mechanical system. The solar panels will be placed on a turntable to rotate with the sun as it moves through the sky throughout the day to enhance energy production. Our design is using a single axis turntable powered by a quad motor system, like those used to turn buses, however we chose to use a square turntable to maximise the surface area in order to fit as many solar panels on as possible. The mechanical system will use several sensors in order to optimize functionality and detect faults quickly to ensure the system runs smoothly and effectively.

Our design is targeted at businesses that work in tall buildings, whether that be an office, vertical farm or hotel who have wasted space on their roofs. The design has been created to help businesses be able to source renewable energy in a more efficient way which will benefit people who want to reduce their carbon footprint in a cost-effective way.

To be able to display our concept design we have used 3D printing to create a physical model of the farm structure to give a representative view of the scale. To print the farm structure, we designed the building using CAD. We used fusion 360 to adjust the aspect ratio of the design and to add chamfers to make the design suitable for 3D printing. We have also used augmented reality to show the mechanical system and how it moves. Augmented reality will be displayed through our phone which can be presented onto flat objects (e.g a table) which is done by scanning a sticker. The system can be manipulated to rotate, move and the size can be altered so our design can be examined with ease. Finally, we have also used CES Edupack to critically analyse materials to find those most suitable for our design.

The assets we have produced is our unique design which has been fully created on CAD. The design has been made with full dimensions, a materials list (including information on where we sourced any parts) and full mechanical calculations which can be sold to Engineers and used for customers. We also have a 3D printed model which can be used for future designs of vertical farm buildings.

Our concept design originated by putting all our initiative together as a group to come up with a unique design. The final result of our design, however, came after many reconsiderations of our original concept which took a lot of perseverance. We had issues with finding: motors which could support the load, turntables that were strong enough to support the solar panels and we tried to use many different kinds of solar panels which wouldn't have been feasible as it would've had a mass too large creating multiple different problems. However, as a group we have used our strong understanding of mechanics to solve problems we came across in order to create a design that is feasible and accurate. (see appendix for concept designs)

Section 3 – Detail design summary

The design initially involved a 30 m diameter circular turntable in order to maximise the amount of space available for solar panels. This was revised after considering the size of the torque generation required from the motor which will be too large which we found after researching components for the project. The final design features a 10 m diameter circular turntable as this was found to be significantly simpler to design. To compensate for the lost area of solar panels, three of these smaller versions were implemented. The motors used are hydraulic motors. The motor was initially located centrally, although this was soon reconsidered in favour of a quad-motor system, with a motor on each corner of the turntable providing drive to four of the wheels. The initial choice of one motor to drive the turntable was revised upon after calculating the friction forces which were higher than expected, we changed to four motors in order to overcome the resistance.

The chosen motor was a hydraulic motor that has a torque of 300 Nm at an rpm of 155 which will then be stepped down by the gearbox to a torque of 10440 Nm and an rpm of 4.46, using a gearing ratio of

34.8. The motor has variable displacement so the speed can be varied from the lower set operational speeds to a higher speed for the turntable to be returned to its initial position at the end of the day.

The turntable rests upon 8 wheels distributed evenly around the turntable in order to bear the load safely. Four of these wheels are driving wheels, with each one of these wheels attached to one of the motors. These wheels will be able to pivot to ensure a smooth motion as the turntable rotates. The weight of the system is 22 tonnes.

The design features brackets on the frames for the option of including sensors for automated solar tracking or to gather operational data. This will enable effective use of the array by the customer as it enables them to review its functionality.

Section 4 - Product design specifications

<table>
<tr><td rowspan="2">Performance
1.1 The array should be able to rotate 360 degrees
1.2 The array should be able to rotate at speeds in the range of 0.2 – 0.3 radians per hour
1.3 The array should be able to support about 25 tonnes.
1.4 The solar panels used should be rated as 320 W or above as the farm has a high energy need and needs to be able to return more power than is used
1.5 The number of wheels should be chosen to be able to support the load
1.6 The array should be as light as possible to minimise strain on the structure</td><td>Customers
4.1 Customers are owners of businesses and so are interested in increased efficiency and innovation, with cost being less of a factor</td></tr>
<tr><td>Ergonomics
5.1 Contact areas with potential for human contact coated with heat insulators.
5.2 Adjustment and tuning can be done at no taller shoulder height, technicians should not require a ladder which increases the risk of injuries</td></tr>
<tr><td>Product life span
2.1 The mechanical system should last at least 25 years without having major repair due to age or wear
2.2 The solar panels used should maintain 90% of initial power output for 25 years</td><td>Environment
6.1 It must withstand the extreme Cairo climate and Khamsin winds.
6.2 The array must be able to operate at an environmental temperature of around 48°C for more than 3 hours, not including the operational increases due to current.</td></tr>
<tr><td rowspan="2">Service life/Maintenance
3.1 Fortnightly minor maintenance (cleaning of panel surface) required because research shows over 3 months a panel accumulated enough dust to reduce peak power by more than half.
3.2 Annual major maintenance (replace lubrication, replacement of o-rings).
5.3 Design should accommodate technicians to enable fast repairs.
3.3 The design may require additional maintenance during periods of Khamsin winds.</td><td>Safety
7.1 Electronics must be insulated for safety of technicians.
7.2 Comply with International Electrotechnical Commission IEC 61727 safety standards</td></tr>
<tr><td>Quality and reliability
8.1 The panels used should be high efficiency to generate more power</td></tr>
</table>

Attribute	Type	Metrics	Requirements
Effective solar tracking	Objective	n/a	Able to track sun movement at least 6 times an hour
Weight	Constraints	Kg	Light weight so it can be installed in buildings' roofs without significant modifications
Safe to operate	Objective	n/a	Should be simple and easy to operate

Low labour requirements	Objective	n/a	Solar roof should require little to no operating maintenance, which eliminates the need for specialised staff to operate machine
Easy installation	Constraints	Hours	Less time and money used to assemble platform
Strength of platform	Objective	Newtons	Able to withstand weight of at least 10 people on the platform, as well as different wind conditions seen in Cairo
Longevity	Constraints	Years	Life span should be more than 25 years to be able to recuperate cost and carbon footprint.

Section 5 - Conceptual mechanical design development

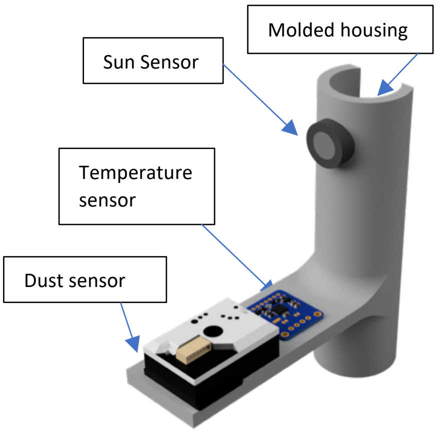


Figure 6: Attachment housing for sensors

The farm uses several sensors to detect faults quickly. The main sensor contributing to the optimization of the array will be a solar tracker. We have chosen the **Sun Sensor ISS-D60** which measures the solar radiation within an 120° window and will output information on the direction in which it is receiving most radiation from. The sensor will sit on the rotating frame holding the solar panels so it will be able to keep the main light levels in its 120° window at all times.

To keep the array in working order, temperature and dust sensors will be fitted at intervals over the solar panel framework. To monitor temperature, we chose the **Maxim digital temperature sensor**. The solar panels we are using have an operating temperature of -40° to 90°. The sensors will read the temperature of the panel, if it comes too close to exceed this range it will be able to notify the control room and the panels can be checked before damage is caused. Whereas the temperature sensors will be mainly used for safety, the dust sensors will be used to keep the efficiency of the farm high. We chose the **Sharp photoelectric sensor** and Due to the farm being in Egypt we are expecting high amounts of sand and dust to be blown in from the desert, The sensors will be able to track how much dust is covering the solar panels and turn on a water jet to clean the panels if the levels get too high.

The sensors will read to farms' central control room where human operators can take appropriate actions.

Gearbox

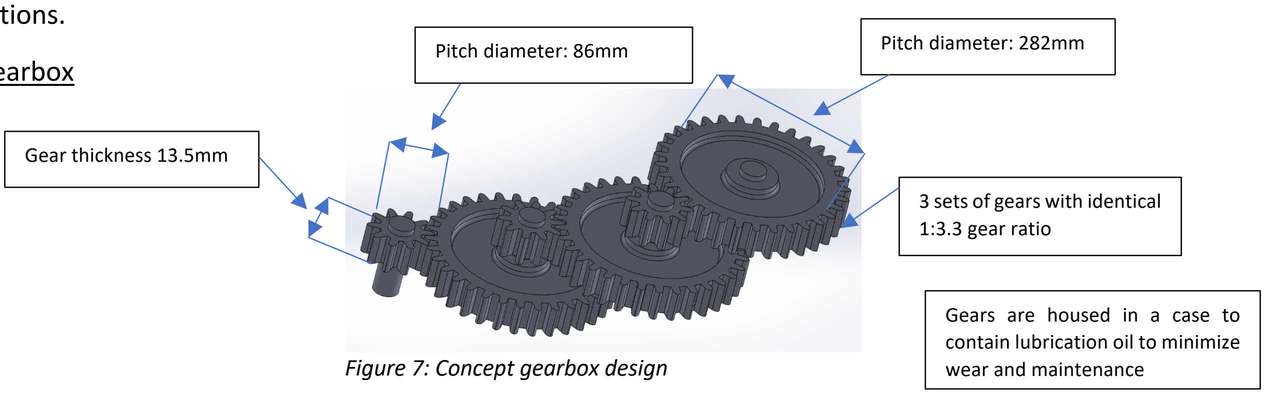


Figure 7: Concept gearbox design

In order to step the speed of the motor down to **4.46 RPM**, we had to use a combination of gears. The gear ratio to be achieved was 34.8:1. It was decided that 6 gears split into pairs would easily be able to cope with the step down. The gears will be made from cast iron and will be held inside a gearbox made from the same material. The gears will be press fitted onto axles that will supply into and out of the gearbox. The axles will pass through a bearing which is press fitted into the box. This will make the box fully sealed so it can hold the lubrication needed to avoid high surface wear between the gears as the mesh. The reason why the gearbox is custom made is because there are no commercially available gearboxes that can handle 1000 Nm + torque.

Desired gear ratio per pair of gears = $\sqrt[3]{34.8} = 3.26 \approx 3.3$
Gear ratio = teeth ratio
Teeth ratio = 33/10 =3.3

Section 6 - Theoretical calculation

Season	Average peak altitude angle
Winter (Dec-Feb)	56.04
Summer (Jun-Aug)	3.54
Autumn (Sep-Nov)	32.55
Spring (Mar-May)	27.55
Yearly average	**29.9**

Table 1: Average peak altitude for Cairo

The average peak angle (see table 1) was calculated from the spreadsheet specific to Cairo with coordinates:30.04878, 31.2221, which was the same farm location as semester 1. We chose the tilt angle of 30 degrees to maximise sunlight. It can be adjusted manually during different seasons.

Torque required to rotate turntable at required speed

The following values were achieved from CAD simulation:	The following values were chosen from our research:
Support Wheel Reaction Force = $\boldsymbol{6659\ N}$ Motor Wheel Reaction Force =$\mathbf{1.62\ x10^4\ N}$ I_{zz} = $\mathbf{5.2\ x\ 10^6\ Kg.m^2}$	Max angular velocity = $\mathbf{0.3\ rad/hr}$ Time between each motion = **10 minutes = 600 seconds** Duration of motion **= 5s** Wheel diameter = $\mathbf{300\ mm}$ Distance from driving wheel to centre pivot= **3.5m** Bearings coefficient of static friction= **0.002**

Angular acceleration = Max angular velocity $\div$ duration of motion
= 0.3 $rad/hr \div 5 = 216\ rad/hr^2$= **1.67x $\mathbf{10^{-5}}$rad/$\boldsymbol{sec^2}$**

Angular displacement of whole plate:
0.3 rad/hr x 60 ÷10 = **0.05 rad**
Wheel diameter = 300 mm = **0.3 m**
Arc length = $r\ x\ \theta$
Displacement = 3.5 x 0.05 = **0.175 m**
Angular displacement for 0.3m diameter driving wheels
arc length = 0.15 x θ= 0.175 m
θ = $\mathbf{66.84}$°

Angular velocity of driving wheels
$v = \omega r$
66.84 x (2π) ÷360 = v x 5 ÷ 2
(area of triangle under Velocity Time graph)

v = 0.467 rad/s
v = 0.467 x60 ÷ (2π)= **4.46 RPM**

Gear ratio = 155÷4.46 = 34.8
1:34.8

Motor speed and torque

T = 300 Nm at 155 RPM

Max output Torque
300 Nm x 34.8 = 10440 Nm

The torque required to accelerate plate	Frictional torque from 20 motor bearings	Frictional torque from 4 driving wheel bearings
Torque = Inertia x Angular acceleration	Torque = μ_{max}x distance from pivot x reaction force x Number of bearings	Torque = μ_{max}x distance from pivot x reaction force x Number of bearings
5.2x10^6 x 1.67 x 10^{-5}= **86.84 Nm**	0.002x 6659 x 20 x 3.5 = **932.26 Nm**	0.002 x 1.62 $x10^4$x 4x5.9 = **764.64 Nm**

Total torque required
86.84 + 932.26 + 764.64= 1783.74 Nm

Motor max output torque **10440 Nm**, torque required to accelerate platform accounting friction is **1784 Nm**.

Gearbox

Large Gear (33 Teeth)

Calculating circular pitch of large gear:

$$p = \frac{D_O}{0.3183 \cdot (N+2)} = \frac{300}{0.3183 \cdot (33+2)} = \mathbf{26.928\ mm}$$

Where p is circular pitch, D_O is the outside diameter and N is the number of teeth
Thickness of tooth = p/2 = **13.464 mm**

$$Root\ Diameter = D_R = 0.3183 \cdot (N - 2.5) \cdot p = 0.3183 \cdot (33 - 2.5) \cdot 26.928 = \mathbf{261.429\ mm}$$
$$Pitch\ Diameter = D = 0.3183 \times N = 0.3183 \times 33 = \mathbf{282.866\ mm}$$

Small Gear (10 Teeth)

Calculating circular pitch of large gear:
Circular pitch of large gear = **26.928 mm**

$$Outer\ Diameter = D_O = 0.3183 \cdot (N+2) \cdot p = 0.3183 \cdot (10+2) \cdot 26.928 = \mathbf{102.857\ mm}$$

$$Root\ Diameter = D_R = 0.3183 \cdot (N - 2.5) \cdot p = 0.3183 \cdot (10 - 2.5) \cdot 26.928 = \mathbf{64.286\ mm}$$

$$Pitch\ Diameter = D = 0.3183 \times N = 0.3183 \times 10 = \mathbf{85.7\ mm}$$

Section 7 – Material and components selection

Solar panels used: LG Neon 2

These solar panels were chosen as they have excellent statistics for energy generation; it has been shown they have 30.4% more energy generated compared to the industry average in high temperature conditions. They also met specification 2.2 from the PDS, as the performance after 25 years is given as 90.8% of the initial performance. This is due to an annual degradation rate of -0.33% after the first year.

Motor used: Danfoss OMR Series Motors 375cc

This motor was selected for its capability to provide very high torque at a low rpm in order to meet specification 1.2 from the PDS; ensuring that the turntable can move slowly enough to track the sun. Furthermore, the motor is lightweight at 9.5 kg and so is insignificant when considering the weight of the mechanical system. Its nature as a hydraulic motor was chosen as it will require less maintenance as a result of having fewer mechanical parts.

<u>Wheels used: Technica 250/50 Heavy-Duty Spring-Loaded Nylon Swivel Castor</u>

These nylon wheels were chosen due to their hardness, durability, and low rolling resistance. The spring suspension will smooth out any vibrations due to wind or other external factors. The maximum load is 1250 kg, which is significant for wheels of this size. This will help to meet specification 1.3 in the PDS regarding load support.

<u>Structural beam material used: AISI 1045 Steel</u>

The steel used for the structural beams was chosen for its resistance to yielding. The young modulus of this steel is in the region of 10^{11} pascals, so too was its flexural modulus. This means that the material will also be resistant to bending, and so the structure should not experience performance-impeding deformities under standard conditions. As can be seen from Graph 1, a steel was found with a high Young's Modulus, and also a relatively low price from Level 2 on CES Edupack and then further narrowed down using Level 3.

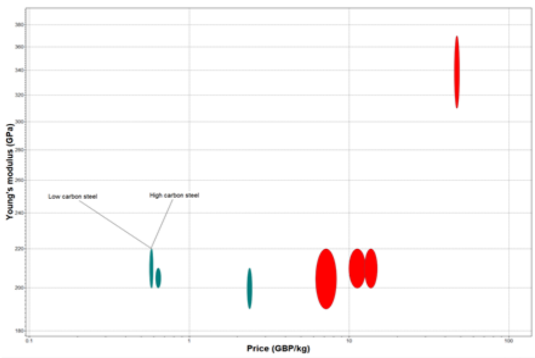


Figure 8 Graph comparing Young's Modulus and Price on Edupack

<u>Main plate material used: Aluminium Alloy 6061</u>

Aluminium was chosen for the plate in order to fulfil specification 1.6 from the PDS. The strength of the material was less relevant as the plate is supported by a rigid frame, and so aluminium was chosen for its relatively low density of about 2.7×10^3 kg per m^3. This alloy of aluminium also offers good corrosion resistance.

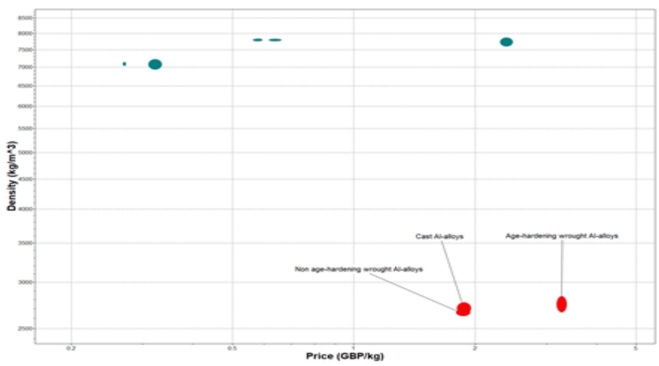


Figure 9 Graph comparing density with price on Edupack

From Graph 2, the wrought aluminium alloy was chosen and then further narrowed down to the exact alloy using Level 3 on CESEdupack.

<u>Solar panel frame material used: Aluminium Alloy 6063 T6</u>

This alloy was chosen as it's commonly used for structural railings and frames since it has a higher strength than most other aluminium alloys (205 -239 MPa). The alloy has excellent weldability to ease the manufacturing process and it also has very good corrosion resistance therefore it will be able to withstand harsh weather conditions it may be subject to on the roof. This satisfies section 6.1 in the PDS.

Section 8 - CAD model development

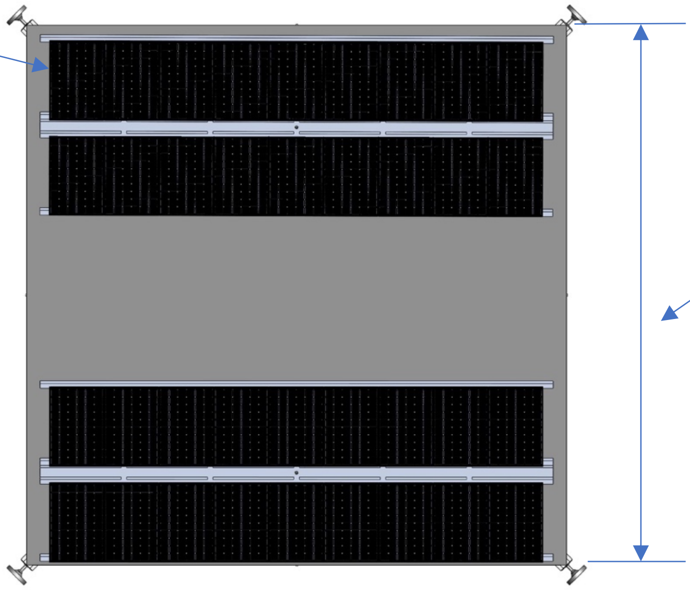


Figure 10: Top view of model

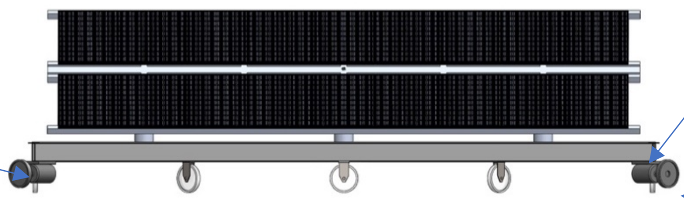


Figure 11: Front view of model

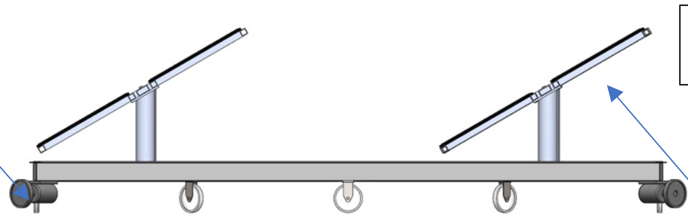


Figure 12: Side view of model

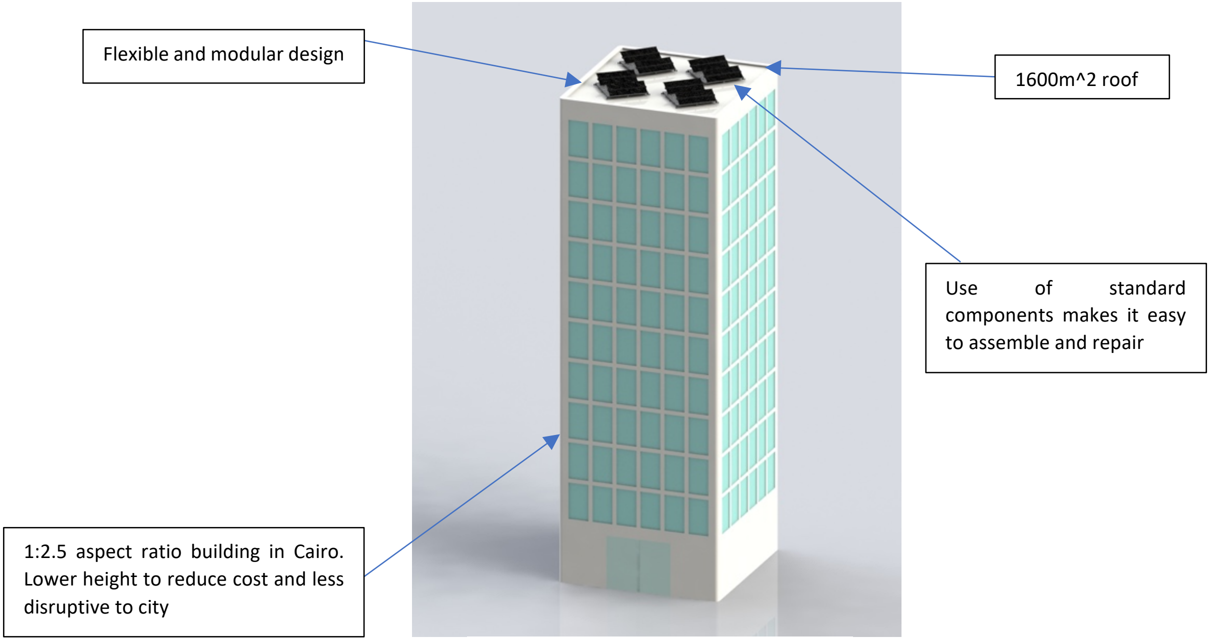


Figure 13: Render of solar panel in use

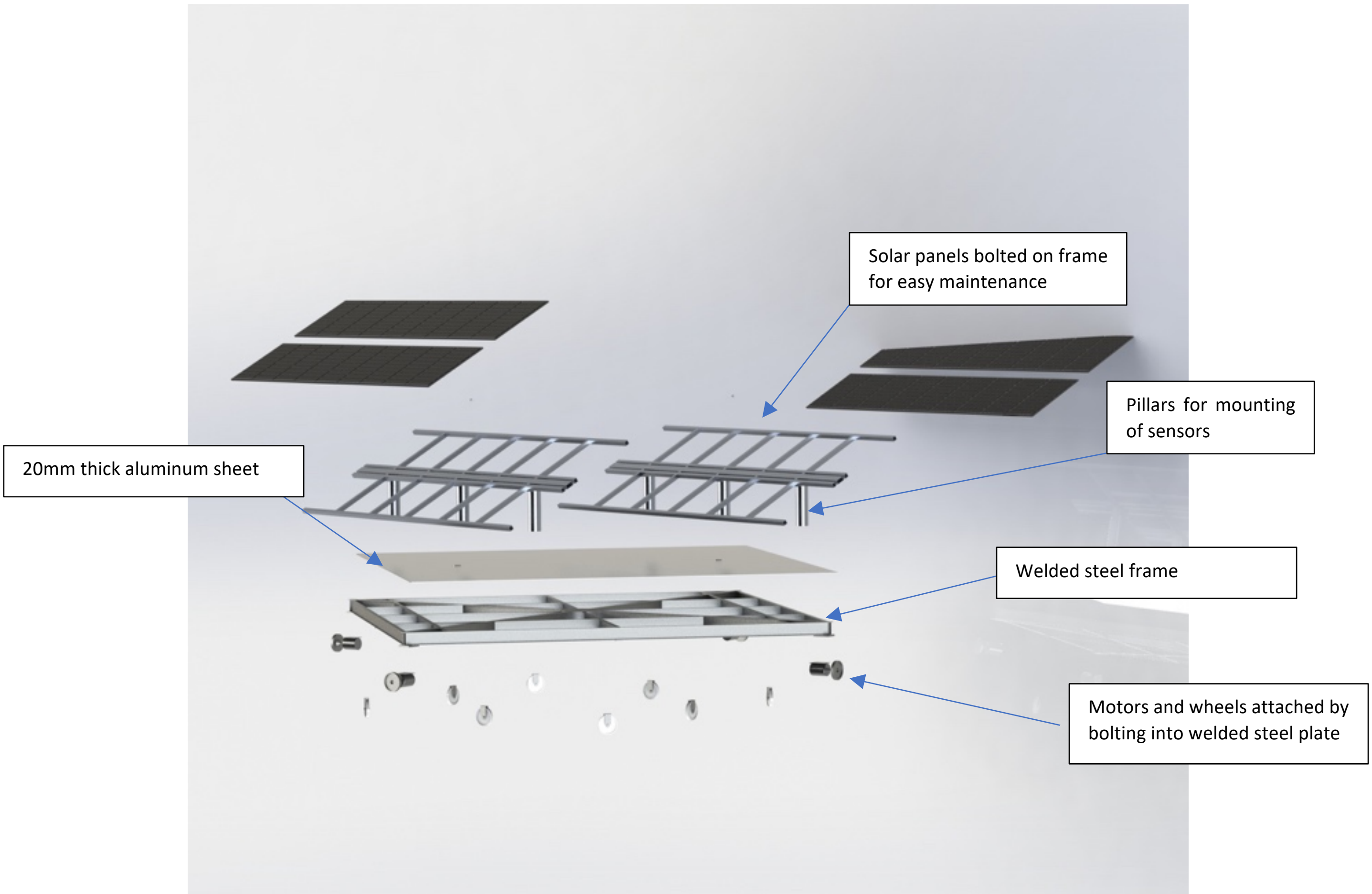


Figure 14: Exploded view of design assembly

RESEARCH JOURNAL CLUB REPORTS

Group number: M14 Person leading this discussion: Liam Man

Journal Paper: Prinsloo, G.J., Dobson, R.T. (2015). Solar Tracking. Stellenbosch: SolarBooks. ISBN 978-0-620-61576-1, p 1-542.

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?*

This paper addresses the issues of solar tracking in multiple axes and provides detail in the potential steps to overcome these problems, why solar tracking is beneficial and the multiple ways of solar tracking.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

This paper has provided insight into the different methods of solar tracking and types of sensors used for this process. The paper also provides detail with gear ratios and drive shafts that should be aimed for to ensure solar tracking is viable.

Information the paper did not cover is specifics about our chosen location. Further information about the sun's movement path in Cairo will be required.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

Recommendations of gear types and solar tracking for different types of solar panel setups were given. Using this information, the optimum tracking method and gear type can be implemented into our design.

Multiple useful equations were given, which can be useful to calculate the sun speed at our chosen location and as a result the required motor speed and gear ratio.

Actions:

1. Research and choosing of relevant gears for our design
2. Research and choosing of solar tracking method and relevant sensor
3. Research into Cairo's sun path and using equations to calculate speed

Group number: M14 Person leading this discussion: James Wilkins

Journal Paper: Al Dahoud, Ali & Fezari, Mohamed & Alrawashdeh, Thamer & Jannoud, Ismael. (2015). Improving Monitoring and Fault Detection of Solar Panels Using Arduino Mega in WSN.

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* This paper address the issue of remote monitoring of complex solar panel systems, it looks at numerous methods and shows data collected when in use
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* This paper gave me an insight into how fault detection systems work and how the information is transfer around and turned into useable data for a human controller. It also gave me ideas for the types of sensors needed to keep solar panels working at maximum efficiency As the report id based around other research I will need to look into signal strength and how the sensors will work over a larger project
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* The paper gives a few examples of sensors that I could then use as research to see how they work. The paper also outlines how all the sensors can read into one Arduino which will collect all the data
Actions: 1. Research into dust and temperature sensors to be used in high temperatures 2. Research into wireless sensor networks and how they can be expanded

Group number: M14

Person leading this discussion: Ryan Bianchi

Journal Paper: Gevorkian,P (2012) Large Scale Solar Power Systems, Cambridge, Cambridge University Press, Chapter 7 p125 - 147

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* This paper addresses the issue of solar panels not producing their full output, due to obstructions such as dust and water. This issue is prevalent in our design due to being located in Cairo, a desert environment where dust is a plenty and could potentially reduce the power output of the panels drastically. There is enough background evidence given.

Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?*

From this paper I have learnt the importance that periodically cleaning the face of the photovoltaic panels has on the production power of it. In some instances, dust can reduce power output by up to 40% and damage the cells beyond repair if it is allowed to build up. Also, the angle that the solar panel is placed at will greatly affect the amount of dust build up.

The chapter also highlights various health and safety measures which need to be followed in order to manage a photovoltaic panel safely in extreme conditions such as fire or earthquakes.

Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design*

Much of the paper's health and safety guidance regarding fire safety can be implemented in our structure. A remote easily accessible kill switch is one example.

Also, some form of periodic cleaning of the solar panels can be implemented possibly mechanically or a skilled workforce can have easy access.

Actions:

1. A weekly clean of the solar panels through a skilled workforce to clean grime off of the solar panels.

2. The angle of the solar panel was decided to be 30^{O} to minimise dust build-up and to allow for maximum sun exposure also.

3. Easily accessible switch for emergency services to turn off the system in the case of fire or electrical malfunction.

Group number: M14 Person leading this discussion: Emma

Journal Paper: Marsh, J., 2020. *Are Solar Trackers Worth It In 2020? | Energysage*. [online] Solar News. Available at: <https://news.energysage.com/solar-trackers-everything-need-know/> [Accessed 26 March 2020].

Aims & Motivation: *What problem or issue does this paper address? Is there sufficient background/context given?* This article addresses what you need to know about solar trackers before potentially buying them, it also helps distinguish between single axis and dual axis trackers. It helped give a basic understanding on what we should look for to help understand what solar tracking system is most suitable for our design.
Knowledge: *What have you learned from this paper? What other information do you require to help you with your work?* This article helped me understand the difference between a single and dual axis tracker. It helped understand any benefits and drawbacks we may have from using a tracker. We now need to research and see how much installation could costs and maintenance to see if they will be cost effective for us.
Impact: *Consider how you can incorporate elements of the papers' knowledge and contribution into your design* We now know to use a single axis for our design as its more suitable for our concept. We know how much more energy we could gain from using them.
Actions: 1 Research maintenance required for solar tracking 2 Research if roof can support as they are heavy 3 Check to see what angle is most sufficient to place panel at to help gain alongside the tracking. ….

APPENDIX A: Meeting Log

Date	Actions	Attendees
13/1/2020	Discuss individual project and personality roles	Anthony, Oliver, Ryan, James, Liam
16/1/2020	Decided on location	Anthony, Oliver, Ryan, James, Liam
20/1/2020	Decide on the mechanism, develop concept designs	Anthony, Oliver, Ryan, James, Liam
27/1/2020	Narrow down concept designs	Anthony, Oliver, Ryan, James, Liam
31/1/2020	First meeting with academic mentor	Anthony, Oliver, Ryan, Emma, Liam
10/2/2020	Selection of components	Anthony, Oliver, Ryan, Emma, Liam
18/2/2020	Complete calculations to determine motor	Anthony, Liam, Emma, James
20/2/2020	Edit design, motor calculations and start putting report together	Anthony, Oliver, Liam, James, Ryan
21/2/2020	Second meeting with academic mentor	Anthony, Oliver, Liam, James
24/2/2020	Edit design, reselect motor, starting CAD	All
2/3/2020	Editing and assembly of CAD elements	All
6/3/2020	Third meeting with academic mentor	Anthony, Liam, Ryan, Emma
9/3/2020	Research on specific sensors, finalise CAD components, further assembly of report	All
16/3/2020	Final assembly of CAD model, further assembly of report	Anthony, Liam, Ryan, Emma, James
18/3/2020	Finalise first draft of report, begin presentation	Anthony, Liam, Emma, Oliver, James
20/3/2020	Fourth meeting with academic mentor	Anthony, Liam, James

APPENDIX B: Academic Mentor Meeting Record

M14

IDP2 2019/20: Academic Mentor Meeting Record Semester 2
Group Number: **Meeting and date:** ☑1 research stage: introduction week 1 ☐2 research to requirements stage-gate: Should include Task 1 plans ☐3 requirements to design stage-gate: Should include Task 2 plans ☐4 design to assessment 1 stage-gate: Presentation
Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them. - Developed draft PDS - Developed Concept sketches - Agreed on location and mechanism (Solar tracker, 2 axis moving Solar panel) - Sunlight tracking algorithm for Cairo Next step CAD, frame design material ~~selection~~ selection motor / ~~hydraulics~~ hydraulics selection Theoretical calculations to aid component selection establish dimensions.
Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.* None
What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback. They work together very well. They have some questions related the report template and marking scheme.
Initialled: Present: RB EH OM LM AF Absent: JW
Initialled: Academic mentor CK. 31/1/2020 CAROL KSANG

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record Semester 2
Group Number: M14 **Meeting and date:** 21/2/2020. ☐1 research stage: introduction week 1 ☑2 research to requirements stage-gate: Should include Task 1 plans ☐3 requirements to design stage-gate: Should include Task 2 plans ☐4 design to assessment 1 stage-gate: Presentation
Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them. → Calculations for motor requirements. → frame design. → basic local calculations.
Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.* → N/A
What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback. They have finalised their concept of model and showed me their model. Some feedbacks have been given. - closed loop system. Good working team.
Initialled: Present: AF, OM, LM, JW Absent: EH, RB
Initialled: Academic mentor CAROL KONG

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record Semester 2
Group Number: **Meeting and date:** ☐1 research stage: introduction week 1 ☐2 research to requirements stage-gate: Should include Task 1 plans ☑3 requirements to design stage-gate: Should include Task 2 plans ☐4 design to assessment 1 stage-gate: Presentation
Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them. * CAD further development. * Refined mechanics calculations. * start making model
Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.* N/A.
What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback. They have shown me ~~the~~ design of the turnable roof (CAD model). There is a question regarding the presentation to be clarified. Their progress is so far good.
Initialled: Present: AF, RB, LM, EH   Absent: JW, OM
Initialled: Academic mentor CK CAROL KONG.

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

IDP2 2019/20: Academic Mentor Meeting Record Semester 2

Group Number: M14

Meeting and date:

☐1 research stage: introduction week 1

☐2 research to requirements stage-gate: Should include Task 1 plans

☐3 requirements to design stage-gate: Should include Task 2 plans

☑4 design to assessment 1 stage-gate: Presentation

Stage Progress: (To be completed by the group before meeting) LIST all of the work you will present to your mentor during the meeting. Your academic mentor is NOT a subject-matter expert on your challenge. They are there to discuss and facilitate your groups progress and provide verbal feedback on your work you bring them.

- Near Complete report.

Group functioning issues: (To be completed by the group before meeting) *specific non-technical issues hindering group performance which may include punctuality, attendance, lack of preparation, disruptions, dominant personalities, work quality, and what can be done to improve matters.*

- Heavily affected by Covid-19, Group members flown home or scared to come in

What was done well in this stage and what could be improved during the next stage (To be completed by Academic Mentor) – Formative feedback.

They have presented their CAD model and their draft of the report to me. Progress is fine. ~~No~~

Initialled: JW, AF, LM
Present:

Absent: RB, EH,

Initialled:
Academic mentor CAROL KONG.

Once you have completed this form, one group member should scan & upload it to the appropriate canvas assignment. Note that in fairness to all groups, meetings should last no longer than 20 minutes.

APPENDIX C: Concept designs CAD

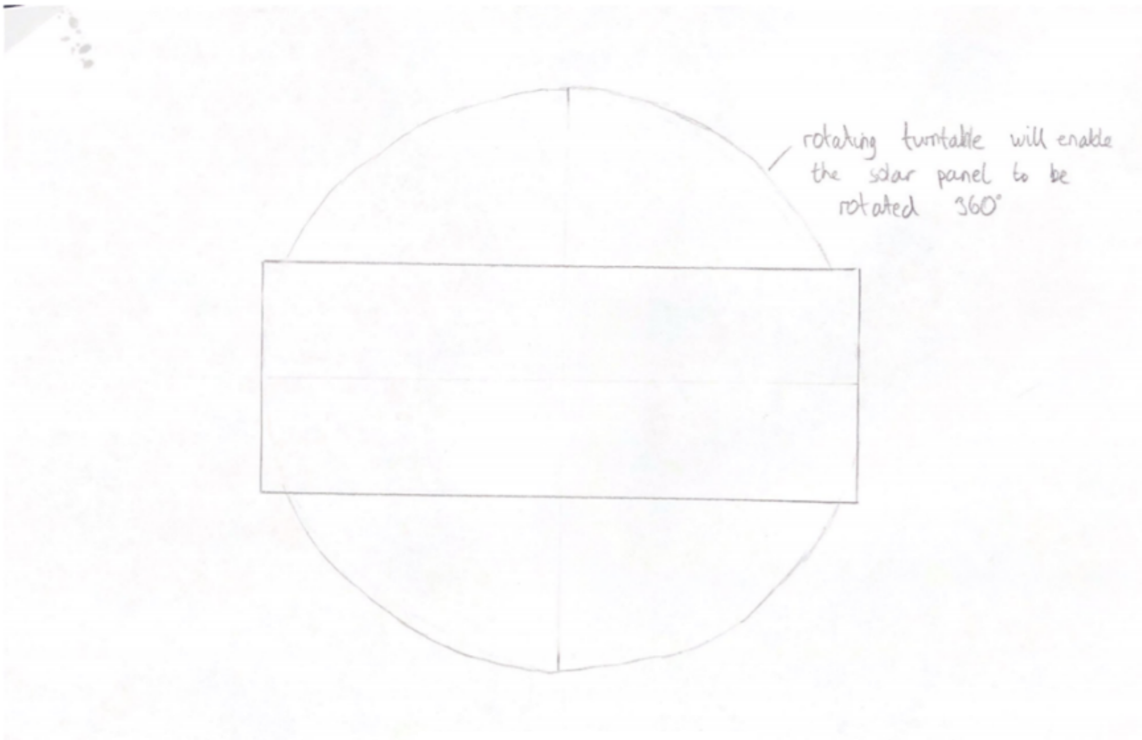


Figure C1: Initial design concepts

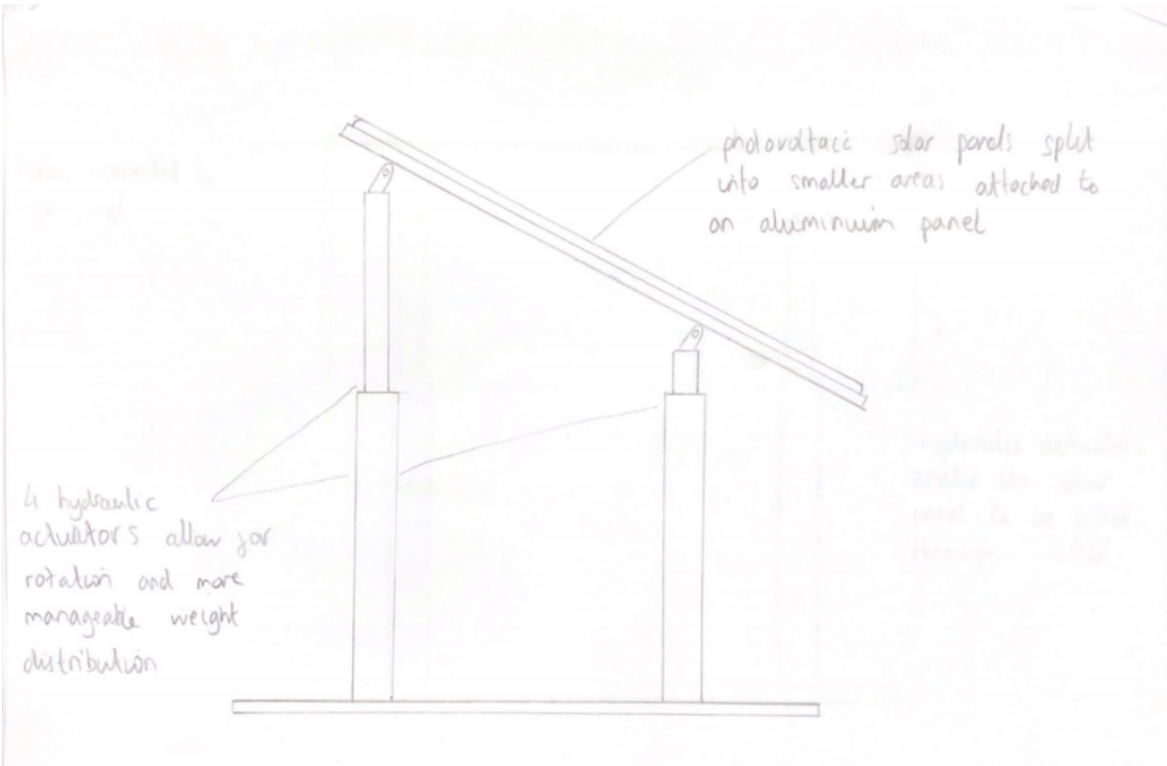


Figure C2: Hydraulic tilting mechanism

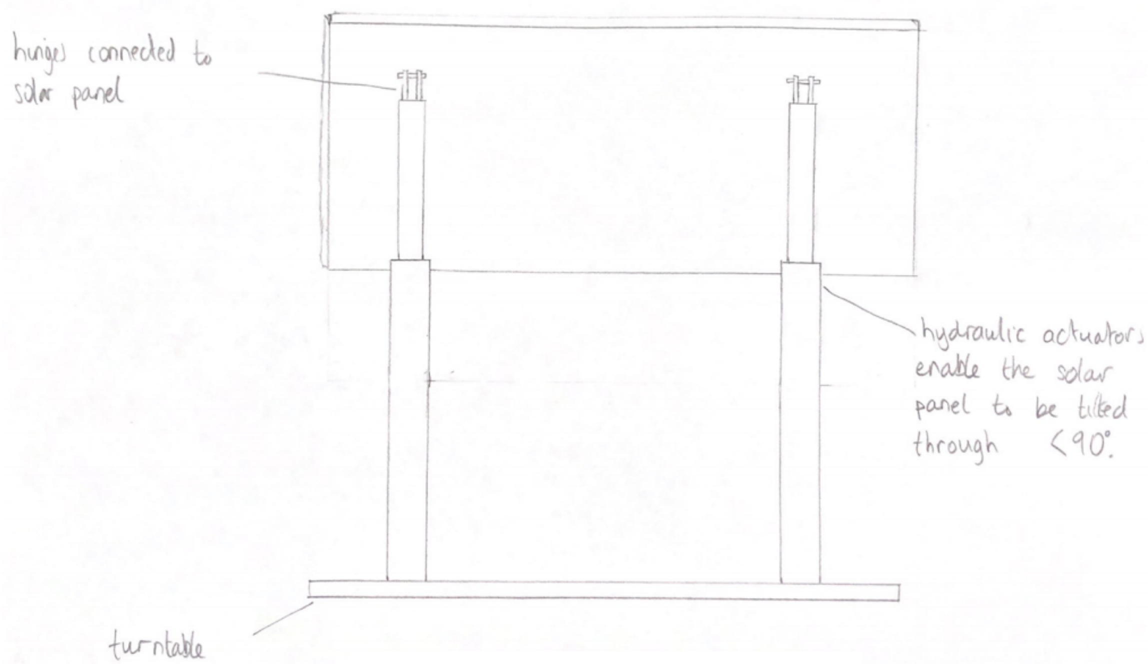


Figure C3: Front view of hydraulic tiling mechanism

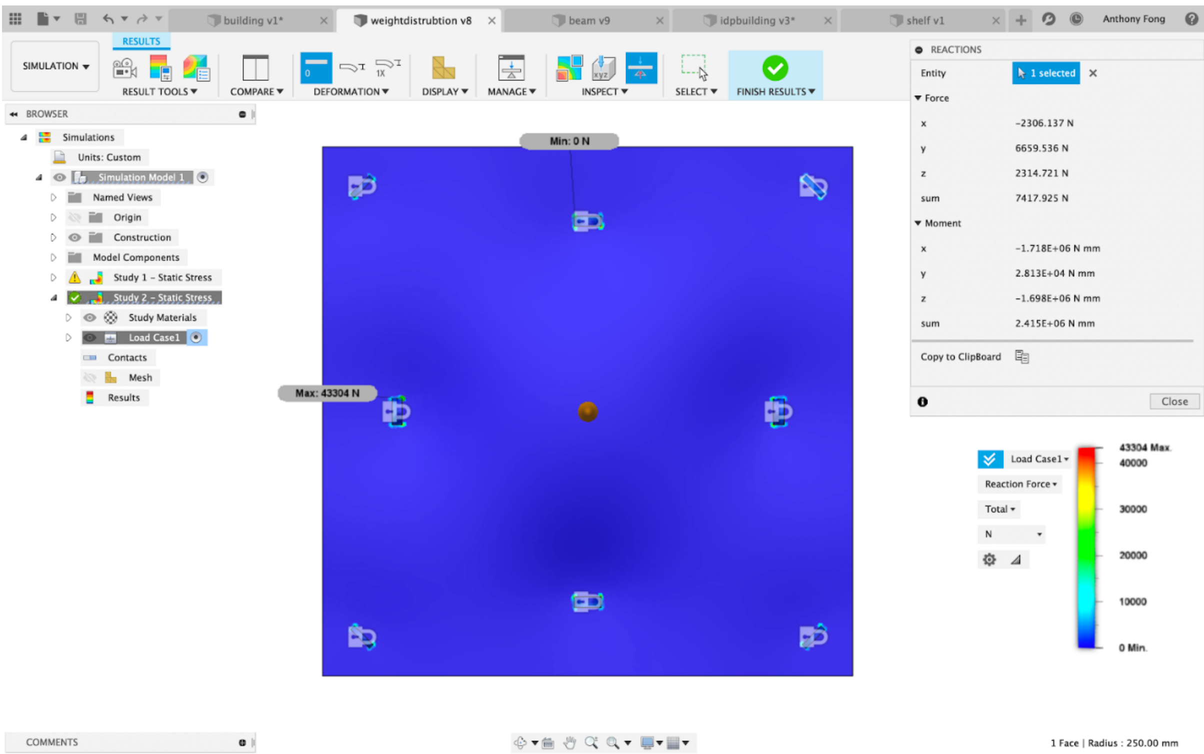


Figure C4: FEA mass load case for Fusion 360 to find wheel reaction force

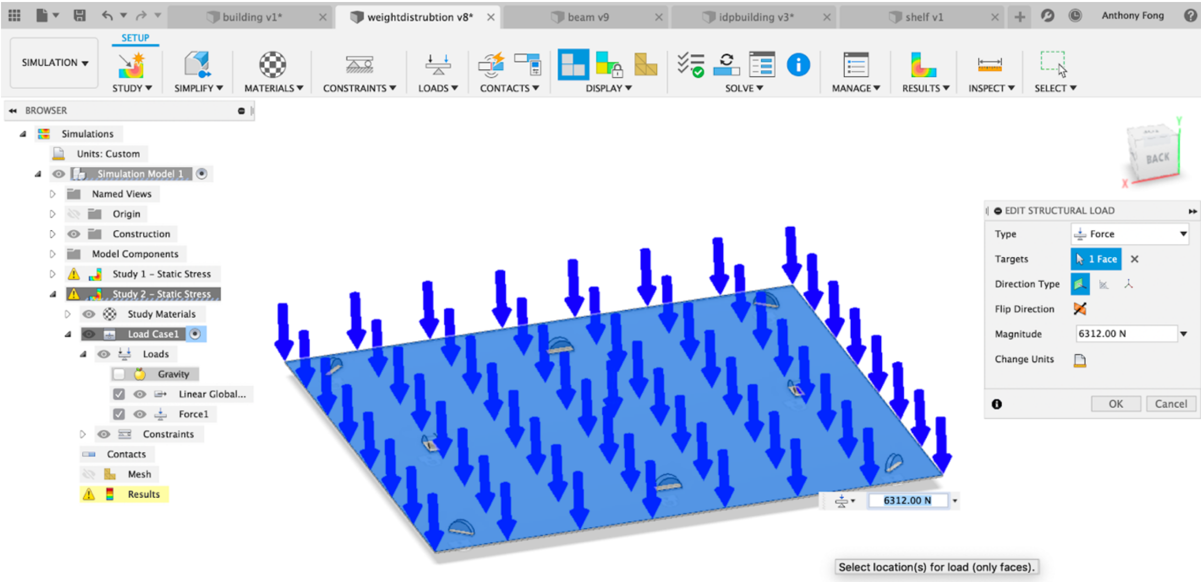


Figure C5: FEA gravity load case for Fusion 360 to find wheel reaction force

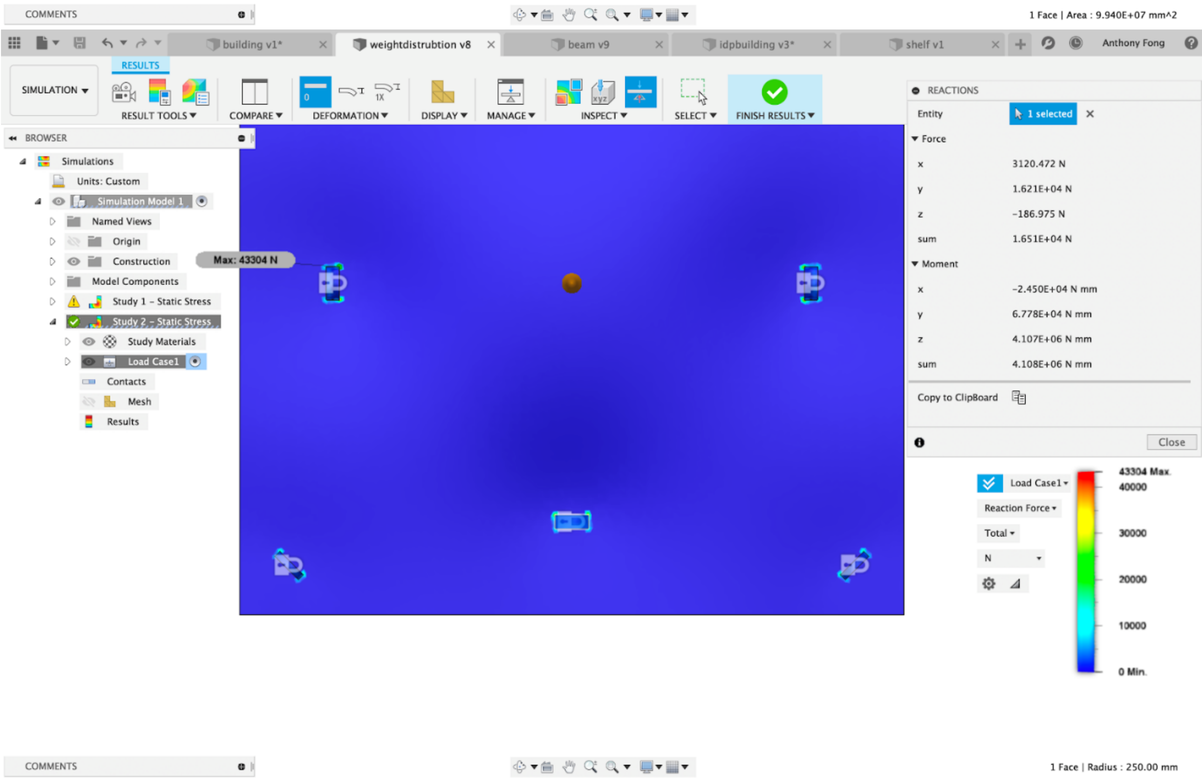


Figure C6: Results for FEA analysis, note normal reaction force for wheels are taken from the Y axis face

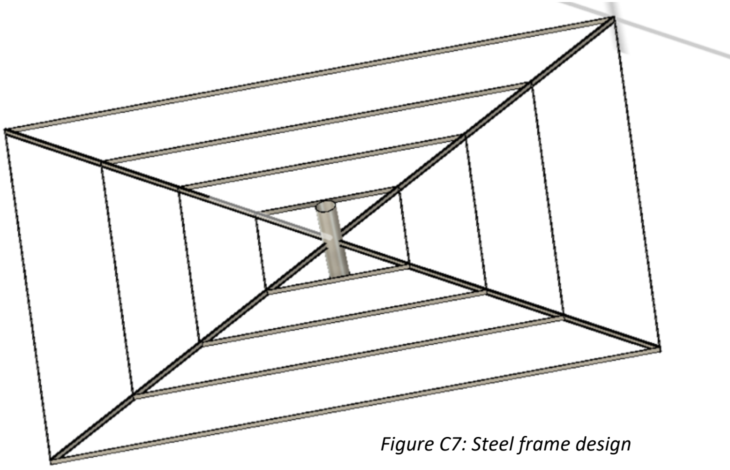


Figure C7: Steel frame design

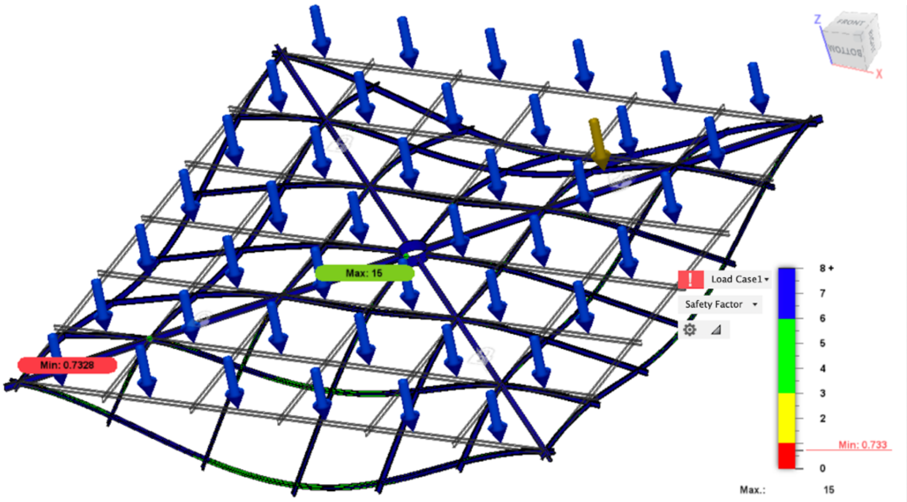
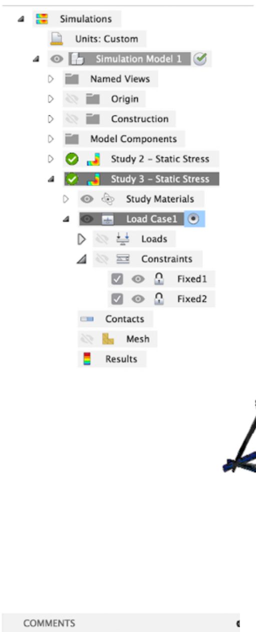
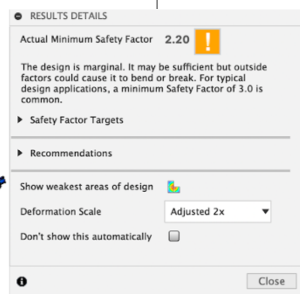
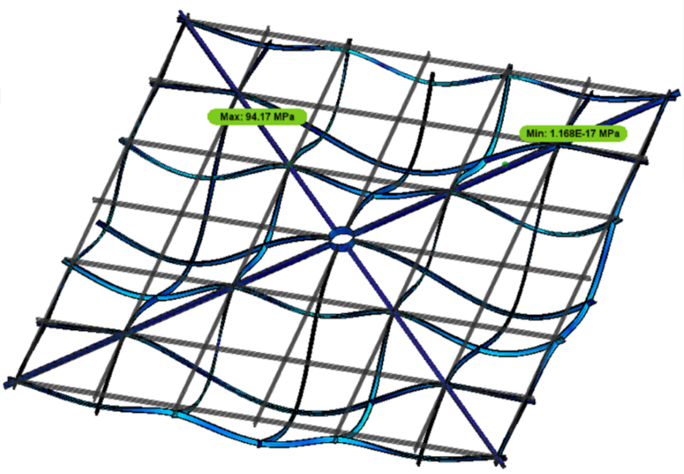


Figure C8: FEA on Fusion 360, initial unoptimized design with safety factor of 0.733







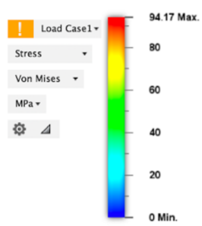


Figure C9: FEA on Fusion 360, optimized design with safety factor of 2

APPENDIX D Useful links and data

https://www.weather-atlas.com/en/egypt/cairo-climate

http://andrewmarsh.com/apps/staging/sunpath3d.html

https://www.suncalc.org/#/30.1166,31.2616,6/2019.12.15/21:55/1/3

data on how many daylight hours & sunlight hours cairo receives

https://news.energysage.com/solar-trackers-everything-need-know/

information on performance increase of single axis solar tracker vs stationary solar array

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5190976/
Sensing the brightest region, useful for Cairo when sunlight could be blocked by clouds

https://www.researchgate.net/publication/274074941_Design_of_an_Intelligent_Dual-axis_Solar_Tracking_Device_for_Solar_System_Usage
Example design of a 2 axis solar tracker, minimal space usage

http://www.asee.org/documents/zones/zone1/2014/Professional/PDFs/48.pdf
Using a Fresnel lens

https://rmets.onlinelibrary.wiley.com/doi/epdf/10.1002/joc.3661
urban areas impact on Cairo climate

http://egyptera.org/Downloads/code%20w%20dalil/code/Egypt_gridcode_for_solar_plant_connection%20on%20MV%20and%20HV.pdf
Egypt code for solar plants

(https://reader.elsevier.com/reader/sd/pii/S1876610217338523?token=10E9E962ED2BD09AA1877DC120C3E95F079F46EF510F0467A2C20EB5B9498E704AE572E4C40447C34626AFC3A119B2ED)
Effect of dust accumulation on power output

2019 January	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Sunrise Time	06:50	06:50	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:51	06:50	06:50	06:50	06:50	06:49	06:49	06:48	06:48	06:48	06:47	06:47	06:46	06:46	
Sunrise Azimuth	116.2	116.07	116.06	115.92	115.77	115.62	115.46	115.3	115.13	114.96	114.78	114.6	114.42	114.22	114.03	113.83	113.62	113.41	113.08	112.86	112.64	112.41	112.06	111.83	111.47	111.23	110.99	110.62	110.37	109.99	109.74	
Sunset Time	17:06	17:07	17:07	17:08	17:09	17:10	17:10	17:11	17:12	17:13	17:14	17:14	17:15	17:16	17:17	17:18	17:19	17:19	17:20	17:21	17:22	17:23	17:24	17:25	17:26	17:26	17:27	17:28	17:29	17:30	17:31	
Sunset Azimuth	243.71	243.84	243.87	244.02	244.18	244.35	244.4	244.58	244.77	244.97	245.17	245.26	245.48	245.71	245.94	246.18	246.43	246.56	246.82	247.09	247.37	247.65	247.94	248.23	248.54	248.72	249.04	249.36	249.69	250.03	250.37	
Azimuth angle	**127.51**	**127.77**	**127.81**	**128.1**	**128.41**	**128.73**	**128.94**	**129.28**	**129.64**	**130.01**	**130.39**	**130.66**	**131.06**	**131.49**	**131.91**	**132.35**	**132.81**	**133.15**	**133.74**	**134.23**	**134.73**	**135.24**	**135.88**	**136.4**	**137.07**	**137.49**	**138.05**	**138.74**	**139.32**	**140.04**	140.63	
Peak Altiude angle	**36.97**	**37.05**	**37.15**	**37.25**	**37.35**	**37.47**	**37.59**	**37.72**	**37.86**	**38**	**38.16**	**38.32**	**38.48**	**38.65**	**38.83**	**39.02**	**39.21**	**39.41**	**39.62**	**39.83**	**40.05**	**40.28**	**40.51**	**40.75**	**40.99**	**41.24**	**41.49**	**41.75**	**42.02**	**42.29**	42.56	
Angle rad	2.225469	2.230007	2.230705	2.235767	2.241177	2.246762	2.250428	2.256362	2.262645	2.269103	2.275735	2.280447	2.287429	2.294933	2.302264	2.309943	2.317972	2.323906	2.334203	2.342755	2.351482	2.360383	2.371553	2.380629	2.392323	2.399653	2.409427	2.42147	2.431593	2.444159	2.454457	
time (s)	36960	37020	36960	37020	37080	37140	37140	37200	37260	37320	37380	37380	37440	37500	37560	37620	37680	37680	37800	37860	37920	37980	38100	38160	38280	38280	38340	38460	38520	38640	38700	
angular velocity (s)	6.02E-05	6.02E-05	6.04E-05	6.04E-05	6.04E-05	6.05E-05	6.06E-05	6.07E-05	6.07E-05	6.08E-05	6.09E-05	6.1E-05	6.11E-05	6.12E-05	6.13E-05	6.14E-05	6.15E-05	6.17E-05	6.18E-05	6.19E-05	6.2E-05	6.21E-05	6.22E-05	6.24E-05	6.25E-05	6.27E-05	6.28E-05	6.3E-05	6.31E-05	6.33E-05	6.34E-05	6.1555E-05
angular velocity (h)	0.216766	0.216856	0.217276	0.217417	0.21759	0.21778	0.218135	0.218358	0.218613	0.218884	0.219172	0.219626	0.219945	0.220314	0.220664	0.221047	0.221462	0.222029	0.222305	0.222766	0.223242	0.223733	0.224084	0.224588	0.224983	0.225673	0.226237	0.226659	0.227252	0.227717	0.228322	0.2215966

2019 February	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Sunrise Time	06:45	06:44	06:44	06:43	06:42	06:42	06:41	06:40	06:40	06:39	06:38	06:37	06:36	06:36	06:35	06:34	06:33	06:32	06:31	06:30	06:29	06:28	06:27	06:26	06:25	06:24	06:23	06:22	
Sunrise Azimuth	109.36	108.97	108.71	108.32	107.93	107.66	107.26	106.86	106.59	106.18	105.78	105.37	104.96	104.67	104.26	103.85	103.43	103.01	102.6	102.18	101.76	101.33	100.91	100.49	100.06	99.64	99.21	98.78	
Sunset Time	17:32	17:32	17:33	17:34	17:35	17:36	17:37	17:38	17:38	17:39	17:40	17:41	17:42	17:42	17:43	17:44	17:45	17:46	17:46	17:47	17:48	17:49	17:49	17:50	17:51	17:51	17:52	17:53	
Sunset Azimuth	250.72	250.95	251.31	251.68	252.05	252.43	252.81	253.2	253.47	253.87	254.27	254.68	255.1	255.39	255.82	256.25	256.68	257.12	257.43	257.88	258.33	258.78	259.12	259.58	260.04	260.38	260.85	261.33	
Azimuth angle	**141.36**	**141.98**	**142.6**	**143.36**	**144.12**	**144.77**	**145.55**	**146.34**	**146.88**	**147.69**	**148.49**	**149.31**	**150.14**	**150.72**	**151.56**	**152.4**	**153.25**	**154.11**	**154.83**	**155.7**	**156.57**	**157.45**	**158.21**	**159.09**	**159.98**	**160.74**	**161.64**	162.55	
Peak Altitude angle	**42.85**	**43.13**	**43.42**	**43.72**	**44.02**	**44.33**	**44.64**	**44.95**	**45.27**	**45.49**	**45.92**	**46.25**	**46.58**	**46.92**	**47.26**	**47.6**	**47.95**	**48.3**	**48.66**	**49.01**	**49.37**	**49.74**	**50.1**	**50.47**	**50.84**	**51.21**	**51.59**	51.96	
Angle rad	2.467197	2.478018	2.48884	2.502104	2.515369	2.526713	2.540327	2.554115	2.56354	2.577677	2.591639	2.605951	2.620437	2.63056	2.645221	2.659882	2.674717	2.689727	2.702293	2.717478	2.732662	2.748021	2.761285	2.776644	2.792178	2.805442	2.82115	2.837033	
time (s)	38820	38880	38940	39060	39180	39240	39360	39480	39480	39600	39720	39840	39960	39960	40080	40200	40320	40440	40500	40620	40740	40860	40920	41040	41160	41220	41340	41460	
angular velocity (s)	6.36E-05	6.37E-05	6.39E-05	6.41E-05	6.42E-05	6.44E-05	6.45E-05	6.47E-05	6.49E-05	6.51E-05	6.52E-05	6.54E-05	6.56E-05	6.58E-05	6.6E-05	6.62E-05	6.63E-05	6.65E-05	6.67E-05	6.69E-05	6.71E-05	6.73E-05	6.75E-05	6.77E-05	6.78E-05	6.81E-05	6.82E-05	6.84E-05	6.59233E-05
angular velocity (h)	0.228797	0.229446	0.230093	0.230609	0.231121	0.231809	0.232347	0.232898	0.233757	0.234334	0.234892	0.235478	0.236075	0.236987	0.237595	0.238198	0.238814	0.239442	0.240204	0.24084	0.241472	0.242116	0.242928	0.243565	0.244214	0.245017	0.245673	0.246341	0.237323712

2019 March	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Sunrise Time	06:21	06:20	06:19	06:18	06:16	06:15	06:14	06:13	06:12	06:11	06:10	06:08	06:07	06:06	06:05	06:04	06:02	06:01	06:00	05:59	05:58	05:56	05:55	05:54	05:53	05:52	05:50	05:49	05:48	05:47	05:46	
Sunrise Azimuth	98.35	97.92	97.49	97.06	96.51	96.08	95.65	95.22	94.78	94.35	93.92	93.36	92.93	92.5	92.07	91.64	91.08	90.65	90.22	89.79	89.36	88.8	88.37	87.94	87.52	87.09	86.54	86.11	85.69	85.26	84.84	
Sunset Time	17:54	17:54	17:55	17:56	17:56	17:57	17:58	17:58	17:59	18:00	18:00	18:01	18:02	18:02	18:03	18:04	18:04	18:05	18:05	18:06	18:07	18:07	18:08	18:08	18:09	18:10	18:10	18:11	18:12	18:12	18:13	
Sunset Azimuth	261.8	262.16	262.64	263.12	263.49	263.97	264.47	264.83	265.33	265.82	266.19	266.69	267.19	267.57	268.07	268.57	268.95	269.46	269.83	270.34	270.84	271.22	271.73	272.11	272.61	273.11	273.49	273.99	274.49	274.87	275.36	
Azimuth angle	**163.45**	**164.24**	**165.15**	**166.06**	**166.98**	**167.89**	**168.82**	**169.61**	**170.55**	**171.47**	**172.27**	**173.33**	**174.26**	**175.07**	**176**	**176.93**	**177.87**	**178.81**	**179.61**	**180.55**	**181.48**	**182.42**	**183.36**	**184.17**	**185.09**	**186.02**	**186.95**	**187.88**	**188.8**	**189.61**	**190.52**	
Peak Altitude angle	**52.34**	**52.72**	**53.11**	**53.49**	**53.87**	**54.26**	**54.65**	**55.04**	**55.43**	**55.82**	**56.21**	**56.6**	**57**	**57.39**	**57.79**	**58.18**	**58.58**	**58.97**	**59.37**	**59.76**	**60.16**	**60.55**	**60.95**	**61.34**	**61.73**	**62.12**	**62.52**	**62.91**	**63.3**	**63.69**	**64.08**	
Angle rad	2.85274066	2.866529	2.882411	2.898294	2.914351	2.930233	2.946465	2.960253	2.976659	2.992716	3.006679	3.025179	3.041411	3.055548	3.071779	3.088011	3.104417	3.120823	3.134786	3.151192	3.167424	3.18383	3.200236	3.214373	3.23043	3.246661	3.262893	3.279125	3.295182	3.309319	3.325201	
time (s)	41580	41640	41760	41880	42000	42120	42240	42300	42420	42540	42600	42780	42900	42960	43080	43200	43320	43440	43500	43620	43740	43860	43980	44040	44160	44280	44400	44520	44640	44700	44820	
angular velocity (s)	6.8608E-05	6.88E-05	6.9E-05	6.92E-05	6.94E-05	6.96E-05	6.98E-05	7E-05	7.02E-05	7.04E-05	7.06E-05	7.07E-05	7.09E-05	7.11E-05	7.13E-05	7.15E-05	7.17E-05	7.18E-05	7.21E-05	7.22E-05	7.24E-05	7.26E-05	7.28E-05	7.3E-05	7.32E-05	7.33E-05	7.35E-05	7.37E-05	7.38E-05	7.4E-05	7.42E-05	7.1459E-05
angular velocity (h)	0.24699053	0.247827	0.248484	0.249137	0.249801	0.250447	0.251119	0.251936	0.252616	0.253262	0.254086	0.254573	0.255223	0.256052	0.256695	0.257334	0.257985	0.258632	0.259431	0.260071	0.260693	0.261327	0.261957	0.262755	0.26335	0.263956	0.264559	0.265158	0.26574	0.266522	0.267084	0.25725174

2019 April	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Sunrise Time	05:44	05:43	05:42	05:41	05:40	05:38	05:37	05:36	05:35	05:34	05:33	05:31	05:30	05:29	05:28	05:27	05:26	05:25	05:24	05:23	05:22	05:21	05:20	05:19	05:18	05:17	05:16	05:15	05:14	05:13	
Sunrise Azimuth	84.29	83.87	83.45	83.03	82.61	82.07	81.65	81.24	80.83	80.41	80	79.47	79.06	78.66	78.25	77.85	77.45	77.05	76.65	76.26	75.87	75.48	75.09	74.7	74.31	73.93	73.55	73.17	72.8	72.42	
Sunset Time	18:13	18:14	18:15	18:15	18:16	18:16	18:17	18:18	18:18	18:19	18:19	18:20	18:21	18:21	18:22	18:23	18:23	18:24	18:24	18:25	18:26	18:26	18:27	18:28	18:28	18:29	18:29	18:30	18:31	18:31	
Sunset Azimuth	275.72	276.23	276.72	277.09	277.58	277.94	278.43	278.91	279.27	279.75	280.1	280.57	281.04	281.39	281.85	282.31	282.64	283.1	283.42	283.87	284.32	284.63	285.07	285.5	285.8	286.23	286.52	286.93	287.34	287.62	
Azimuth angle	**191.43**	**192.36**	**193.27**	**194.06**	**194.97**	**195.87**	**196.78**	**197.67**	**198.44**	**199.34**	**200.1**	**201.1**	**201.98**	**202.73**	**203.6**	**204.46**	**205.19**	**206.05**	**206.77**	**207.61**	**208.45**	**209.15**	**209.98**	**210.8**	**211.49**	**212.3**	**212.97**	**213.76**	**214.54**	**215.2**	
Peak Altitude angle	**64.46**	**64.85**	**65.23**	**65.61**	**65.99**	**66.37**	**66.75**	**67.12**	**67.5**	**67.87**	**68.24**	**68.6**	**68.97**	**69.33**	**69.69**	**70.04**	**70.4**	**70.75**	**71.09**	**71.44**	**71.78**	**72.12**	**72.45**	**72.78**	**73.11**	**73.4**	**73.76**	**74.07**	**74.39**	**74.7**	
Angle rad	3.341084	3.357315	3.373198	3.386986	3.402868	3.418576	3.434459	3.449992	3.463431	3.479139	3.492404	3.509857	3.525216	3.538306	3.55349	3.5685	3.581241	3.596251	3.608817	3.623478	3.638139	3.650356	3.664842	3.679154	3.691197	3.705334	3.717028	3.730816	3.744429	3.755949	
time (s)	44940	45060	45180	45240	45360	45480	45600	45720	45780	45900	45960	46140	46260	46320	46440	46560	46620	46740	46800	46920	47040	47100	47220	47340	47400	47520	47580	47700	47820	47880	
angular velocity (s)	7.43E-05	7.45E-05	7.47E-05	7.49E-05	7.5E-05	7.52E-05	7.53E-05	7.55E-05	7.57E-05	7.58E-05	7.6E-05	7.61E-05	7.62E-05	7.64E-05	7.65E-05	7.66E-05	7.68E-05	7.69E-05	7.71E-05	7.72E-05	7.73E-05	7.75E-05	7.76E-05	7.77E-05	7.79E-05	7.8E-05	7.81E-05	7.82E-05	7.83E-05	7.84E-05	7.653E-05
angular velocity (h)	0.267644	0.268228	0.268781	0.269521	0.270069	0.2706	0.271141	0.271653	0.272354	0.272874	0.273556	0.273851	0.274336	0.274998	0.275464	0.275915	0.276544	0.27699	0.277601	0.278016	0.278429	0.279008	0.279403	0.279784	0.280344	0.280707	0.281238	0.281571	0.281889	0.282402	0.275497

2019 May	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Sunrise Time	05:12	05:11	05:10	05:09	05:08	05:08	05:07	05:06	05:05	05:05	05:04	05:03	05:02	05:02	05:01	05:01	05:00	04:59	04:59	04:58	04:58	04:57	04:57	04:56	04:56	04:56	04:55	04:55	04:55	04:54	04:54	
Sunrise Azimuth	72.05	71.68	71.32	70.96	70.59	70.36	70.01	69.66	69.31	69.09	68.74	68.4	68.07	67.86	67.53	67.33	67.01	66.69	66.5	66.18	66	65.7	65.52	65.22	65.06	64.9	64.61	64.46	64.31	64.03	63.89	
Sunset Time	18:32	18:33	18:33	18:34	18:35	18:35	18:36	18:37	18:37	18:38	18:39	18:39	18:40	18:41	18:41	18:42	18:42	18:43	18:44	18:44	18:45	18:46	18:46	18:47	18:47	18:48	18:49	18:49	18:50	18:50	18:51	
Sunset Azimuth	288.02	288.42	288.69	289.07	289.45	289.7	290.07	290.44	290.67	291.03	291.38	291.59	291.93	292.26	292.46	292.79	292.97	293.28	293.59	293.76	294.05	294.33	294.48	294.76	294.9	295.16	295.41	295.53	295.77	295.88	296.11	
Azimuth angle	**215.97**	**216.74**	**217.37**	**218.11**	**218.86**	**219.34**	**220.06**	**220.78**	**221.36**	**221.94**	**222.64**	**223.19**	**223.86**	**224.4**	**224.93**	**225.46**	**225.96**	**226.59**	**227.09**	**227.58**	**228.05**	**228.63**	**228.96**	**229.54**	**229.84**	**230.26**	**230.8**	**231.07**	**231.46**	**231.85**	**232.22**	
Peak Altitude angle	**75**	**75.3**	**75.6**	**75.89**	**76.18**	**76.46**	**76.74**	**77.01**	**77.28**	**77.55**	**77.81**	**78.06**	**78.31**	**78.56**	**78.79**	**79.03**	**79.26**	**79.48**	**79.7**	**79.91**	**80.11**	**80.31**	**80.51**	**80.7**	**80.88**	**81.06**	**81.23**	**81.39**	**81.55**	**81.7**	**81.85**	
Angle rad	3.769388	3.782827	3.793822	3.806738	3.819828	3.828205	3.840772	3.853338	3.863461	3.873584	3.885801	3.8954	3.907094	3.916519	3.925769	3.935019	3.943746	3.954742	3.963468	3.97202	3.980223	3.990346	3.996106	4.006229	4.011465	4.018795	4.02822	4.032932	4.039739	4.046546	4.053004	
time (s)	48000	48120	48180	48300	48420	48420	48540	48660	48720	48780	48900	48960	49080	49140	49200	49260	49320	49440	49500	49560	49620	49740	49740	49860	49860	49920	50040	50040	50100	50160	50220	
angular velocity (s)	7.85E-05	7.86E-05	7.87E-05	7.88E-05	7.89E-05	7.91E-05	7.91E-05	7.92E-05	7.93E-05	7.94E-05	7.95E-05	7.96E-05	7.96E-05	7.97E-05	7.98E-05	7.99E-05	8E-05	8E-05	8.01E-05	8.01E-05	8.02E-05	8.02E-05	8.03E-05	8.03E-05	8.05E-05	8.05E-05	8.05E-05	8.06E-05	8.06E-05	8.07E-05	8.07E-05	7.9776E-05
angular velocity (h)	0.282704	0.283004	0.283474	0.283732	0.284002	0.284625	0.284853	0.28508	0.285477	0.285873	0.286071	0.286426	0.286584	0.286924	0.287251	0.287578	0.287865	0.287967	0.288252	0.288524	0.288771	0.288807	0.289224	0.289258	0.289636	0.289817	0.2898	0.290139	0.290281	0.290422	0.290538	0.28719229

2019 June	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Sunrise Time	04:54	04:54	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:53	04:54	04:54	04:54	04:54	04:55	04:55	04:55	04:55	04:56	04:56	
Sunrise Azimuth	63.75	63.62	63.37	63.24	63.13	63.01	62.9	62.8	62.7	62.61	62.52	62.44	62.36	62.29	62.22	62.16	62.1	62.05	62	61.97	62.06	62.03	62.01	61.99	62.11	62.1	62.11	62.11	62.25	62.27	
Sunset Time	18:51	18:52	18:52	18:53	18:53	18:54	18:54	18:55	18:55	18:56	18:56	18:56	18:57	18:57	18:57	18:58	18:58	18:58	18:59	18:59	18:59	18:59	19:00	19:00	19:00	19:00	19:00	19:00	19:00	19:00	
Sunset Azimuth	296.21	296.43	296.51	296.71	296.79	296.98	297.04	297.22	297.26	297.43	297.46	297.49	297.64	297.66	297.67	297.8	297.8	297.79	297.9	297.88	297.86	297.83	297.92	297.87	297.83	297.77	297.72	297.65	297.58	297.51	
Azimuth angle	**232.46**	**232.81**	**233.14**	**233.47**	**233.66**	**233.97**	**234.14**	**234.42**	**234.56**	**234.82**	**234.94**	**235.05**	**235.28**	**235.37**	**235.45**	**235.64**	**235.7**	**235.74**	**235.9**	**235.91**	**235.8**	**235.8**	**235.91**	**235.88**	**235.72**	**235.67**	**235.61**	**235.54**	**235.33**	**235.24**	
Peak Altitude angle	**81.99**	**82.12**	**82.25**	**82.37**	**82.48**	**82.59**	**82.69**	**82.79**	**82.87**	**82.95**	**83.03**	**83.09**	**83.15**	**83.21**	**83.25**	**83.29**	**83.32**	**83.35**	**83.37**	**83.38**	**83.39**	**83.39**	**83.38**	**83.36**	**83.34**	**83.31**	**83.27**	**83.23**	**83.18**	**83.12**	
Angle rad	4.057192	4.063301	4.069061	4.07482	4.078136	4.083547	4.086514	4.091401	4.093844	4.098382	4.100477	4.102396	4.106411	4.107981	4.109378	4.112694	4.113741	4.114439	4.117232	4.117406	4.115486	4.115486	4.117406	4.116883	4.11409	4.113217	4.11217	4.110949	4.107283	4.105713	
time (s)	50220	50280	50340	50400	50400	50460	50460	50520	50520	50580	50580	50580	50640	50640	50640	50700	50700	50700	50760	50760	50700	50700	50760	50760	50700	50700	50700	50700	50640	50640	
angular velocity (s)	8.08E-05	8.08E-05	8.08E-05	8.08E-05	8.09E-05	8.09E-05	8.1E-05	8.1E-05	8.1E-05	8.1E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.12E-05	8.11E-05	8.11E-05	8.12E-05	8.12E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.11E-05	8.1052E-05
angular velocity (h)	0.290838	0.290928	0.290994	0.291059	0.291295	0.291335	0.291547	0.291549	0.291723	0.2917	0.291849	0.291986	0.291925	0.292037	0.292136	0.292026	0.2921	0.29215	0.292002	0.292015	0.292224	0.292224	0.292015	0.291977	0.292125	0.292063	0.291988	0.291902	0.291987	0.291875	0.2917857

2019 July	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Sunrise Time	04:57	04:57	04:57	04:58	04:58	04:59	04:59	05:00	05:00	05:00	05:01	05:02	05:02	05:03	05:03	05:04	05:04	05:05	05:05	05:06	05:06	05:07	05:08	05:08	05:09	05:09	05:10	05:11	05:11	05:12	05:12	
Sunrise Azimuth	62.43	62.46	62.5	62.67	62.72	62.91	62.97	63.17	63.24	63.32	63.54	63.76	63.86	64.1	64.21	64.46	64.58	64.84	64.98	65.25	65.4	65.69	65.98	66.15	66.45	63.22	66.94	67.26	67.46	67.79	68	
Sunset Time	19:00	19:00	19:00	19:00	19:00	19:00	19:00	19:00	18:59	18:59	18:59	18:59	18:58	18:58	18:58	18:57	18:57	18:57	18:56	18:56	18:55	18:55	18:54	18:54	18:53	18:53	18:52	18:51	18:51	18:50	18:49	
Sunset Azimuth	297.43	297.35	297.26	297.16	297.06	296.96	296.85	296.74	296.49	296.37	296.25	296.11	295.85	295.71	295.57	295.29	295.14	294.99	294.7	294.54	294.24	294.07	293.77	293.59	293.28	293.1	292.78	292.46	292.27	291.94	291.62	
Azimuth angle	**235**	**234.89**	**234.76**	**234.49**	**234.34**	**234.05**	**233.88**	**233.57**	**233.25**	**233.05**	**232.71**	**232.35**	**231.99**	**231.61**	**231.36**	**230.83**	**230.56**	**230.15**	**229.72**	**229.29**	**228.84**	**228.38**	**227.79**	**227.44**	**226.83**	**229.88**	**225.84**	**225.2**	**224.81**	**224.15**	**223.62**	
Peak Altitude angle	**83.06**	**82.99**	**82.91**	**82.83**	**82.74**	**82.64**	**82.54**	**82.43**	**82.32**	**82.19**	**82.06**	**81.93**	**81.79**	**81.64**	**81.49**	**81.33**	**81.16**	**80.99**	**80.81**	**80.63**	**80.44**	**80.24**	**80.04**	**79.83**	**79.62**	**79.4**	**79.18**	**78.95**	**78.72**	**78.48**	**78.24**	
Angle rad	4.101524	4.099604	4.097335	4.092623	4.090005	4.084943	4.081976	4.076566	4.07098	4.06749	4.061556	4.055273	4.048989	4.042357	4.037994	4.028744	4.024031	4.016875	4.00937	4.001865	3.994011	3.985983	3.975686	3.969577	3.95893	4.012163	3.941652	3.930481	3.923675	3.912156	3.902905	
time (s)	50580	50580	50580	50520	50520	50460	50460	50400	50340	50340	50280	50220	50160	50100	50100	49980	49980	49920	49860	49800	49740	49680	49560	49560	49440	49440	49320	49200	49200	49080	49020	
angular velocity (s)	8.11E-05	8.11E-05	8.1E-05	8.1E-05	8.1E-05	8.1E-05	8.09E-05	8.09E-05	8.09E-05	8.08E-05	8.08E-05	8.08E-05	8.07E-05	8.07E-05	8.06E-05	8.06E-05	8.05E-05	8.05E-05	8.04E-05	8.04E-05	8.03E-05	8.02E-05	8.02E-05	8.01E-05	8.01E-05	8.12E-05	7.99E-05	7.99E-05	7.97E-05	7.97E-05	7.96E-05	8.0528E-05
angular velocity (h)	0.291923	0.291787	0.291625	0.291636	0.291449	0.291435	0.291223	0.291183	0.291131	0.290881	0.290804	0.290701	0.290597	0.290469	0.290155	0.290186	0.289846	0.289679	0.289485	0.289291	0.289072	0.288839	0.288791	0.288347	0.288272	0.292148	0.287712	0.287596	0.287098	0.286955	0.286627	0.28990138

2019 August	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Sunrise Time	05:13	05:14	05:14	05:15	05:15	05:16	05:17	05:17	05:18	05:18	05:19	05:20	05:20	05:21	05:21	05:22	05:23	05:23	05:24	05:24	05:25	05:25	05:26	05:27	05:27	05:28	05:28	05:29	05:29	05:30	05:30	
Sunrise Azimuth	68.35	68.69	68.92	69.28	69.52	69.89	70.26	70.52	70.9	71.16	71.56	71.96	72.24	72.65	72.93	73.35	73.78	74.08	74.51	74.82	75.25	75.57	76.02	76.47	76.8	77.25	77.59	78.05	78.39	78.86	79.21	
Sunset Time	18:49	18:48	18:47	18:46	18:46	18:45	18:44	18:43	18:42	18:41	18:40	18:39	18:39	18:38	18:37	18:36	18:35	18:34	18:33	18:31	18:30	18:29	18:28	18:27	18:26	18:25	18:24	18:23	18:22	18:20	18:19	
Sunset Azimuth	291.41	291.08	290.74	290.4	290.19	289.84	289.49	289.14	288.79	288.43	288.08	287.72	287.48	287.11	286.75	286.38	286.01	285.63	285.26	284.76	284.38	283.99	283.61	283.23	282.84	282.45	282.06	281.67	281.28	280.76	280.36	
Azimuth angle	**223.06**	**222.39**	**221.82**	**221.12**	**220.67**	**219.95**	**219.23**	**218.62**	**217.89**	**217.27**	**216.52**	**215.76**	**215.24**	**214.46**	**213.82**	**213.03**	**212.23**	**211.55**	**210.75**	**209.94**	**209.13**	**208.42**	**207.59**	**206.76**	**206.04**	**205.2**	**204.47**	**203.62**	**202.89**	**201.9**	**201.15**	
Peak Altitude angle	**77.99**	**77.73**	**77.48**	**77.21**	**76.94**	**76.67**	**76.39**	**76.11**	**75.83**	**75.54**	**75.24**	**74.95**	**74.65**	**74.34**	**74.03**	**73.72**	**73.4**	**73.08**	**72.75**	**72.43**	**72.1**	**71.76**	**71.42**	**71.09**	**70.74**	**70.4**	**70.05**	**69.7**	**69.34**	**68.99**	**68.63**	
Angle rad	3.893131	3.881438	3.871489	3.859272	3.851418	3.838852	3.826285	3.815639	3.802898	3.792077	3.778987	3.765722	3.756647	3.743033	3.731863	3.718075	3.704112	3.692244	3.678281	3.664144	3.650007	3.637615	3.623129	3.608643	3.596076	3.581416	3.568675	3.553839	3.541099	3.52382	3.51073	
time (s)	48960	48840	48780	48660	48660	48540	48420	48360	48240	48180	48060	47940	47940	47820	47760	47640	47520	47460	47340	47220	47100	47040	46920	46800	46740	46620	46560	46440	46380	46200	46140	
angular velocity (s)	7.95E-05	7.95E-05	7.94E-05	7.93E-05	7.91E-05	7.91E-05	7.9E-05	7.89E-05	7.88E-05	7.87E-05	7.86E-05	7.86E-05	7.84E-05	7.83E-05	7.81E-05	7.8E-05	7.79E-05	7.78E-05	7.77E-05	7.76E-05	7.75E-05	7.73E-05	7.72E-05	7.71E-05	7.69E-05	7.68E-05	7.66E-05	7.65E-05	7.63E-05	7.63E-05	7.61E-05	7.7974E-05
angular velocity (h)	0.28626	0.286101	0.285719	0.28552	0.284938	0.284711	0.284482	0.284043	0.283798	0.283343	0.28307	0.282783	0.282101	0.281784	0.281296	0.280963	0.280615	0.280069	0.279717	0.27935	0.278981	0.278389	0.277989	0.277588	0.276976	0.276557	0.275928	0.275491	0.274859	0.274583	0.273919	0.28070727

2019 September	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Sunrise Time	05:31	05:32	05:32	05:33	05:33	05:34	05:34	05:35	05:35	05:36	05:36	05:37	05:38	05:38	05:39	05:39	05:40	05:40	05:41	05:41	05:42	05:42	05:43	05:43	05:44	05:45	05:45	05:46	05:46	05:47	
Sunrise Azimuth	79.69	80.16	80.52	81	81.36	81.85	82.21	82.71	83.07	83.57	83.94	84.44	84.94	85.31	85.82	86.19	86.7	87.08	87.58	87.96	88.47	88.85	89.36	89.74	90.24	90.75	91.13	91.63	92.01	92.52	
Sunset Time	18:18	18:17	18:16	18:14	18:13	18:12	18:11	18:10	18:08	18:07	18:06	18:05	18:03	18:02	18:01	18:00	17:58	17:57	17:56	17:55	17:53	17:52	17:51	17:50	17:48	17:47	17:46	17:45	17:43	17:42	
Sunset Azimuth	279.96	279.56	279.16	278.64	278.23	277.83	277.43	277.02	276.49	276.08	275.67	275.26	274.72	274.31	273.9	273.48	272.94	272.53	272.11	271.7	271.16	270.74	270.32	269.9	269.36	268.94	268.52	268.1	267.56	267.14	
Azimuth angle	**200.27**	**199.4**	**198.64**	**197.64**	**196.87**	**195.98**	**195.22**	**194.31**	**193.42**	**192.51**	**191.73**	**190.82**	**189.78**	**189**	**188.08**	**187.29**	**186.24**	**185.45**	**184.53**	**183.74**	**182.69**	**181.89**	**180.96**	**180.16**	**179.12**	**178.19**	**177.39**	**176.47**	**175.55**	**174.62**	
Peak Altitude angle	**68.27**	**67.9**	**67.54**	**67.17**	**66.8**	**66.43**	**66.06**	**65.68**	**65.31**	**64.93**	**64.55**	**64.17**	**63.79**	**63.41**	**63.02**	**62.64**	**62.25**	**61.87**	**61.48**	**61.09**	**60.7**	**60.31**	**59.92**	**59.54**	**59.15**	**58.76**	**58.37**	**57.98**	**57.59**	**57.2**	
Angle rad	3.495371	3.480187	3.466922	3.449469	3.43603	3.420496	3.407232	3.391349	3.375816	3.359933	3.34632	3.330437	3.312286	3.298672	3.282615	3.268827	3.250501	3.236713	3.220656	3.206868	3.188542	3.174579	3.158348	3.144385	3.126234	3.110002	3.09604	3.079983	3.063926	3.047694	
time (s)	46020	45900	45840	45660	45600	45480	45420	45300	45180	45060	45000	44880	44700	44640	44520	44460	44280	44220	44100	44040	43860	43800	43680	43620	43440	43320	43260	43140	43020	42900	
angular velocity (s)	7.6E-05	7.58E-05	7.56E-05	7.55E-05	7.54E-05	7.52E-05	7.5E-05	7.49E-05	7.47E-05	7.46E-05	7.44E-05	7.42E-05	7.41E-05	7.39E-05	7.37E-05	7.35E-05	7.34E-05	7.32E-05	7.3E-05	7.28E-05	7.27E-05	7.25E-05	7.23E-05	7.21E-05	7.2E-05	7.18E-05	7.16E-05	7.14E-05	7.12E-05	7.1E-05	7.3583E-05
angular velocity (h)	0.273432	0.272956	0.272271	0.271969	0.271266	0.270752	0.270058	0.269511	0.268989	0.268437	0.267706	0.267147	0.266761	0.266022	0.265441	0.264682	0.264268	0.263504	0.262911	0.262142	0.261713	0.260924	0.260303	0.259509	0.25908	0.258449	0.257645	0.257022	0.256395	0.255751	0.26490059

Figure D1: Raw data on peak altitude angle at chosen Cairo site

APPENDIX G Component sources

Solar panels used: https://www.lg.com/global/business/neon-2

http://www.lg-solar.com/downloads/spec-sheet/DS_NeON2_60cells.pdf

Motor used: https://hydraulicsonline.com/product/danfoss-omr-motor/

Wheels used: https://www.technicawheels.co.uk/p4949-250-50-heavy-duty-spring-loaded-nylon-swivel-castor.html

APPENDIX H XR model

Figure H1: 3D printed farm with QR code for AR camera

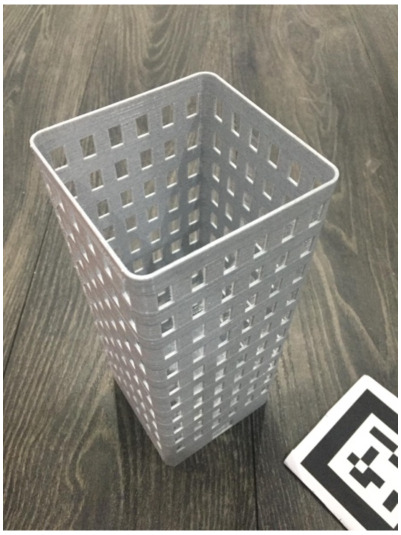


Figure H2: Inside view of 3D printed model

Figure H3: Closeup view of 1:400 scale model next to scale human figure and

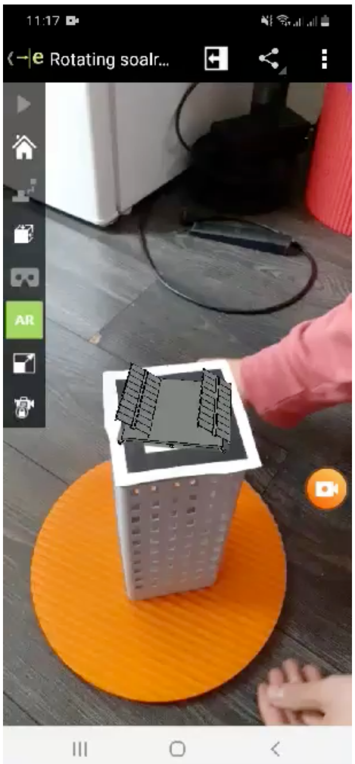


Figure H4: Screenshot of AR model on a phone

Figure H5: View of entire XR model