Optimal Structural Design and Prototyping of connectors to support roof-mounted solar tiles

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1. ABSTRACT

A well-engineered solar roof tiles mounting system is presented here by eliminating the drawbacks associated with the solar roof. A comprehensive literature review is conducted here and identified the inconstancies like a gap in research in the area of solar roof mounting units, conflicts in previous studies, and open questions left from another research. Innovated design presented here is easy to install and can accommodate a range of solar tiles manufactured by leading manufacturers. The design also solves the roof leaking issues, tilting of the tiles, and corrosion of mounting units by design optimization and surface protection methods. The final report for this project will hold engineering calculations, drawings, simulation results, and prototypes test results and future recommendations.

2. INTRODUCTION

2.1 Problem statement:

Solar roof replaces the existing roof with aesthetically pleasing solar tiles that can power our homes for decades; however, solar tile technology itself is very complicated technology and often besieged with problems. Based on our findings, there are three main problems with the roof solar tile designs.

× Structural damage due to uplift from the wind.
× Corrosion of the solar roof tiles mounting units.
× Leaking issues of the rooftop due to poor installation.

There are four leading causes of the above-addressed problems. The first and foremost issue is the structural collapse, which happens when the mounting unit fails to withstand the force of wind and gravity effectively and thus causes uplift from the wind.

On to the second issue, the corrosion occurs because, in solar panel assembly, both anode and cathode contain metals, in most of the case rainwater, acts as the electrolyte and eventually leads to corrosion, also we noticed that photovoltaic hardware currently used to construct and install solar tiles are less noble metals.

The final problem is roof leaking; this happens because the mounting clamps currently available in the market are required to bolt it down on the roof; therefore, they don't compromise the waterproofing capability of the roof and consequently cause leakages and void the roof warranty. The gap between the adjacent tiles is another leading cause of roof leakage.

2.2 Aim of the project:

This project aims to design and develop a well-engineered solar roof tile by overcoming the exiting defects such as structural damage due to uplift from the wind, corrosion of the mounting units, and leaking issues of the rooftop due to poor installation by mitigating these defects to the pre-existing models. The more innovative and improved design would consist of the solution for the above issues and transforming the design into a physical reality by prototyping a new model.

3. REVIEW OF LITERATURE

In this era of energy conservation, solar energy is one of the most untapped, yet obvious ones. As with any new technology, there are certain glitches here as well. This literature review concentrates on the current issues and causative components on solar roof tiles technology. The main problems which are identified in the problem statements are reviewed.

3.1 Structural damage of solar roof tiles due to external loads.

In any structural component of buildings, the elements of nature play a significant role in its lifespan. The uplift of roofing structures due to wind is one of the main issues that can plague the Solar roof tile installations too. A study (Meroney & Neff, 2010) using Computational Fluid Dynamics (CFD) to calculate the wind load on the structure considering the drag and lift gives an insight into this issue, which can also be used in the testing phase to estimate the maximum load which the structure can afford to take without causing damage. A detailed study (Cao & Yoshida, 2013) of wind load resistance for a flat-roofed building was done for different parameters such as single array setup, multi-array setup, the effect of distance between arrays, the effect of building depth, etc. A lightweight Solar roof tile was developed suitable for sloping roofs which also ensured astounding capabilities like hurricane resistance, fire resistance owing to the specialized coatings, flexibility in terms of moldability, the ability to withstand the external load, as well as ease in transportation and installation (Bellavia,2015). A substantial study (Ali & Chokwitthaya, 2017) on using Solar panels to reduce the uplift caused by wind on gable-roofed low-rise buildings provide certain valuable insights which can be adopted in the Solar roof tile technology as well. It lists the advantage of having a backup solar power source after an immediate power outage, especially after a thunderstorm. The research outlines the importance of the placement of solar panels, away from the edges and corners, for optimal reduction of uplift forces.

Snowfall is yet another problem area that literally obscures the Solar Roof Tiles or Photovoltaic (PV) units from getting an ideal exposure of Solar Energy. A recent study (Jelle, 2013) explores the option of using a low-friction, ultra-hydrophobic material in the BIPV unit. It also calculates an optimal slipping-angle-threshold, which ensures the slipping away of snow crystals from the PV surface.

3.2 Corrosion of the solar roof tiles mounting units

Corrosion is another prevalent issue that is caused by the metal components in the solar roof tile assembly, which may eventually lead to a lot of structural damage. An innovative technology uses an Anode sacrificially for the protection of Cathode from corrosion (Whitmore, 2019). This technology further suggests the use of an activator, which promotes the corrosive nature of the Anode material for ensuring the continuous protection of the Cathode material from corroding. The said activator could be included in the material which is used for ionic conduction by fillers such as gels or liquids with alkali hydroxides. Extensive research (Nürnberger & Köse, 2019) was done on the causes of corrosion in terms of humidity and presence of certain elements in the atmosphere like Sulphur Dioxide, which further transforms into Sulphurous dioxide and finally Sulphuric acid as well as the effects brought on by the salts of Chloride. The research indicates that 'aerosols' in Chloride plays a significant role in corrosion. Another case study in the same research paper was on the effect of Timber on corrosion. The paper indicated that the Timber being a porous material is an excellent host for moisture content and other acidic corrosive agents from the atmosphere, thereby adding to the burden of corrosion. It further ventures into self-metallic and bi-metallic corrosive behaviors of Aluminium, Stainless Steel, etc.

3.3 Leaking issues of the solar rooftop

Leakage is yet another common issue that needs further understanding. The design and development of a solar roof architecture in Bangalore (Mani & Reddy, 2008) is particularly impressive with illustrative aspects of an inter-locking system for the prevention of leakage. The design is inspired by allowing a free flow of water so that rainwater is not collected anywhere on the roof. The existing technology (Weber, 1983) involves the joining of the PV unit to the roof using screws, which makes the leakage an unavoidable issue in the long run. Certain variations can be tried with the usage of tar or any non-permeable materials such as plastic to cover the joints and thereby preventing the water from passing through it. The system also mentions the concept of using an adhesive to join the PV unit, which needs further research for the range of its effectiveness. Another cutting-edge work (Becerril-Romero & Giraldo, 2016) is focused on converting ceramic tiles, which are commercially used into solar cells for BIPV purpose, a novel method of using kesterite (Siebentritt & Schorr, 2012) technology.

3.4 conclusion

A comprehensive literature survey concerning the current issues in the solar roof tile industry is done. The four fundamental issues reviewed are damage to the structure due to wind and the resulting uplift, snowfall obscuring the PV units, corrosion of the metallic components, and leakage. The review sheds light on specific solutions for the identified issues as well. Additionally, certain cutting-edge technologies such as the novel kesterite technology and conversion of commercial ceramic tiles for BIPV purposes are also identified, which require further research. In the past many years, the design of the photovoltaics received enough attention; however, the design and analysis of solar roof mounting unit have not been concentrated much. The futuristic technology of Solar Roof Tiles is promising even though it requires a considerable amount of research and modifications to meet all the challenges it may encounter.

4. METHODOLOGY

The methodology here clearly defines how to proceed, how to measure the progress, and what constitutes the success of this entire project. The methodological approach of this project consists of five stages:

1) Study of current designs of solar tiles and local weather conditions in New Zealand
2) Identifying the critical load acting areas and clamping system
3) Design and development of ideal clamping unit with a waterproofing membrane in place.
4) Study about anodizing and surface protection method to avoid oxidation.
5) Fabricate a fully functional prototype to test the product features in real world conditions

4.1 Study of current designs of solar tiles and local weather conditions in New Zealand:

The investigation of existing solar tiles available in the market is a necessary ingredient for creating, developing, and delivering a successful solution for the addressed problems. The below table depicts different types of solar panels available in the New Zealand market, and each varies in their dimensions and efficiency.

Table 1: Tile Comparison

S/N	Product	Self-weight	Efficiency
1	Tesla solar tiles	8-10 lbs	15%
2	Apollo II tile	3.2 lbs	16%
3	SunTegra tile	3.0 lbs	15%
6	Bristile	6 ~ 9 lbs	16%
7	Tractile	4 ~ 6 lbs	20%

Further research is required to provide practical evidence of the issues and this can be done in two effective ways.

- ✓ Visit Zero Energy House built in Auckland to get the designs and clamping methods used.
- ✓ Contact the solar tiles companies for the brochure and details of the tiles

4.2 Predesign analysis to Identify the critical load acting areas and clamping system:

The investigation of critical load acting areas of the solar tiles is one of the most crucial aspects of this study. Here we will conduct a study about Wind parameters like wind speed, wind pressure, and pressure coefficient acting on the solar tiles and connectors. A good understanding of wind-induced forces will allow us to design an effective clamping system to protect the building integrated rooftop solar tiles

4.3 Design and development of ideal clamping unit with a waterproofing membrane in place.

This phase consists of simple four steps design process and it is explained below.

- <u>Step 1 Designing a solution to maximize roof strength and minimize installation time</u>

Timber can be replaced with steel frame to support unique solar tiles supporting panels increasing the roof strength while reducing the cost and insulation time.

- <u>Step 2: Designing a solution for water leakage issues by introducing Primary water proofing unit</u>

Once the steel frame is in place, the waterproof tile support panels can be screwed into purlins, and this acts as a waterproofing membrane and gives an insulated finish. The challenge here is to investigate an ideal waterproofing membrane with the below material properties.

- ✓ High tensile strength, to resist tearing
- ✓ Lightweight, so to be easily applied
- ✓ Whether protection and rainproof
- ✓ High fire resistance

- Step 3: Designing solar tiles supporting bars

On top of the insulated sheet (water proof tile support sheet), battens can be installed to support the solar tiles using specially designed fixing screws.

- Step 4: Designing locking mechanism and spacers to accommodate solar tiles

Link channels with a secured locking mechanism can be used to space the batten to accommodate solar tiles. Link channels can be locked into the lower batten. Here we need to identify the critical load acting areas.

Each link channel is also essential in waterproofing the roof. Should a storm hit, the excess rainwater flows into the link channel then out on to the tile below, keeping the roof waterproof and free from debris. The gap between solar inserts and tile support panels underneath ensures valuable airflow inside the roof cavity, which in turn maximizes solar energy output.

- Step 5: Conduct post design analysis to identify the critical loading areas

CFD provides a numerical approach to perform a cost-effective analysis for pressure loads and dynamic wind loads acting on solar roof tiles in a fast and efficient way. Areas of complex recirculating flow and localized vortices are easily simulated and identified for design improvements.

- ✓ SolidWorks simulation speeds up decision making by introducing different load to tiles and mounting parts in a precise, realistic computer environment.

The numerical analysis presents quantitative data for pressure, force, and velocity that is easy to comprehend and highly detailed.

4.4 Study about anodizing and surface protection method to avoid oxidation.

This phase investigates cost-effective anodizing coating and surface protection methods to protect steel frames, battens, and link channels from oxidation. Anodizing protects hardware against further oxidation.

4.5 Fabricate a fully functional prototype

This phase is to test the product features in real-world conditions. Two sets of building-integrated solar tiles have to be purchased. The fabrication and test phase includes the following:

- Fabrication of the clamps, and mounting unit as per the proposed design.
- Integrating the waterproofing membrane.
- Test the prototype in real-world conditions.

After the test phase, a detailed test report with findings and future recommendation have to be prepared.

5.0 PROJECT LIMITATIONS:

The limitations to the methodology exist as restraints of the following:

a. Time
b. Cost
c. Performance

a. Time:

Time is constrained, and by November, the final prototype should be ready. In this project, designing and CFD analysis are going to be the most time-consuming task. Several redesigns might be needed to find the right solutions for the identified problems. The lack of time will automatically reduce the amount of research done on each topic.

b. Cost:

The maximum budget that Wintec provides for this project is 1000 NZD. To complete this project in that given budget correct planning and execution is required. The software for the design and analysis is provided free by Wintec. But the solar tiles costs and the material costs cannot be determined at this stage of the project. There are chances that the actual costs could overrun the budget. For example, when buying a solar tile, the standard shipping might be free, but in this case, the time is limited, so we should look for faster options.

c. Performance

The performance is another main factor that determines the outcome of this project. If a team member fails to do a task in the given time, that will affect the project as a whole.

5. WHY - WHY ANALYSIS


WHY?
Current Issues
Roof Leakage
Drilling many holes on the roof
Design of clamps
Lack of design research
Waterproof Seals not used
Cost
Contractor unaware of waterproofing
Oudated machinery
Hign cost of new machines
Availability of latest equipments
Gap between tiles
Design of Tiles
Lack design research
Design of clamps
Lack of Desin Research
Tilting of tiles
Wind
Climate conditions in an area
Hign Speed of wind
Clamping Method
Design of clamps
Lack of proper design research
Corossion
Environment
Climatic parameters
Rain, temperacture and humidity
Atmospheric pollution
Acidic particles, quality of precipitation
Nature of the metals
Galvanic corossion
Usage of dissimilar metals

6. SWOT Analysis

STRENGTHS	OPPORTUNITIES
✓ CFD software packages provided by Wintec help to perform a cost-effective analysis in a fast, accurate way. ✓ The knowledge about Solidworks (A 3D modelling and analysis tool) helps us to do design improvements and analysis under one roof. ✓ Excellent technical writing skills help us to communicate our ideas and prepare high quality, well-versed documentation.	✓ We can effectively solve issues of leakages, tilting of solar tiles, and corrosion issues by design innovation. ✓ We can commercialize our solutions. ✓ We can get an opportunity to present our solutions to market leaders in solar tiles.
WEAKNESS	**THREATS**
× Lack of specialized knowledge in Ansys (a highly advanced simulation tool), which is superior to Solidworks when it comes to CFD. × We have only intermediate knowledge in computational fluid dynamics.	× Restriction to use Wintec facilities due to the ongoing pandemic. × Time constraints. The prototype and documentation should be ready by early November 2020. × International shipping delays. Solar tiles are not readily available in the local market. × Unexpected design failure might occur in real-world conditions.

7. CONTIGENCY OF THREATS

As a part of contingency planning, we took interim measures to respond to threats, and it is given below.

1. Easy to use student edition of Ansys allows us to complete CFD analysis remotely at our comfort. Wintec can allow workshop access by limiting the number of students coming into their facility.

2. A Gantt chart helps us to view the start and end dates of the project in a straightforward view so that we can timely track the schedule and manage time efficiently to complete the project on time.

3. Decide on and order parts in advance, allow three months for parts to arrive. Design and fabricate clamps before the solar tiles arrive.

4. Select a promising solution. Rapid prototyping will allow us to do some design modification to meet the project objectives.

8. PROJECT PLAN

1) Study of current designs of solar tiles.

a) Visit Zero Energy House built in Auckland to get the designs and clamping methods used.
b) Contact the solar tiles companies for the brochure and details of the tiles

2) Predesign analysis to Identify the critical load acting areas and clamping system

- a) Collect wind parameters and local weather conditions in NZ
- b) Perform CFD using Solid works
- c) Pinpoint critical loading areas of solar tiles

3) Design and development phase

a) Design a solution to maximize roof strength and minimize installation time

b) Design a solution for water leakage issues

c) Design supporting bars

d) Design spacers to accommodate solar tiles

e) Conduct post design analysis

4) **Study about anodizing and surface protection method to avoid oxidation**.

a) Investigate cost-effective surface protection method

b) Study anodizing method to protect steel frames, battens, and link channels

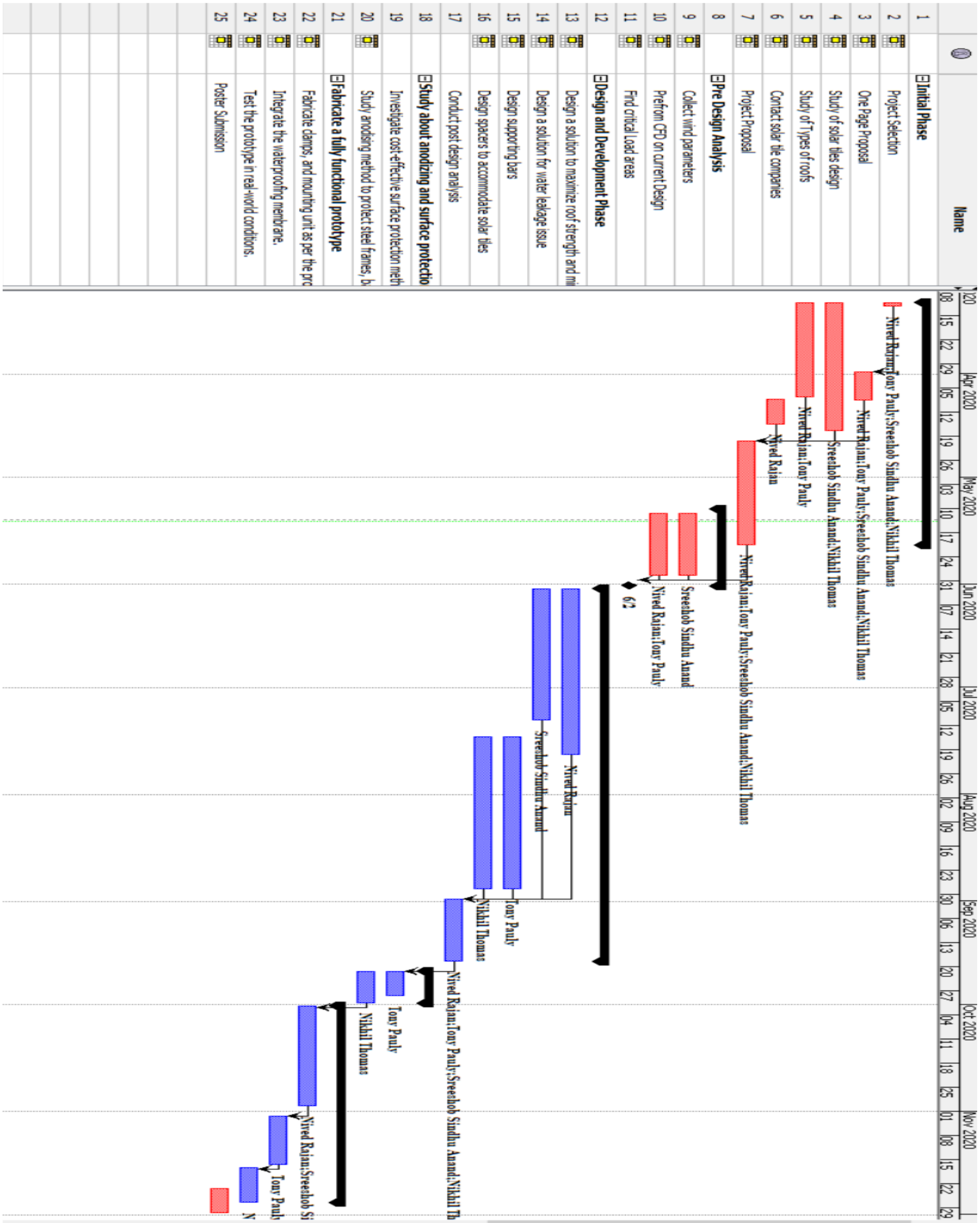
5) Fabricate a fully functional prototype

a) Fabricate clamps, and mounting unit as per the proposed design.

b) Integrate the waterproofing membrane.

c) Test the prototype in real-world conditions.

7.1 Gantt Chart: -



9. HAND SKETCHES OF DESIGN SOLUTIONS

Hand sketches are an essential part of the design and development process. We made the hand sketches of our concept to convey our ideas and demonstrate our concept and functionality before designing it using a 3D modeling software.

9.1 Design and development stage 1

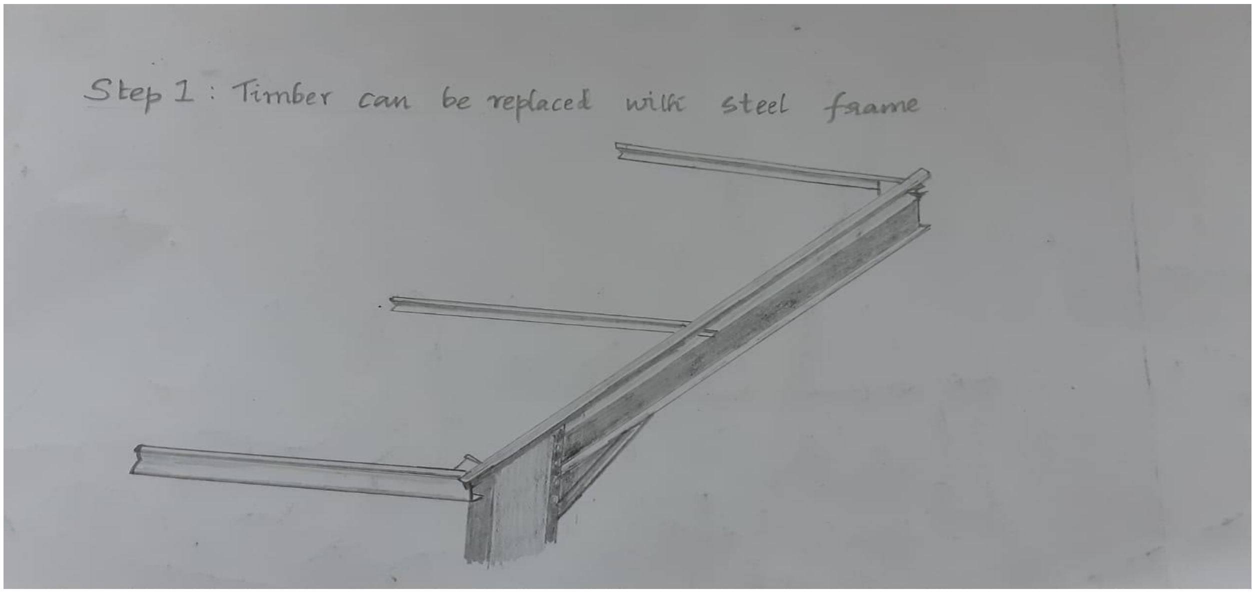


Figure 1: Design and development stage 1

9.2 Design and development stage 2

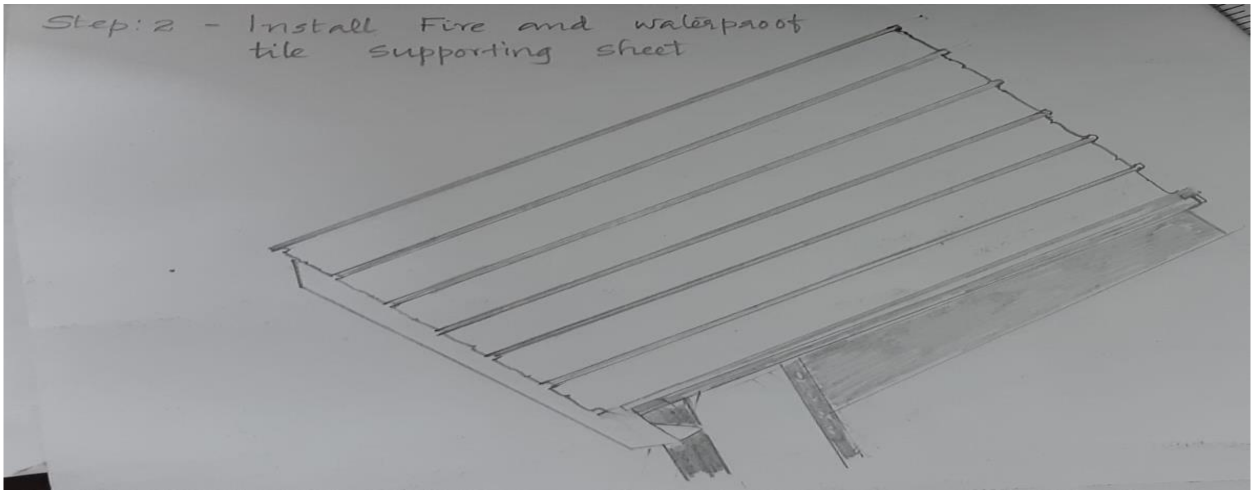


Figure 2: Design development stage 2

9.3 Design and development stage 3

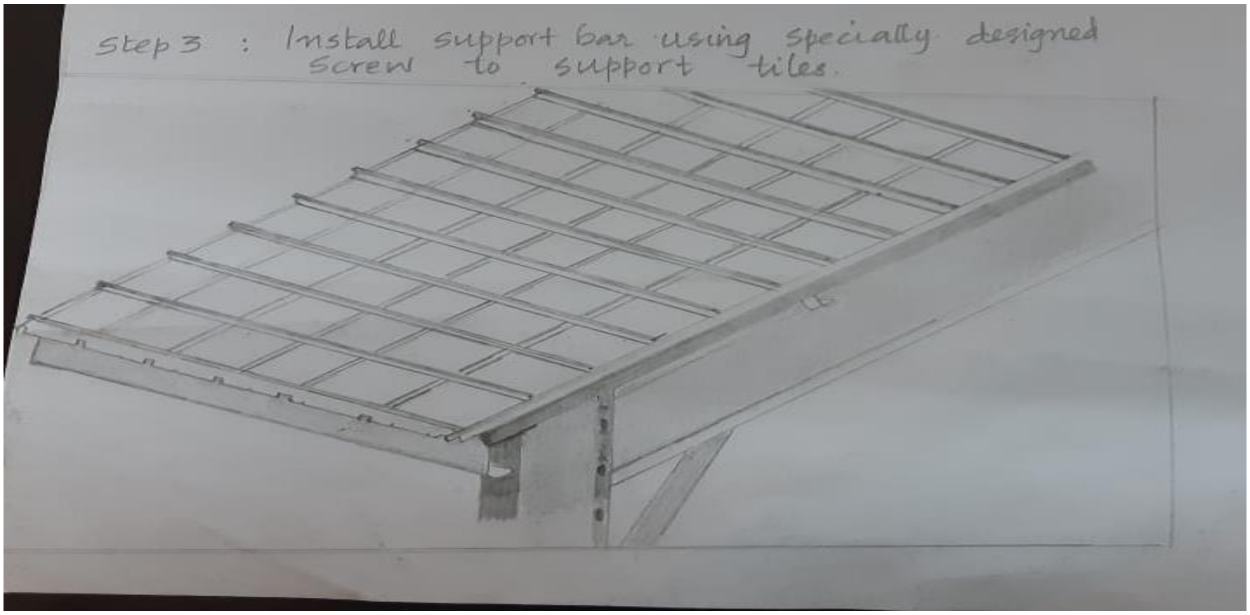


Figure 3: Design and development stage 3

9.4 Design and development stage 4

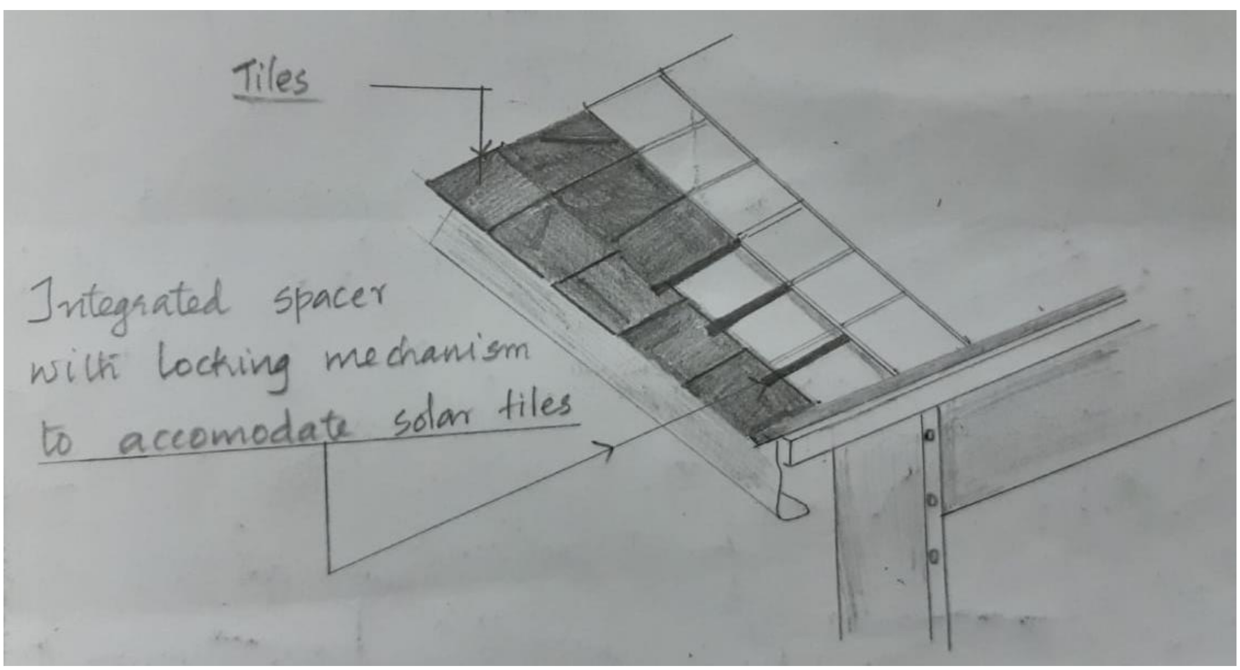


Figure 4: Design and development stage 4

10.RESOURCES WITH BUDGET

We have a Wintec budget for each student in our group; this will cover initial site visits and study. The software we require for design and CFD is available through our Wintec student access. Final project costing is dependent on the finalized design, which is the next step in our process. The estimate is given in the below table.

Table 2: Resource with budget

S/N	**Resource type**	**Rate /unit (NZD)**	**Quantity**	**Subtotal (NZD)**	**Remarks**
01	Transportation	30	03	90	to visit site and material purchase
02	C21 solar tiles	80	02	160	
03	Solid works/3D modelling and CFD tool	0		0	The software we require for design and CFD is available through our Wintec student access
04	Galvanized frame	14	08	112	To improve the roof strength
05	Waterproof membrane sheet	60	01	60	The material is yet to decide, and costing is dependent on the finalized design
06	Fabricated link channels	6	04	24	
07	Fabricated Batten to lock the tiles	4	08	32	
08	Anodizing and surface protection	06	12	72	
Subtotal (NZD)				550	

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12. REFLECTION:

Student Name	Student ID	Email ID	Tasks Done
1. Nived Rajan	19492925	nivraj15@student.wintec.ac.nz	• Literature Review • Hand Drawing of Designs • Contingency Plan • Methodology
2. Sreeshob Sindhu Anand	19485180	sresin08@student.wintec.ac.nz	• Methodology • Abstract • Project limitations • Why Why Analysis • Gantt Chart
3. Tony Pauly	19490954	tonpau27@student.wintec.ac.nz	• Why Why Analysis • SWOT Analysis • Introduction • Recourses with budget • Literature Review
4. Nikhil Thomas	19491540	niktho25@student.wintec.ac.nz	• Project plan • Introduction • Methodology • Introduction • Resource with budget

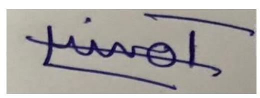
13. STUDENT DECLARATION

I have not copied any part of this report from any other person's work, except as correctly referenced. No other person has written any portion of this report for me.

1. **Student Name:** Sreeshob Sindhu Anand

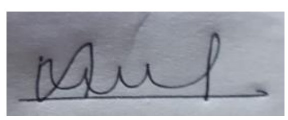
Student declaration of the above ____________________________________ signed.

2. **Student Name:** Tony Pauly



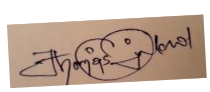
Student declaration of the above ____________________________________ signed.

3. **Student Name:** Nived Rajan



Student declaration of the above ____________________________ signed.

4. **Student Name:** Nikhil Thomas



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