Brunel University London

THE NORTH FACE

SunUp.

AN ARTICULATING PHOTOVOLTAIC MESH FOR HIKING BAGS

BRADLEY BRISTER | MAJOR PROJECT REPORT | 2019

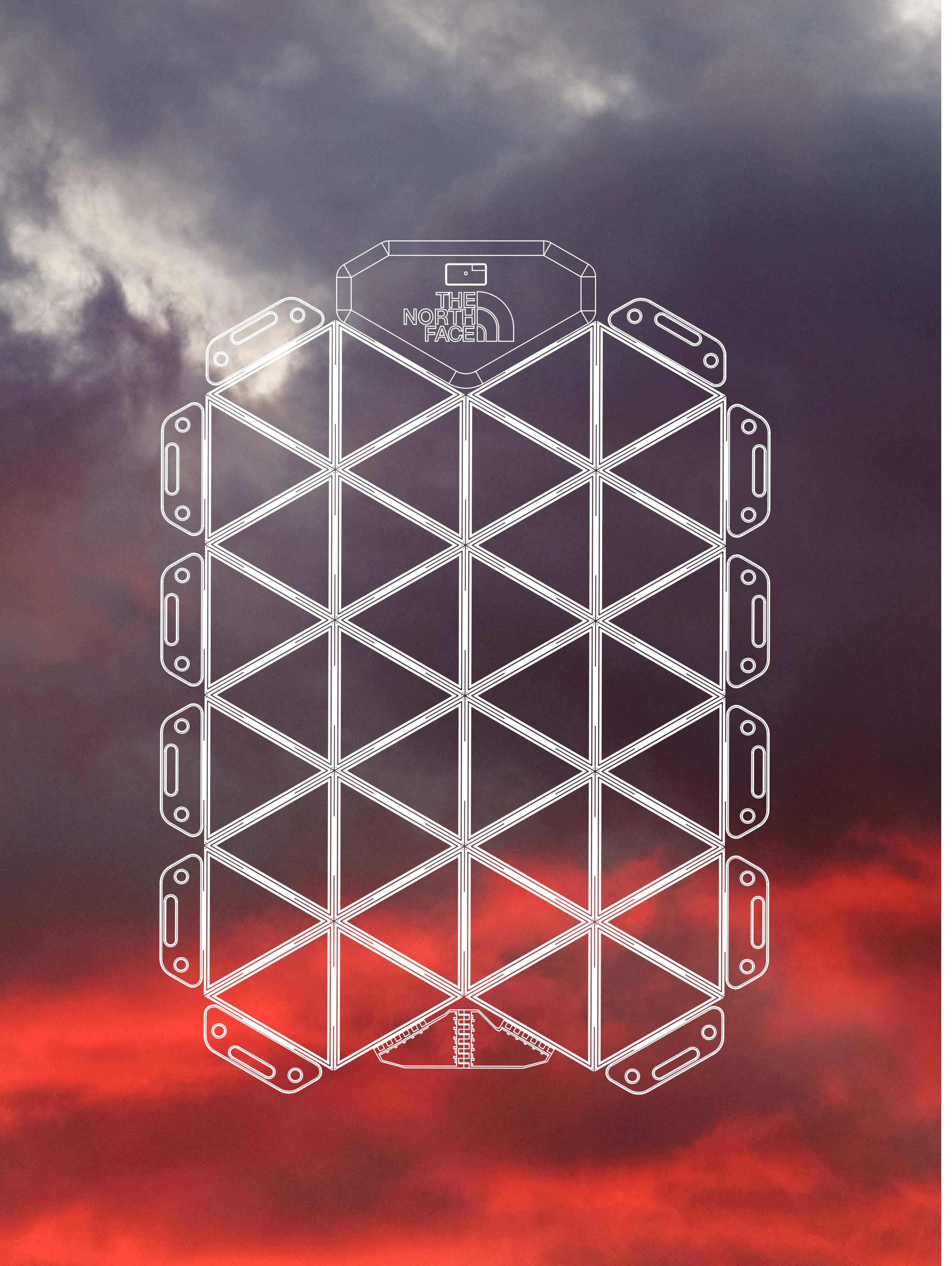

Fig 1. Zeller, S. (2017) Sky, dusk, dawn and cloud.

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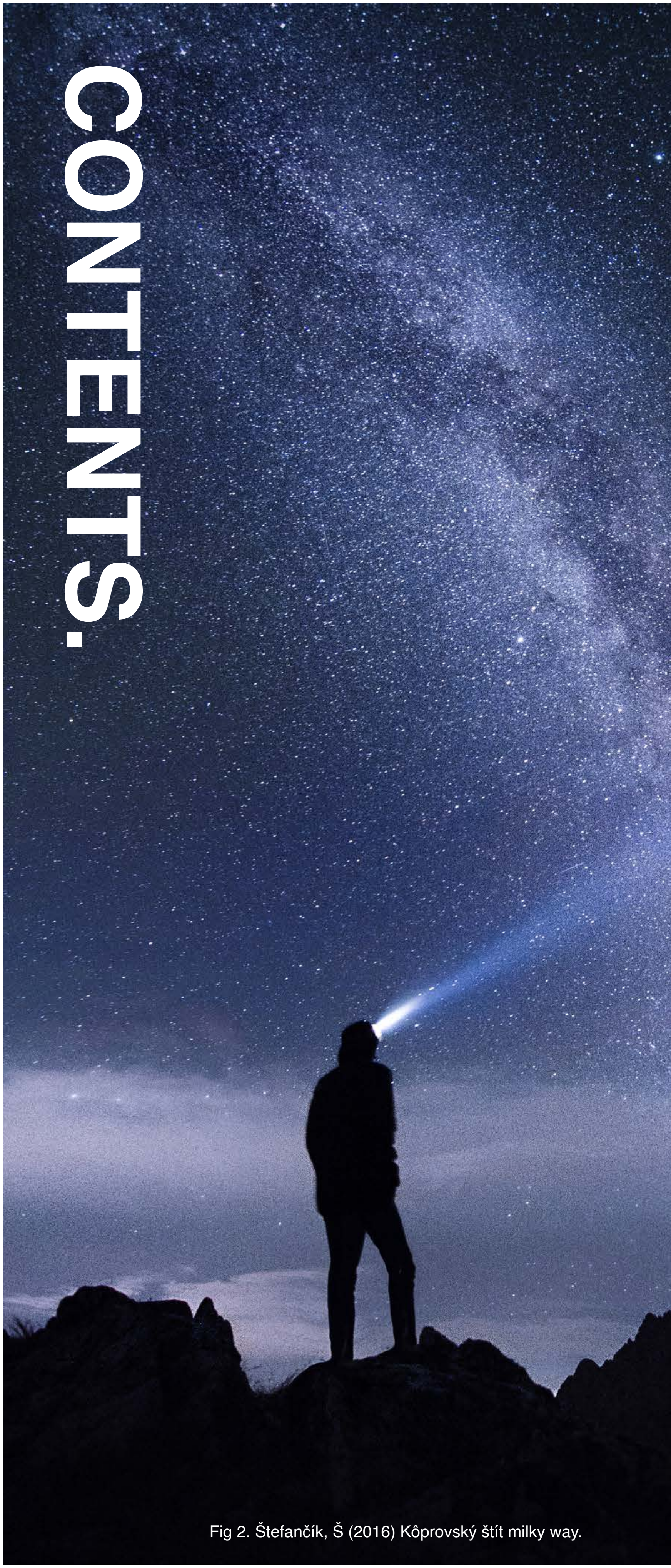


Fig 2. Štefančík, Š (2016) Kôprovský štít milky way.

ABSTRACT

The following report follows the design and development of the SunUp project, A collaborative project with the VF Corporation.

With the increase in smart devices and general battery powered equipment being taken out hiking there comes a need to provide reliable power for these devices.

The current methods either involve large storage batteries to ensure the user has enough or to generate the power along the route.

The obvious target is to allow the user to be fully self-sufficient, to generate enough power in one day to match their electrical usage on the same day.

This report aims to investigate the problems surrounding the current uses of solar whilst hiking and propose an integrated solution befitting the north face brand.

The project aim is to develop an articulating solar array that provides the user with a rugged and dependable alternative to the current energy generating solutions.

INTRODUCTION

1.

1.01

COLLABORATIVE BACKGROUND

This project was undertaken with oversight and guidance from Dr Marco Cavallaro in collaboration with the VF Corporation (VFC) and more specifically The North Face brand.

VFC is also the parent company to Vans, Timberland, Jansport and Eastpak to name a few.

The purpose of this was to provide the author with an insight into how a project is run within the industry and to provide an experience more relevant to future development than the standard major project. This aspect was a key factor in the author's decision to propose the initial brief to VFC.

The North Face is part of the VF Corporation, one of the leaders in the outdoor market. Their company purpose is as quoted "We power movements of sustainable and active lifestyles for the betterment of people and our planet" This is a philosophy the design decisions made in this report should reflect.

The North Face brand was chosen as the primary focus as it best suited the problem market. The report investigates the problems surrounding device charging whilst hiking and camping and as such The North Face's approach to exploration and adventure made it the most appropriate fit.

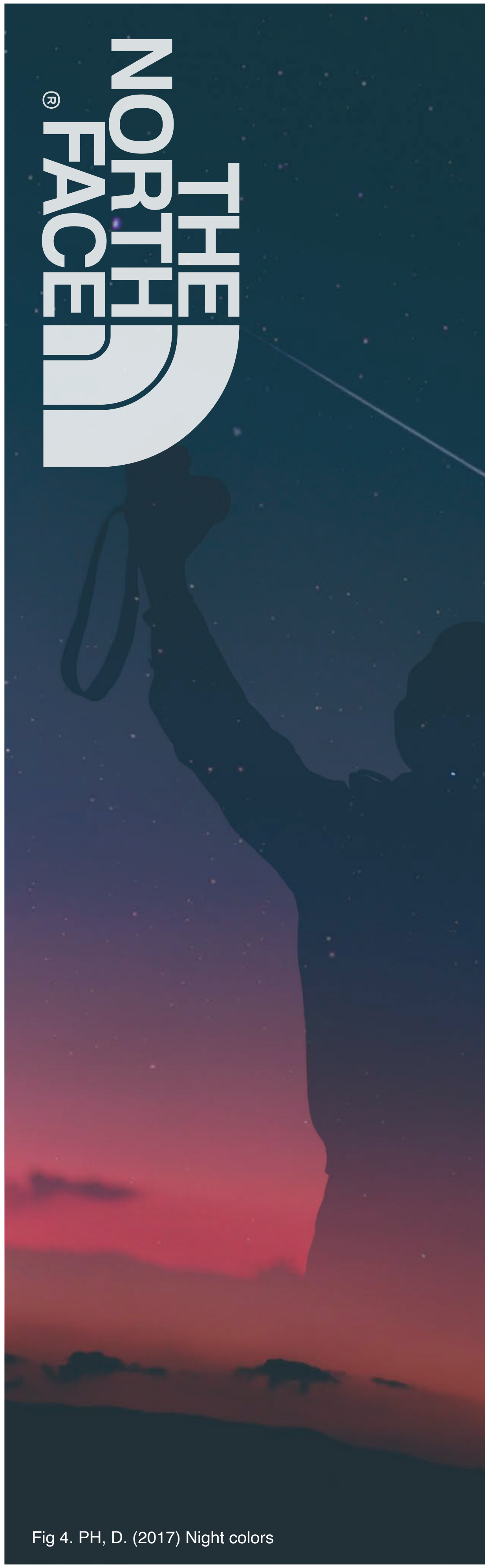
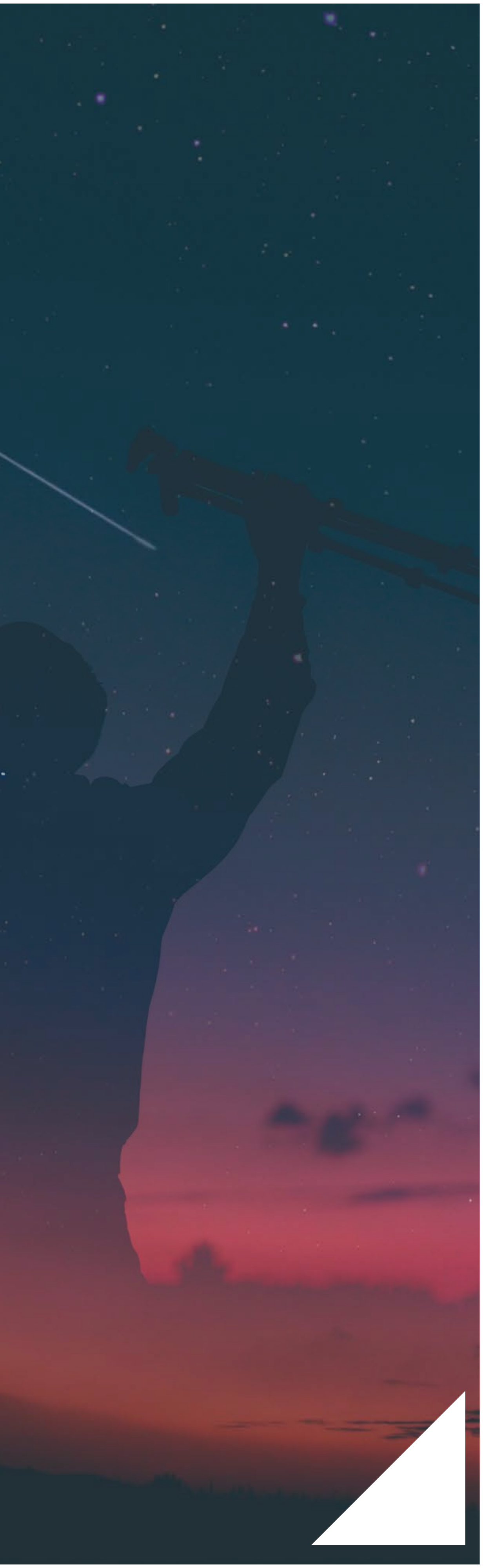


Fig 4. PH, D. (2017) Night colors



1.02

THE BRIEF

The collaborative company provided several briefs to chose from however the author proposed a different project focusing more on the consumer end interaction with electronics.

The brief outlines a problem area to look into, it shows the starting point of the project and provides a launching point for further indepth research as described in the following areas. Before moving through to the technical research stages however further refinement of the specific problem this project aimed to solve was required.

The full proposal is as follows:

To create a solar charging and battery storage system to keep a plethora of devices and embedded sensors fully charged in all environmental conditions.

And maintain a high-efficiency output whilst being rugged and durable in environments from which data from such embedded sensors would be utilised.

To produce a manufacturable interconnected solar array that has the same flexibility as a thin film variant but with the efficiency of a rigid panel.

THE PROBLEM

2.01 DEVICE USAGE WHILST HIKING
2.02 DIFFERING APPROACHES

2.

Fig 5. Seeling, C. (2016) Aerial cloud sunset

2.01

DEVICE USAGE WHILST HIKING

The number of people (over 16 years old) engaged in regular active pursuits in the UK is approximately 24 million (OIA UK, 2014). according to a 2014 report by the UK outdoor industry association. This makes up roughly 58% of the population. This number is expected to increase as more and more people seek an escape from the city. The same report showed 80% of the UK population lived in cities.

Coupling this with the meteoric increase in smart-device usage globally it stands to reason that the number of people taking powered devices outdoors with them is increasing at an equivalent rate.

Surveys carried out during this project help to back up this data. 97% of people take a phone out hiking with them (Appendix A). On average people take 3 powered devices with them. Most commonly a phone, a camera and a GPS. People are taking these devices hiking predominately for either security, utility or entertainment.

The race to produce the best devices of any kind has increased at the same accelerated rate in which technology has. The only main aspect of modern smart technology that hasn't experienced such a stark leap forward is the battery technology powering all these devices. Phones with 4K screens and 30MP cameras are still run on the same batteries they were 5 years ago.

The battery capacity of even flagship phones hasn't increased, for example, the Sony Xperia Z2 (2014) (Sony Mobile UK., 2015) has a 3200mAh battery whilst the iPhone XS Max (2018), (Apple Inc, 2018) has a 3174mAh battery. Obviously, advances in efficiency were made to increase battery life but this inherent defect of underpowered devices still persists and is likely to remain until some major advances are made.

Currently whilst offering large arrays of equipment to almost every facet of the outdoor market TNF has no proposal to help solve the problem of device and sensor charging whilst out exploring.

2.02

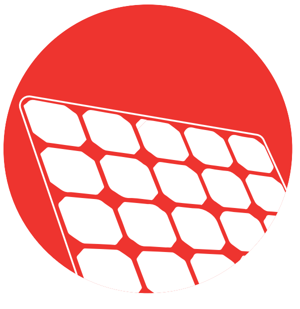
DIFFERING APPROACHES

WHY ARE THERE SO MANY?

This increase in consumers taking devices outdoors with them has lead to an increase in the number of people offering charging solutions. The four main areas these fall into are as follows: Solar panels and Battery banks. The more experimental approaches such as Hydrogen Fuel Cells and the turbine driven versions like Wind, Wave or Hand Crank powered charging systems.

In general, people take 3 devices with them hiking, this leads to an average battery requirement of 3000mAh for phones (charged once per day), 3000mAh for cameras (roughly charged once every 3 days) and 2000mAh for a GPS (charged once per 4 days). For an average trip of 4 days, you would need 18000mAh (4500mAh per day). (Triggs, R., 2018).

The discussions below will touch on the key benefits and downsides to each approach and help to inform the context around the problem focus.



SOLAR PANELS

Solar panels take energy from the sun and convert it to electrical energy. The standard efficiencies of the panels sits at around 21% at the top end. (The Eco Experts, 2019).

The predominant way in which people use solar panels is by draping them over the top of their pack. However solar panels are greatly affected by the angle they are placed in orientation to the sun. Any slight deviation from this optimum angle decreases overall efficiency. So any panels draped down the vertical length of the backpack is essentially wasted.

The benefit of solar over the other options is it can be gathering electricity whilst out on the hike.

BATTERY BANKS

The battery banks consist of taking a large chemical storage medium big enough to last the entire trip. It prevents reliance on environmental factors to provide power.

Given that 80% (Appendix A) of people took a phone with them for safety reasons it makes sense to have a reliable source of power for what could be their emergency line of communication.

Any design proposals should integrate a form of battery storage redundancy for the emergency situation that power is needed and the environmental factors are unable to provide appropriate power.

The downside is the excessive weight cost these add to the trip.

2.02

DIFFERING APPROACHES

EXPERIMENTAL STORAGE

Some companies offer more unconventional portable storage solutions. Such as Brunton with their USB Hydrogen Fuel Cell. Whilst this successfully provides hydrogen cores with enough charge to power a phone it wouldn't be classed as an environmentally friendly or cost-effective method.

In the case of the Brunton charger, you would buy cores to charge up your phones, much to the same effect you would have with disposable batteries. Or purchase a recharge station for several hundred pounds.

In essence, they often are perfectly adequate at charging but the extra hassle and cost surrounding the recharging, upkeep and proprietary equipment required to use them make them unfeasible for the everyday consumer.

WIND & WAVE POWER

The turbine or crank based generation methods rely on converting rotational energy into electrical by turning some form of dynamo.

This method whilst the simplest is inherently inefficient. The amount of power generated per rotation is generally denoted by the amount of force you can apply to the device. This means that the smaller the device is, the less inertial mass you can impart force to it the less power it can output.

Whilst large scale variants work well miniaturising it tends to only be enough for small amounts of lighting.

They also require to be stationary to be most effective and as such can only be active when at a base camp or stationary.

THE PROBLEM

The main focus of this project is to investigate further into the technology behind solar panels and current battery banks. To devise a way to compromise between the reliance of a battery bank and the renewable supply of solar power. The project will focus on better utilising the contours of a rucksack and integrating the system more closely with hikers daily routines.

It will also investigate the inherent downsides of solar power such as fragility and flexibility to provide a product tailored more closely to the user's experience. The main focus should be to design a mechanism that allows all of the above whilst still being simple and suitable for manufacturing.

RESEARCH

3.

Fig 6. Bhosale, R. (2018) He dreamed about a stargazing

3.01

THE FIELD

Before moving into the technical research stage it is important to understand the state of the industry. Specifically in regards to the number of people actively out engaging in outdoor pursuits. As of 2015 58% of UK residents over the age of 16 enjoy the outdoors. (OIA UK, 2014).

To find further information as to the sort of devices people were taking hiking with them and the general perception of devices whilst hiking a survey of over 400 applicants was undertaken.

From this, a few key things were learnt why people take electronics hiking, how long they need the device to stay charged for and what sort of environments they were hiking in.

Which electronics people take hiking and why?
The top 6 devices people take hiking were as follows: Phone, Battery Bank, Camera, GPS, Smartwatch, USB Torch/Headlamp. The being the Phone, Camera and GPS. The average hiker takes as few extra items with them as possible, the main aspect being weighed up when it comes to what to bring and what not is reliability vs weight.

If they can assume it will definitely provide them with power through whatever trip length they need then they are more willing to compromise on weight. It was found that battery banks are the predominant form of charging whilst out hiking because of this. Whilst they are much heavier than solar systems they don't have a reliance on environmental factors so will always provide power. This is essential because of the reasons people take their devices hiking.

The main reason people said they took electronics hiking with them was for safety. Having a phone or GPS whilst out hiking is a lifeline, allowing you contact to emergency services or check in with friends and family. This follows with a common mentality amongst outdoors people which is to go equipped for the worst case. This needed to be considered when designing the final product as it has to remain reliable even when the sun isn't up.

How long they need it to be charged for?
90% of respondents said they required a charge for at least 4 days worth of trip. The limiting factor in trip length is the amount of consumables such as food can be carried at once, Phone charge has little effect on people decisions on trip length. (Appendix A)

What Sort of Environments?
For the purposes of this project, we are focusing on sub-optimal scenarios, the environmental condition the product must survive in is defined by likely UK walking areas based on survey feedback. The user is predominantly only active hiking for 8 hours a day and the local solar coverage of these areas all lie below the national average due to the mountain ranges creating turbulent weather systems and therefore a higher than average level of cloud cover.

The main locations were Scottish Highlands, The lake district and Snowdonia. Each with a respective solar coverage of 820kWh/m2, 770 kWh/m2 and 720 kWh/m2. Lower than the national average of 849kWh/m2 (Solargis MapBox, 2018).

The key points here are that the design would incorporate a battery backup, cover as much of the pack as possible and provide enough charge to keep the trip fully charged for at least 4 days of suboptimal conditions.

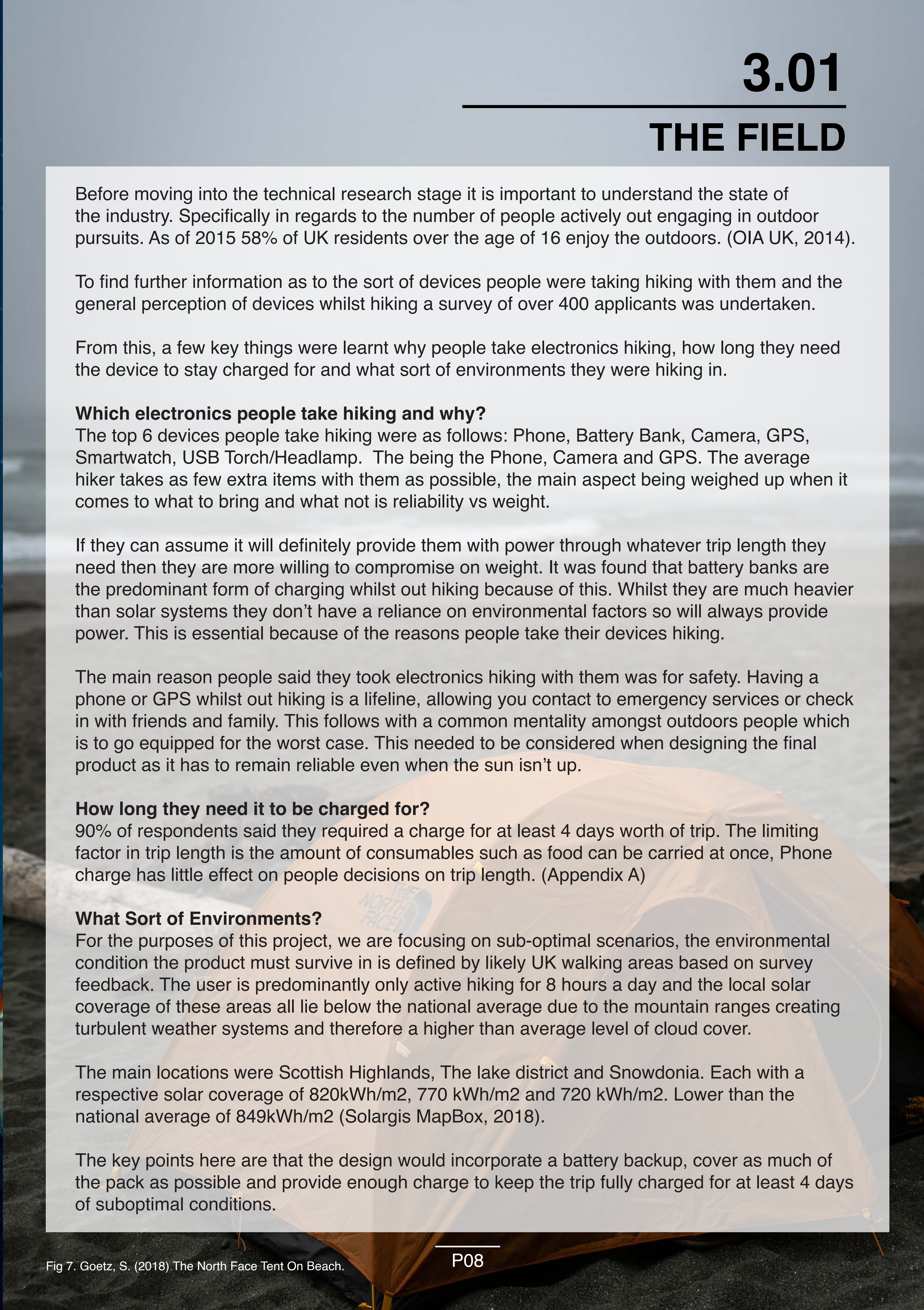


Fig 7. Goetz, S. (2018) The North Face Tent On Beach.

3.02

USER INTERACTION

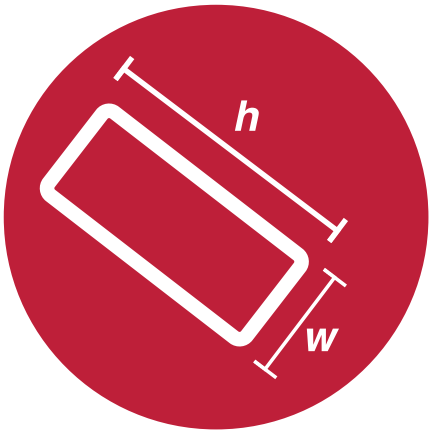
During the research stages a questionnaire (Appendix A) was sent out to better understand peoples current issues with solar and other charging solutions

Some respondents found it annoying that they couldn't use their phone whilst it was charging as it had to be stowed in the bag connected by a short cable. Or they had to wait until they were stationary again.

Most listed weight as their biggest issue with battery banks. However, many of the responses said that they would tolerate the extra weight if it meant reliably charged devices.

As with most higher end technology one of the chief complaints after weight and fragility were that to buy a decent system the cost was far too high.

The complaints about solar panels mostly revolved around the unreliability of the sun in the UK and as such said, they would always want a battery bank as back up so they weren't without power in an emergency situation.



A less frequent but still valid complaint is the physical size of battery banks can make them quite difficult to fit in when it comes to long expeditions. Often the pack-ability of a device is more important than it's overall weight.

The main reason people gave for not wanting to invest in expensive solar systems was the lack of expandability and the fact that they are usually quite fragile and likely to break after a few expeditions anyway.

3.03

SOLAR PANELS

Solar panels work by the conversion of solar irradiance into electrical energy through a phenomenon called the photoelectric effect. Simply it means that when a photon strikes the surface it excites an electron close to the surface causing it to be emitted. This causes a flow between the terminal creating a potential difference.

Solar panels tend to be categorised by two main groups, the rigid and flexible variants. Rigid panels are the monocrystalline or polycrystalline panels whereas the flexible ones are the thin film amorphous panels.

RIGID PANELS

Monocrystalline and Polycrystalline panels are for any real-world test basically identical currently however there is some difference in features in the performance that account for an industry preference and bias towards the MC variants. However, both have a between 18-21% depending on the manufacturer

In both cases, they are formed from a grown crystal of silicon which is then doped in phosphorous o create a negative junction differential relative to the positive bottom surface. The wafers are then coated in silicone nitride to reduce and light lost through reflection. Where the two variants differ is that MC panels are comprised of this singular wafer whereas PC panels are built up of many fractured segments melted back together. This makes them significantly cheaper as they can utilise more of the wasted material and can be formed more easily.

Monocrystalline panels have a better low light performance and traditionally a slightly higher average efficiency. However, due to the significant price difference between MC and PC panels more research and development have been put into PC panels and as such, the performance difference that used to exist is essentially non-existent now.

FLEXIBLE PANELS

Thin Film Amorphous panels but from non-crystalline silicone deposited on a flexible surface film. There are numerous different technologies employed for this such as Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIG/CIGS), Organic photovoltaic (OPV/ DSC/ DYSC) however the main downside to all of these is the efficiency. The average efficiency for a TF panel sits at around 4-12%. The main benefit of a TF panel is it’s flexibility, the fact the entire panel can bend and flex means it’s mostly impervious to extreme conditions. It is also resistant to cuts and fracturing as a result. (CivicSolar Inc., 2018)

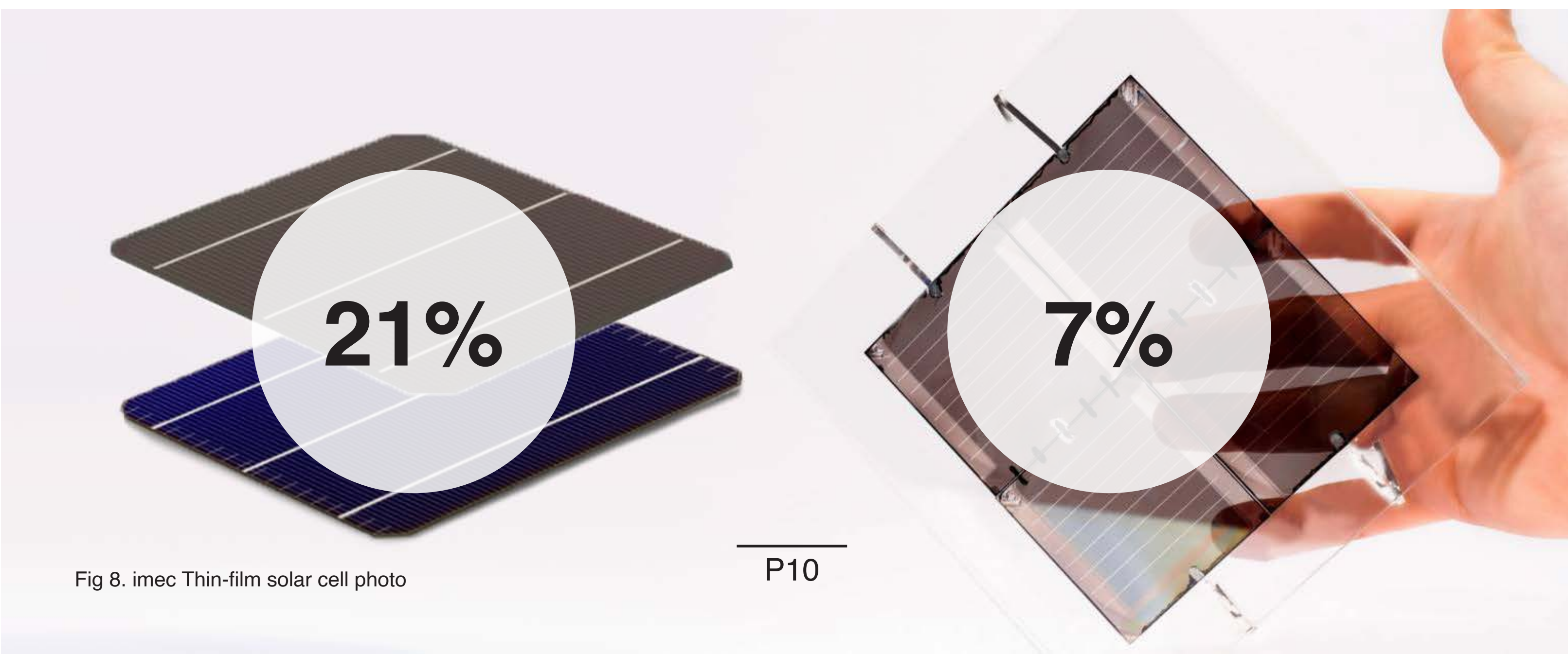


Fig 8. imec Thin-film solar cell photo

3.04

PHOTOELECTRIC EFFECT

An area to keep under observation for future development is the work currently being done to increase the efficiency of thin film panels. Some technologies currently under research indicate a possible future for low-cost high-efficiency thin film fully flexible panels. Work such as that being carried out to place plasmonic nanostructures before the junction (Atwater, Harry & Polman, Albert,2010) to decrease the amount of light scattered or reflected by the film in order to boost efficiency.

Most of the wasted energy is in terms of sunlight not utilised. Solar panels mostly operate with optimum efficiency around a certain frequency as defined by the photoelectric equation.

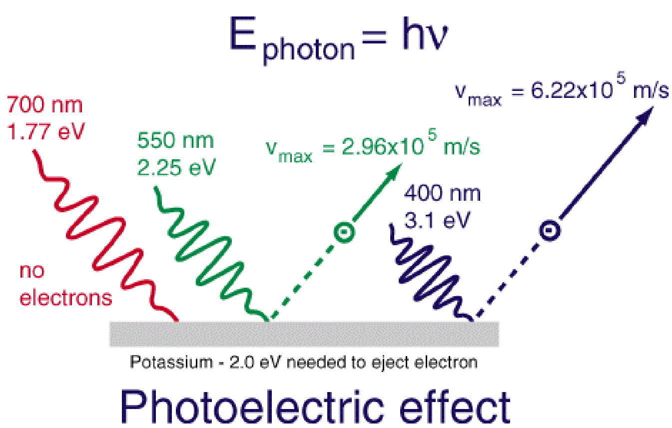


Fig 9. Herman, M. Photoelectric Effect, Diagram,

As you can see here the kinetic energy of the emitted electron is indifferent of the intensity of the light, rather the frequency of the photons. The larger the airmass value between the sun and the panel the larger the Doppler shift in frequency is. The operating frequency of a panel has to be set up to absorb the largest percentage of light throughout the entire day. This leaves a lot of the spectrum untapped.

The author would propose an approach of multilayered TF laminates with each film being tuned to a different wavelength of light. The initial wavelengths that remain unabsorbed by the layer in front would be absorbed by the layers further back. This area, however, remains very much in experimental research stages and as of yet no mass manufacturable solution to high-efficiency TF panels has been proposed.

This disparity between the two main types of solar panel is the area of focus for my project. The research undertaken here shows a current gap between a fully flexible solar array with the efficiency of a rigid panel. The project aims to provide a suitable method for interlinking rigid panels to simulate the same flexibility of TF panels.

From the solar panel research, it was determined the best technology to use would be either monocrystalline or polycrystalline rigid panels due to their efficiency benefits. The recommendation for the final product would be to use polycrystalline due to the cost saving compared to MC panels.

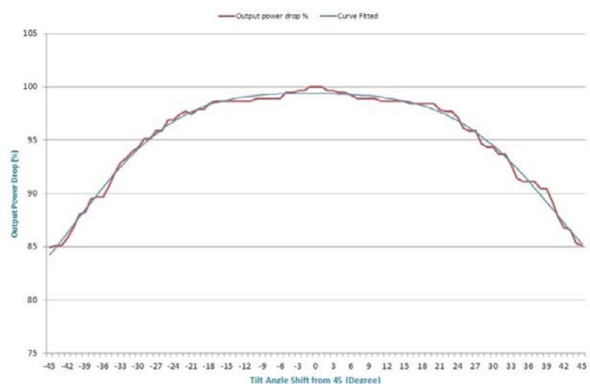
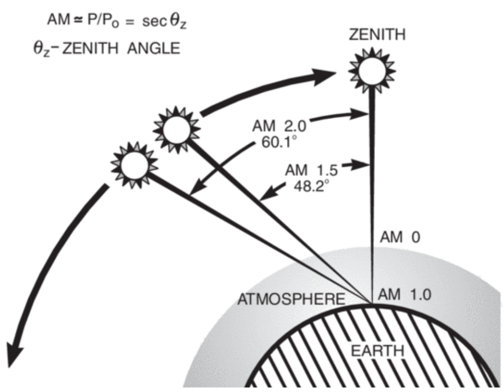


Fig 10. 'The Impact of Tilt Angle on Photovoltaic Panel Output', (2017)



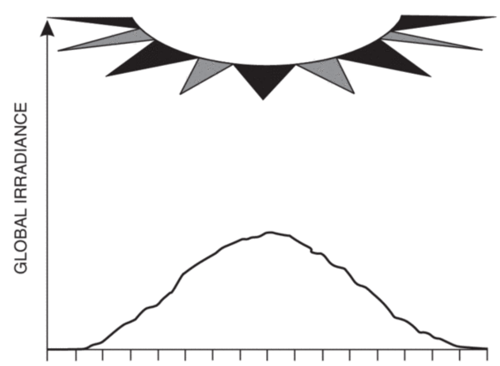
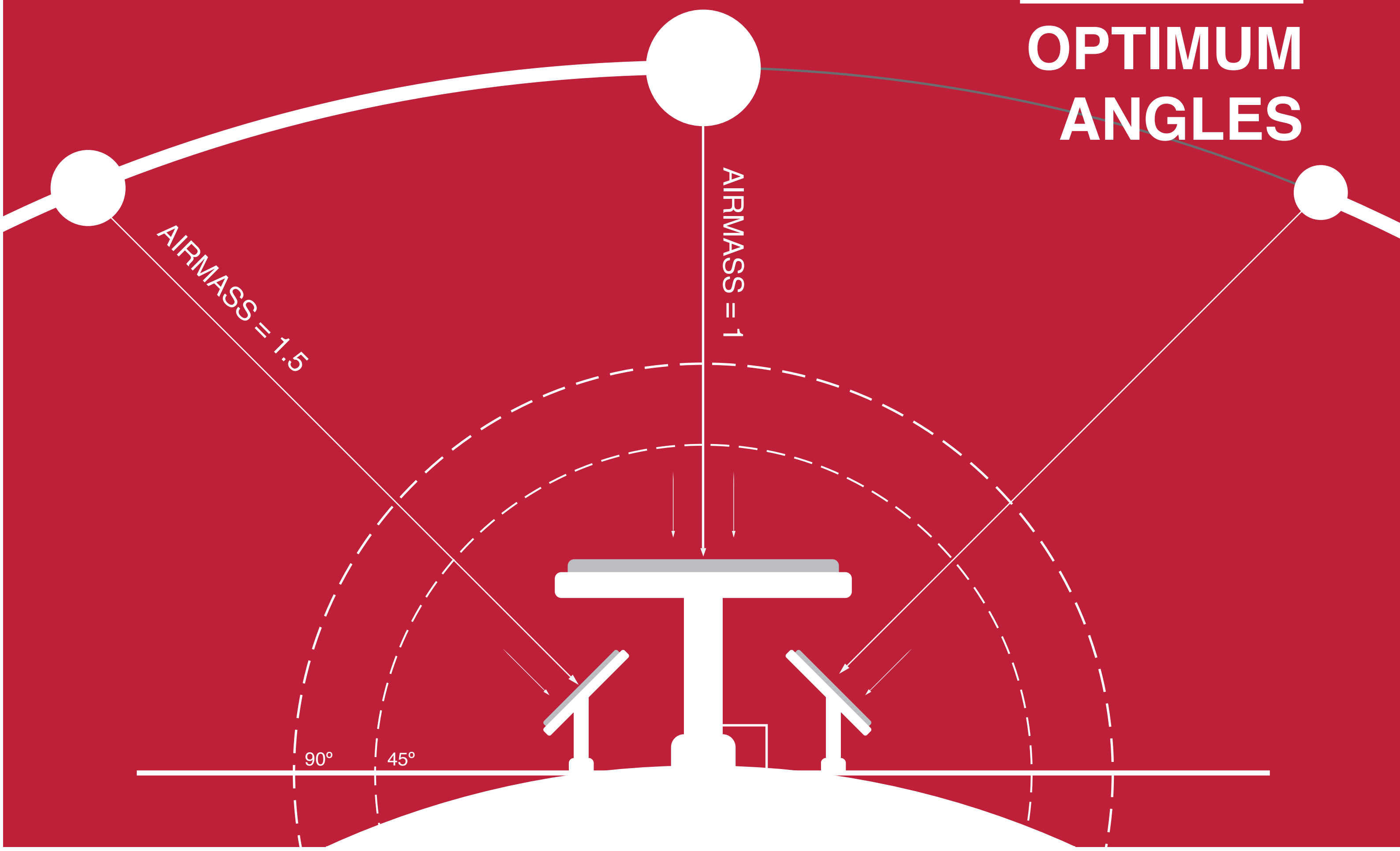


Fig 12,13. Newport Coperation (2018) Introduction to Solar Radiation.

3.05

OPTIMUM ANGLES



With solar panels, the angle at which the sun is hitting the panel makes a huge difference to the power output. Traditional studies, however, focus on domestic panels when they are stationary.

Such as (The Impact of Tilt Angle on Photovoltaic Panel Output, 2017) in which the author determines the optimum angle for his current location to maintain the lowest deviation from the perpendicular angle throughout a full day.

As you can see from Fig 10. the output power graph slopes down quite significantly as the angle progresses away from the perpendicular optimum angle.

Another factor affecting the efficiency of the panel is not only the angle of the panel but also the angle of the sun. The shallower the angle of the sun the larger airmass the sunlight has to travel through which in turn reduces its power potential. (Newport Corporation, 2018)

As Fig 13. shows the peak times for solar flux density is as close to noon as possible.

In effect, the greatest cost to performance ration will be gained by only utilising the top of the pack. Any extra panel mounted vertically to the side of the pack would have very poor efficiency.

This limits the usable space on a backpack to the hood and the shoulder straps, the shoulder straps provide a minimal surface area to design a panel for so for the purposes of this project it was recommended to focus on utilising every available section of the hood of the pack to greater harness that potential.

By moving the panel to be perpendicular with the sun when the sun has the smallest possible value of airmass you gain the greatest power output possible from the panel.

3.06

ENERGY STORAGE RESEARCH

After the research into different suitable solar systems was finished the next logical step is to research how that energy could be stored. Again as was the case with solar a completely zoomed out approach has been taken and as such the current state of the art, methods have been considered and analysed.
Ultimately however the key aspects the different technologies will be evaluated against is its availability for manufacture, battery capacity and cost.

LITHIUM ION

Fig 14. Karlsson Robotics Coin Cell Battery

The most prevalent type of rechargeable battery is the Lithium Ion. Unlike older batteries like the Nickle metal hydride chemistry batteries, Li-Ions have no memory so don't suffer performance deficits when discharged and charged for irregular time intervals. (BatteryUniversity.com, 2018).

A major benefit of using lithiums is that they are so readily available. They are used in the majority of rechargeable appliances and as such come in such a wide variety of shapes and sizes, capacities and voltages. This would mean they wouldn't have a limiting effect on the design stages as it would be highly likely that a battery could be sourced of almost any dimension.

A downside of Li-Ion batteries is their low-temperature performance (Mahmud,2017). As the environmental temperature decreases the internal resistance within the cells increases, this means more energy is wasted as heat during the conversion from chemical storage back to electrical causing a reduction in efficiency. This issue was mentioned in both the surveys and by industry members participating in the IRE evening (See Appendix A).

LITHIUM FERROUS PHOSPHATE

Fig 15. Enerpower (2018) LiFePo4 Batteries photos

LiFePo4 batteries have much the same characteristics as Lithiums, they suffer from the same low-temperature performance is equally poor however the different battery chemistry makes them far more stable when pieced or at high temperatures. The onset temperature for thermal runaway for a LiFePo4 battery is 246°C, unlike Li-ion which ranges from 104°C to 144°C as shown by (Al Hallaj, Et Al, 1999).

The benefit of LiFePo4 is they are publicly perceived as being much safer and less of a fire risk than Li-Ion's. The downside of this is that LiFePo4 batteries are more expensive and less widely available.

FIBRE SUPERCAPACITORS

Fig 16. Zhang, R., Xu, Y., Harrison, D., Fyson, J., Southee, D. and Tanwilaisiri, A. (2015) 'Fabrication and characterization of smart fabric using energy storage fibres',

3.06

FURTHER DISCUSSION

In summary, these experimental fibres allow for energy storage within a wearable fibre.
It stores the charge through two main mediums, Firstly through Electro-static double layer capacitors (EDLCs) which store charge electrostatically. And also through Pseudocapacitors which stores the charge electrochemically which is a faradiaic effect.

Pseudocapacitance contributes about 100x more to the overall charge than the EDLC. (Zhang, R., Xu, Y., Harrison, D., Fyson, J., Southee, D. and Tanwilaisiri, A. , 2015)

However, at the moment research has the total current capacity of these fibres at a maximum of around 1.5-2mA and are only operating at voltages of 0-1v. These, however, would make good storage devices for embedded sensors in a few years time due to their ability to be woven into tight corners.
As this technology develops it is worth noting that at some point in the future this technology employed with a TF multilayer laminate could form a fully flexible fabric with both energy storage and generative capabilities.

LITHIUM CERAMIC BATTERIES

Fig 17. Tindie (2018) 105mAh 3.75V
Ultraflexible LITHIUM-CERAMIC

LCBs are fully able to be cut and pierced and still remain stable and outputting voltage, they also don't suffer from the same low-temperature performance decrease as the other lithiums and are much more chemically and therefore less prone to thermal runaway.

Although like the Supercapacitors they aren't as widely manufactured as the other lithiums so would be a highly expensive option.

SUMMARY OF BATTERY VARIANTS

To conclude there are interesting advances being made with battery technology however nothing that is within the next 5 years of being mass manufactured and of an appropriate price for commercialisation.

For the simple reason of cost and availability, the most suitable chemistry to use is lithium ion batteries. They may suffer from low temperatures performance deficits but to invest in more expensive chemistries to solve this would increase the cost of the product by too much. The LCB and Supercapacitor variants don't currently provide a large enough capacity option to warrant consideration.

Whilst LiFePo4 batteries offer a more stable chemistry and less risk of fire they still don't offer sufficient performance benefit to warrant the increase in price. They should, however, be considered if the public perception of the lithium batteries being fire hazards could too heavily influence sales. There is a small degree of difference in actual safety due to both still being large amounts of energy densely packed into small shells however if the collaborative company deemed it dessert to be shown to be combatting this safety issue LiFePo4 batteries would provide a simple solution to this.

3.07

EXISTING PRODUCT ANALYSIS

Fig 18. Biolite SolarPanel 5+. (2018)

Fig 19. Nomad 7 Plus Solar Panel - 7 Watt Solar Panel. (2018)

BIOLITE SOLAR PANEL 5+

The Biolite features a 5-watt panel with a 2200mAh internal battery. It has a rear metal stand and alignment sundial. It uses a monocrystalline panel. The smaller 5w form factor allows it to be upright on the top of the bag for maximum efficiency.

The main features are software simulated Multi power point tracking technology to help increase the usable energy out as well as the sundial for alignment to the optimum angle.

As discussed earlier the closer the panel is to perpendicular with the sun the more power the panel can generate. The angle has a large effect on the amount of energy produced.

GOAL ZERO NOMAD 7+

The Nomad panel features a 7-watt panel with no internal battery. It uses a monocrystalline panel and outputs to a USB port through a small charge controller in much the same respect as the other systems.

This panel relies on the fact people are already carrying an extra battery bank in order to gather charge whilst hiking or to be directly supplied int the phone when stationary.

Production photos suggest the panel is designed to sit flat on the back of a pack and as such reduces it’s operating efficiency massively.

BRIEF DESCRIPTION OF ANALYSIS

In summary, the panels below all suffer from the same few points. Panels are best suited for a stationary use case. They have each tried to solve this issue to varying effectiveness however the rigid panels are more effective than the thin film panels when bag mounted and used on the trail. The flexibility of the thin film again makes it super portable and virtually indestructible when out exploring.

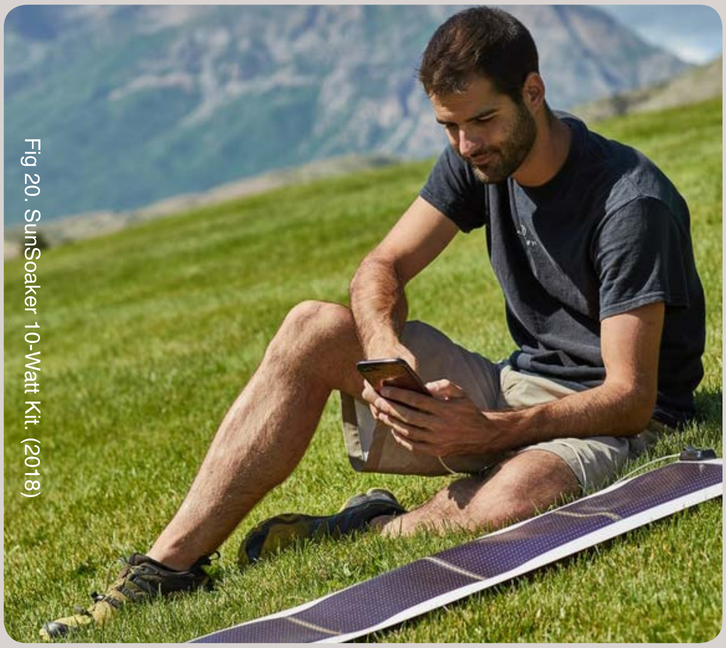


Fig 20. SunSoaker 10-Watt Kit. (2018)

Fig 21. Solar Technology International (2017) Freeloader Sixer.

SUNSOAKER

The sun soaker is a 10w thin film panel. It like the Nomad 7+ has no internal battery however if you see the difference in size between a 7w monocrystalline panel and a 10w thin film you can see the reason for shifting towards rigid panels as the massive efficiency difference allows for a vastly reduced form factor.

It has a standard USB type-A output similar to the rest. However, due to it being a thin film panel it can be rolled up into the smallest surface area and is one of the lightest.

This flexibility is something the designs should hope to emulate.

FREELOADER SIXER

The freeloader panel has the smallest panel at a 3w high-quality monocrystalline one however the small size is due to the fact it's designed to sit on the shoulder strap of the user.

This means the panel is facing closer to the optimum angle for a larger percentage of the time and given it's close to hand it can be easily adjusted.

This is however done at the expense of large battery capacity or panel size and as such is only suitable for shorter length trips or less power hungry trips.

The user interaction from the built-in display is another feature worth emulating.

3.08

SUMMARY OF RESEARCH

A few key points can be drawn from the research stages.

User Interaction
The main user criticisms to focus the design stages on is the unreliability and fragility of current systems and also the lack of integration with the pack to be used whilst walking. Often these devices are designed as completely separate entities with little or no thought of the system they'd be deployed in tandem with. Factors like weight and size should also be considered for the product specifications.

Solar Technology
For the purposes of this project, it is recommended to use either a polycrystalline or monocrystalline rigid panels with an efficiency of at least 18%.

Panel orientation
The panel should be designed to best fit the contours on the roof of the pack as this greatly increases the operating efficiency when used during the active hours of the day.

The fact that the panel may not be directly facing the sun is an inherent downside to the idea of having a solar panel on a moving pack. The only way to mitigate this is to have the panel on the roof of the pack as this provides unobstructed access from all sides bar the front. If the user is walking directly into the sun the efficiency of the bag will drop. But the walking direction in relation to the sun is a mostly random affair so shouldn't have a consistent impact on the power output.

Battery Requirements
In terms of power storage currently, the most feasible solution is to use Li-Ion batteries due to their availability and a vast array of different sizes. It makes the most sense to use some sort of small pouch or coin-shaped cell for the prototype due to the size limitations. The battery needs to support a trip length of on average 4 days or more with enough reserve power an emergency communications device if no sun is available.

The technology in these fields is advancing and the prices are getting lower, with this should come incremental improvements in the functionality and cost-effectiveness of the product.

Fig 22. Imoesi, E. (2019) White Mountain Range

SPECIFICATION

4.01 FULL PDS
4.02 USER REQUESTED FEATURES

4.

4.01

FULL PDS

1 Tecnical Specifications

1.1 The battery capacity should be above 4000mAh to provide 1 full device charge per day with a reserve left over.

1.2 The panel should be between 10-20w.

1.3 The array should be configured in a series and parallel hybrid string to reduce chances of breakages causing the full failure of the product.

2 Materials

2.1 The battery should be a series of lithium Ion cells

2.2 The panels should be made from either polycrystalline or monocrystalline structures, as long as the other technical specifications are met.

2.3 The casing should be made form a shock resistant, non-flammable or UV degradable plastic such as ABS.

2.4 The connections between the panels should be removable by authorised technicians.

3 Weight and Size

3.1 The product should weigh under 3kg including the batteries.

3.2 It should contour appropriately to the top of a north face backpack so as to take up no room inside the pack.

4 Manufacturing

4.1 The casing should be suitable for mass manufacture

4.2 It should be formed from as few components as possible with minimal assembly time taken into account

4.3 The design should allow for a repeating modular nature to ensure the ability to be adapted later down the line to other ranges of the north face backpacks.

5 User Contact Points

5.1 The product must have at least 1 type A USB port output

5.2 The product should have the ability to be expanded with larger battery capacities or daisy-chain panels together.

5.3 The outputs should offer a multitude of integration points in the pack.

5.4 The connection to the pack should be removable but the panel should fit securely without permanent fasteners

5.5 The user must have an LCD readout for charging data and battery level indicator

6 Performance Requirements

6.1 The device should provide a minimum of 1 phone charge per 12 hours.

6.2 It should be durable enough to survive all weather conditions usually found within the UK with a design for much worse.

6.3 All materials should be comfortable performing at temperatures from 0-40°C

6.4 If no sun is visible the panel should still operate as a battery bank

6.5 It should be able to survive light to moderate damage, any direct hits from hard rocks and general rough usage.

6.6 The product should be TSA and other airport security suitable to be used when travelling abroad.

7 Safety Requirements

7.1 The product should adhere to all relevant British standards with regards to the usage of lithium batteries and solar cells. BS EN 61960-4

7.2 The batteries should be self-contained and wired to a BMS to prevent cascade damage

7.3 Electronics should be fully sealed to prevent water ingress and short circuits

7.4 The Control circuitry should ensure no overcharging or undercharging damage

4.02

USER REQUESTED FEATURES

Should fit securely to the top of the bag but still be removable.

It should be able to be used in addition to larger battery banks.

Integration into the hip pockets so it can be used whilst moving.

The highlighted sections here are the main requested features from the research survey stages.

More importantly, they are the features that provided the best opportunity for design elaboration and development whilst still falling within the design problem area.

They are features worth considering during the Design process but not at the expense of the core problem.

As long as these features didn't interfere with the projects aim to create a semi-flexible solar system with the flexibility and usability of a flexible panel whilst maintaining the efficiency and compact nature of a rigid panel.

PROJECT FOCUS

5.

Fig 24. Wurth, K. (2016) It's A New Day, Mountain Sunrise.

5.01

CONCEPT GENERATION

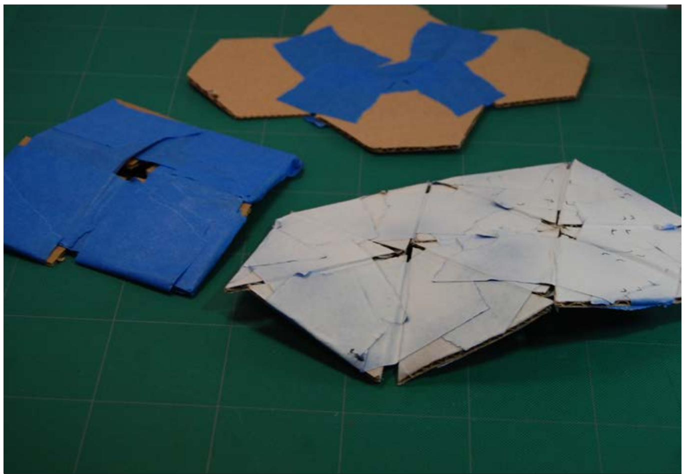


Fig 25. Brister, B (2019) Card Shape Modelling

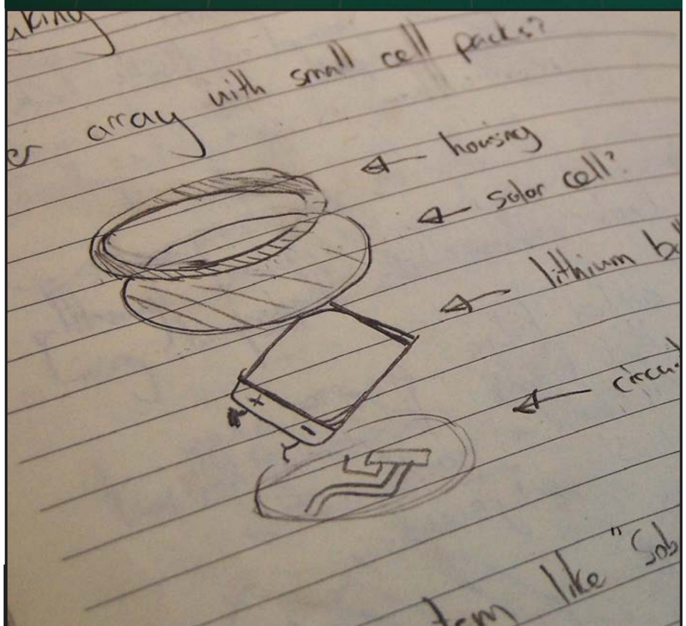


Fig 26. Brister, B (2019) Log book Sketches.

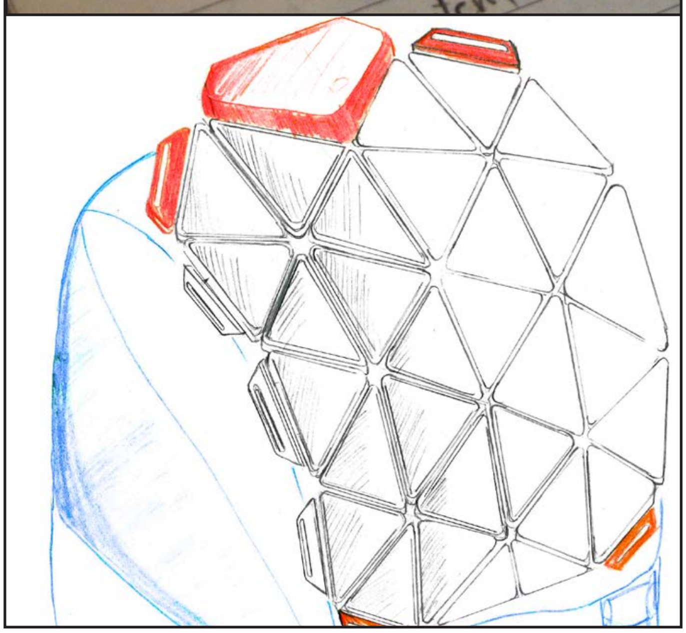


Fig 27. Brister, B (2019) Concept Skeches.

The first few aspects to establish during the development stages were which geometry of the panels allowed for the greatest movement and what dimensions allowed for the smallest difference in the efficiency of an equally sized rigid panel laid on a flat surface.

This would ensure that when contoured to the pack the power output of the articulating array would be higher as more surface area can be utilised.

The initial plan was to use either hexagons or squares as they afford the greatest availability currently in the market however with the number of interconnects between the panels being so high it was found through some simple card modelling Fig 25. that the degrees of flexibility for any shape with the number of sides being a factor of 3 would prevent movement in more than 2 planes.

The dimensions of the geometry were established through simulations explained on the facing page.

The content of each module was simplified down to the bare essentials and once the specifications were laid out the aesthetic design could be completed. Making sure to include the user interaction points discovered in the research and keeping the style in keeping with The North Face's aesthetic.

Another important factor was to have The North Face Logo front and centre so it is easily visible when in use.

5.02
SIMULATIONS

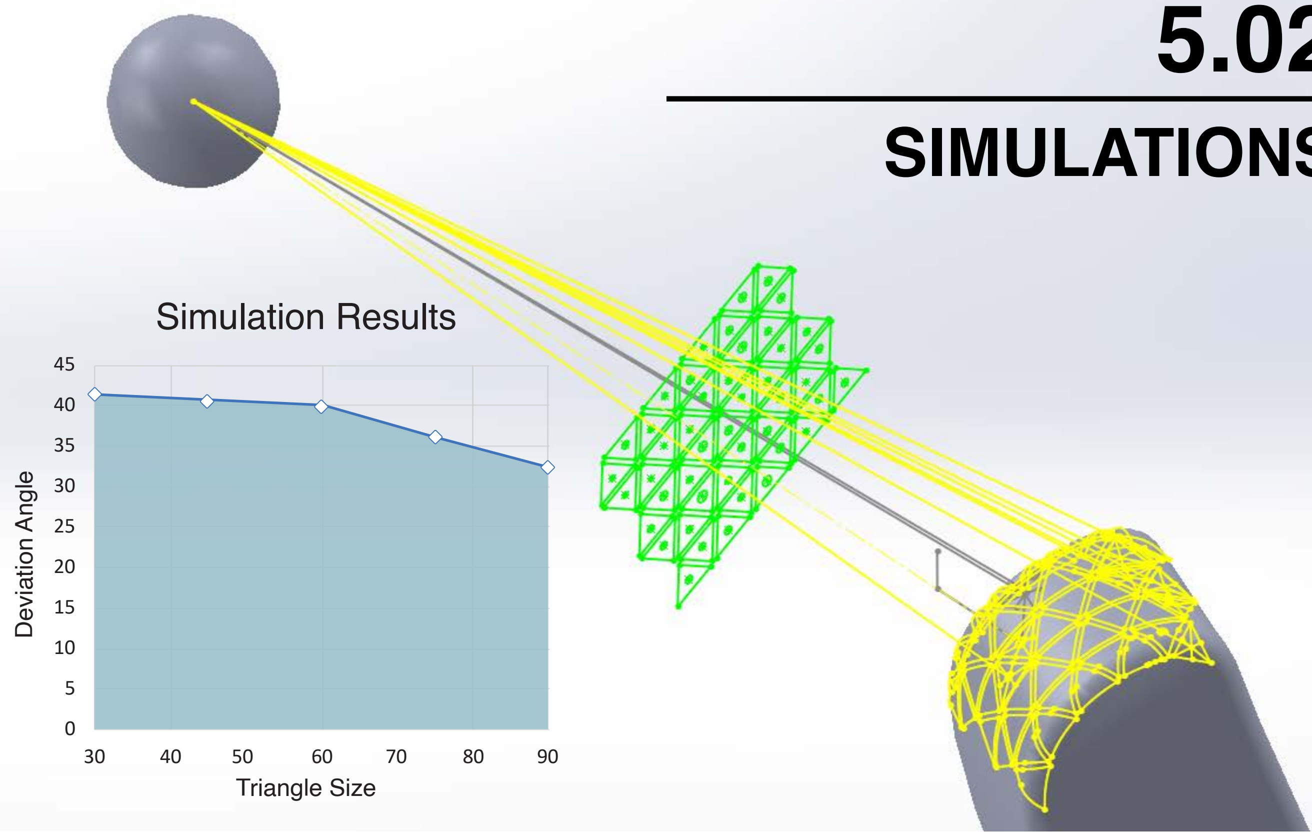


Fig 28. Brister, B (2019) Simulation Screenshot.

Once the geometry for the modules was defined the next part was to scientifically determine the most efficient shape.

In order to do this a series of simulations was ran using SolidWorks and it's plane measuring tool. The purpose of this was to lay a virtual model of the solar array with varying sized triangles and calculate the standard deviation from the optimum plane. The closer the average plane value is to the optimum angle the higher the overall efficiency of the panels.

Each triangle size was measured at both facing the sun and facing away from the sun positions in order to give a fair average between the two extremes.

The graph in Fig 28 shows the relationship between triangle size and module efficiency. The results from these simulations show the larger you make the triangle the lower the deviation from the optimum angle but the less flexible it becomes. The size of the final prototype was decided at ~75mm as it was the largest size the panels could be whilst maintaining the flexibility to cover the contours of the pack.
The graph shows the deviation angles tending towards 30 Degrees as the triangle dimensions increase. The degree of flexibility was decided through trial and error on the sample backpack (Terra 65) to best contour to the lid of the pack however if the design is required to fit particularly sharp corners with a high resolution then smaller panels would be recommended.

Another factor at play is the overall module efficiency. The cell efficiency is defined by the chemical makeup of the cells. However solar modules are usually made up of several cells placed on a sheet. The gaps in between. In order to calculate the overall module efficiency, you divide the module efficiency by the ratio of active to inactive areas. By making the triangles smaller you make the percentage of the inactive area higher as the borders on the module designs would be at their smallest before changing triangle size.

In all the 75mm sizing and 1mm thin border thickness best ensures the compromise of flexibility and efficiency.

5.03

HINGE PROTOTYPING

As a solution to the issues of fragility and wires work hardening that was found in the survey and research stages, the proposed solution was to design an electrically conductive mechanical hinge.

Within this mechanical hinge, there should be sufficient contact so that no power drops during movement and strong enough to survive the environments described in the specification.

It also had to be waterproof with as few separate parts as possible to help reduce assembly times.

This component is the part the entire project hinges around. The hinge sections had to provide a wireless reliable connection between each module.

The initial design as shown as Fig 30 used copper rods to conduct across a central conductive shaft. This, however, meant the edge faces of the shaft were only tangentially in contact with the other faces so reliable conduction wasn't possible.

The ball joint design whilst offering superior flexibility and articulation couldn't be reliably waterproofed. It also only provided an option for one connection per face whereas in order to wire both the battery and the solar panels up properly A minimum of 2 lines per series string was needed. More if the design wanted more advanced geometry on the lid of the pack.

The design shown Fig 29 using two adjacent plates with slightly raised profiles showed the best reliable connection between hinge legs.

The idea of having the two parts snap together like printed there later proved to be too weak to hold the pads close enough together for a reliable connection.

Fig 29. Brister, B (2019) Hinge Photos & Sketches.

The hinge design shown in Fig 30(11) proved the most reliable. It also allowed room for expansion up to 6 or 7 pinned connections whilst operating at the desired degree of flexibility.

As shown in Fig 30(12) a full-sized printed model was built to demonstrate and test the degree of flexibility it had and to test for any mechanical weak spots or areas in need of aesthetic alteration.

After several iterations of the final hinge design as shown in Fig 30 the final 6 wide block type design was chosen. The spacing and dimensions were altered repeatedly to get them as thin as possible without compromising on strength.

The final joint design was tested for reliability wiring up the system to a battery and LED to check for flickering.

The design shown in Fig 30 (8) was the final iteration before construction. It added a slightly raised bump the inside connector to push the two conducting plates together.

For the purposes of the prototype, the connecting plates are being substituted with modified ring connectors however this design is recommended for the final product with a small amount of modification. Such as the termination crimp being oversized for this purpose.

As a result, any final product thickness could be made even thinner.

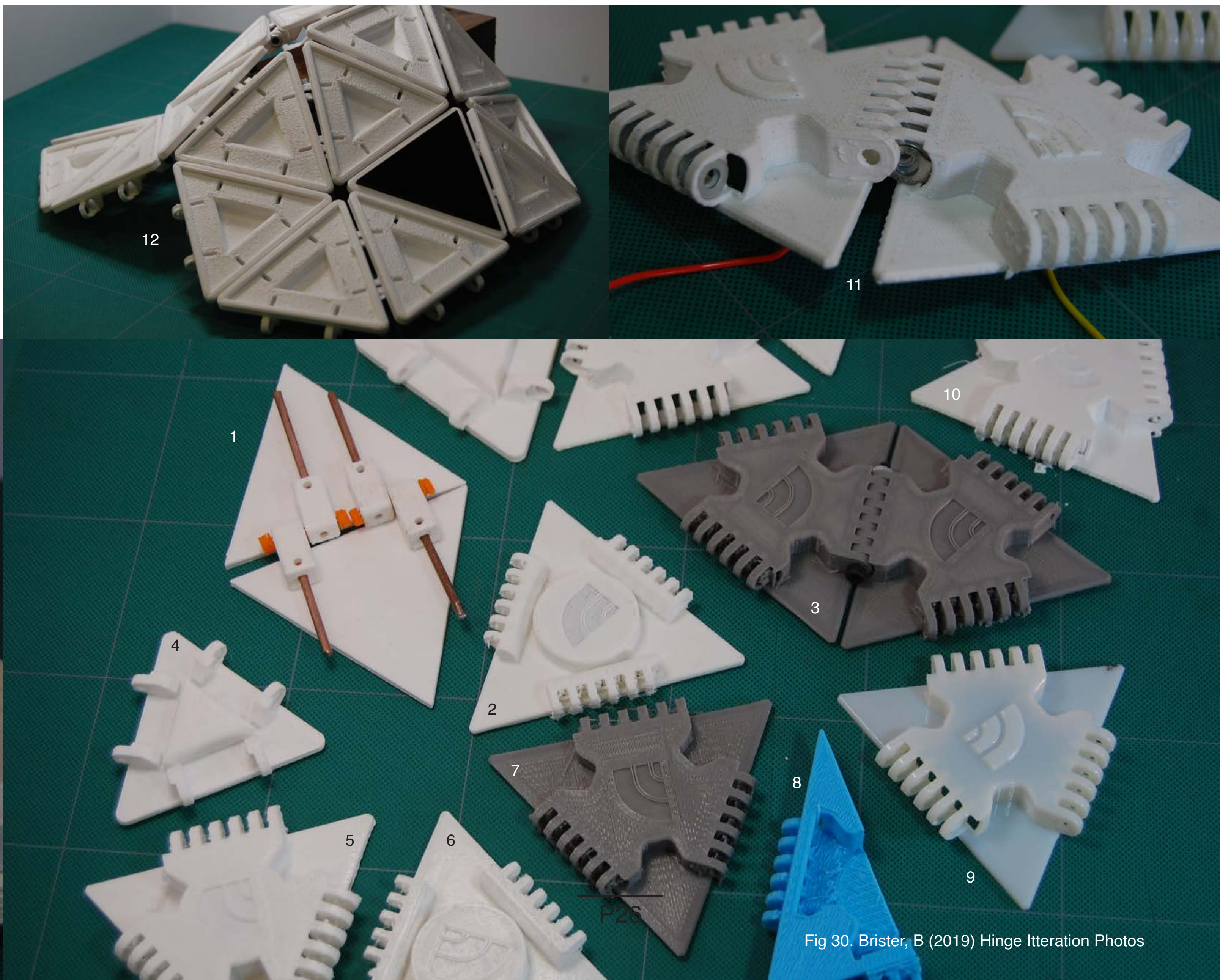


Fig 30. Brister, B (2019) Hinge Itteration Photos

5.04

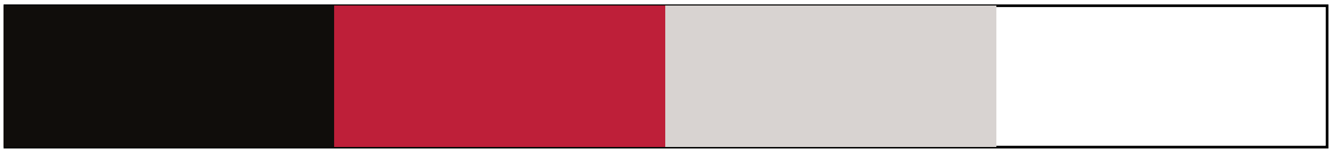
DESIGN CONSIDERATIONS

The design approach for the prototype differs from the final product in a few key areas. The sizings of the prototype are governed by the component dimensions unlike that of the final product. In this case, the largest solar panels available were approximately 75mm long and the size of the connectors meant the base had to be a minimum of 8mm thick on the inside.

The final product won't have these limitations and as such the final prototype should be viewed as a proof of concept rather than the definitive guide on sizings and dimensions for the final mass produced product.

The hinge design stage produced a triangular section with 6 possible pin layouts, this enables future expansion to the product or possible backpacks.

The design for this particular prototype should include attaching points to integrate with the Terra 65 backpack and should also follow the same colour scheme as shown below.



Another consideration to make is that the user may want to remove the bag from the roof of the pack. It should, therefore, be worked into the design some form of port or plug that can allow the panel to detach fully from the hood when not needed.

Permanent integration into the bag would limit the trips the bag could be taken on and as such should be avoided however the wiring and electronic infrastructure should be permanently woven into the bag to make it less likely to come loose or get damaged when used.

Whilst the design should be removable it should function at it's best when incorporated within the bag. For example, the custom charging leads woven into the hip pockets would be a TNF only feature.

FINAL DESIGN

6.

Fig 31. Dumlao, N. (2017) Sun sets over cloud-shrouded peaks.

6.01

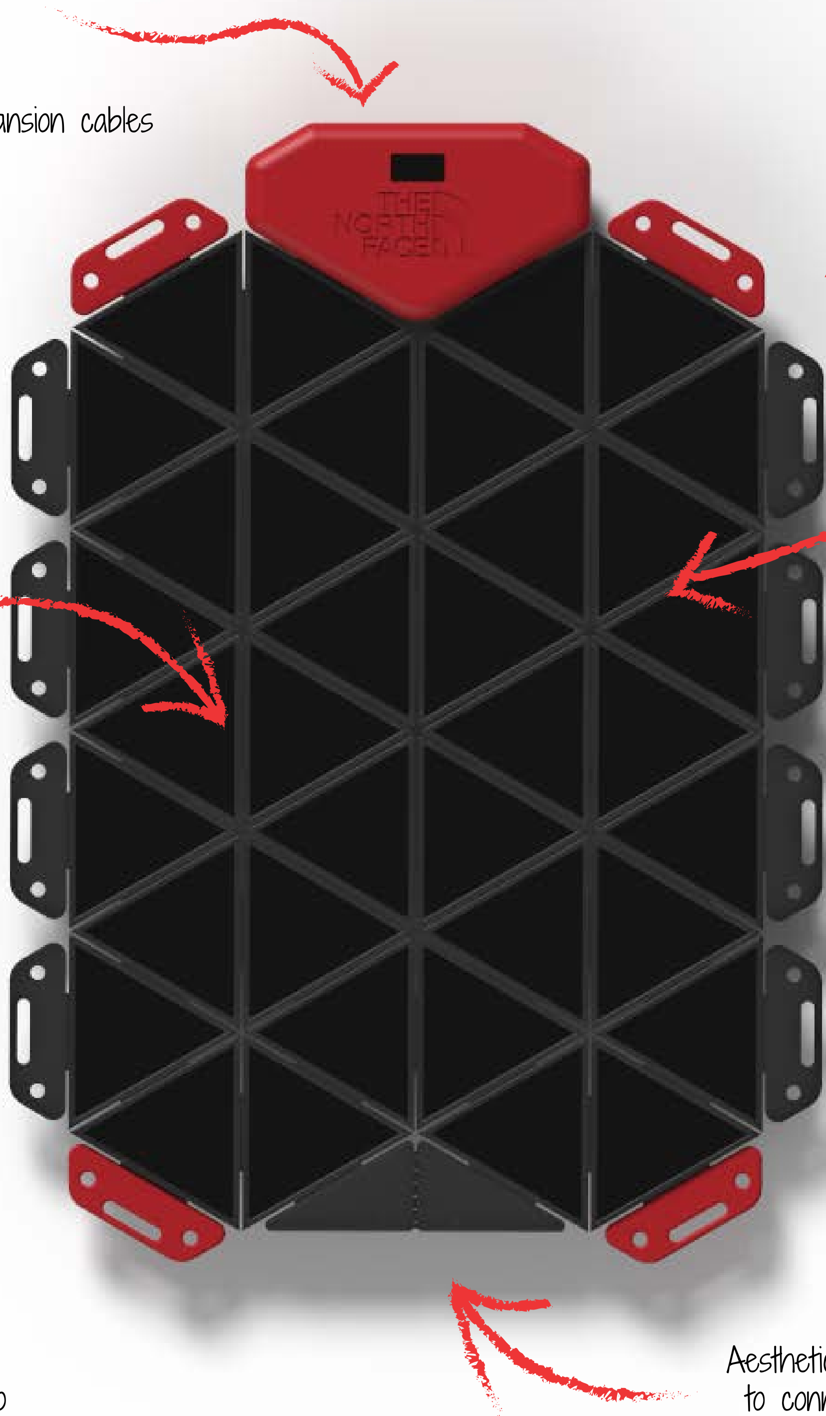
FINAL DESIGN

Below is the final design for the prototype. The number of pins at each hinge has been increased from 2 to 6 to enable more complex layouts pm different backpacks in the north face line. There will be some differences between the prototype produced for this project and this recommended final design, predominantly in regards to the thicknesses and tolerances which all had to be increased for the purposes of the build.

Electronics Control Box, BMS + charge controller

1x USB type A out
1x USB micro In
2x Power out bag expansion cables
1x LCD screen
1x Power button

4000mAh
Lithium
Battery



220mA high
efficiency solar
panel

Fasteners and lashing
points for connecting to
the pack.

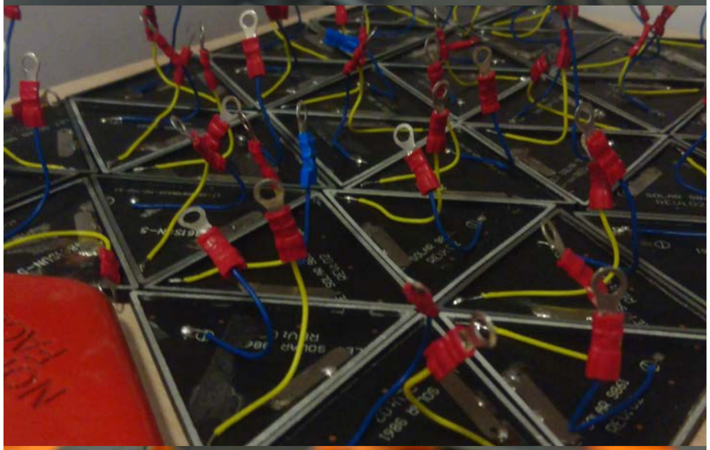
Aesthetic end caps used
to connect both strings
together.

6.02

THE FINAL BUILD

The final build featured a total of 129 components. This was due to the repeating nature of the design so most things were built 36 times. The control box was taken from an existing solar system as were the panels. The triangular sections were printed on a Stratasys F370 which provided a functional part albeit with a slightly lower surface finish than would be desired.

The parts were all sanded down and sprayed to match the proposed colour scheme. The FDM parts required a lot more finishing however due to the complex geometry it didn't come out as polished as originally intended. However, all finishes are appropriate for a final prototype.



The 36 solar cells had to be required to function with their new shapes and then soldered to the terminal legs.

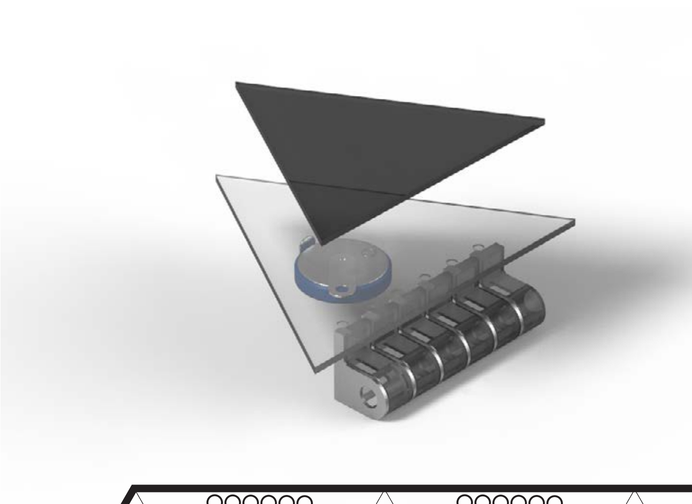
Each panel was wired individually with a positive and negative output terminal. The terminals were then placed into

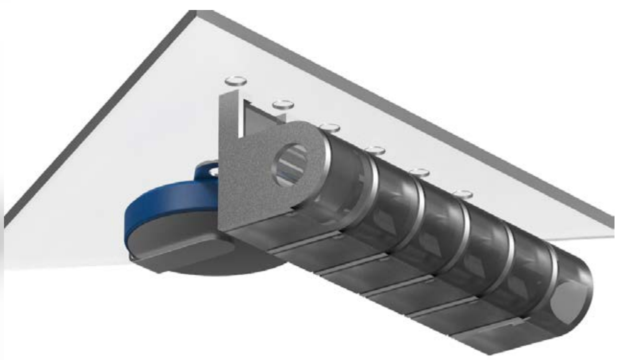
their hinge legs with an m3 washer to act as a conductive spacer keeping the tension between the two hinge halves. This was then all bolted with nylon (self-lubricating) threaded rod and a pair of dome capped nuts. These were then all tested thoroughly and sealed shut for waterproofing.

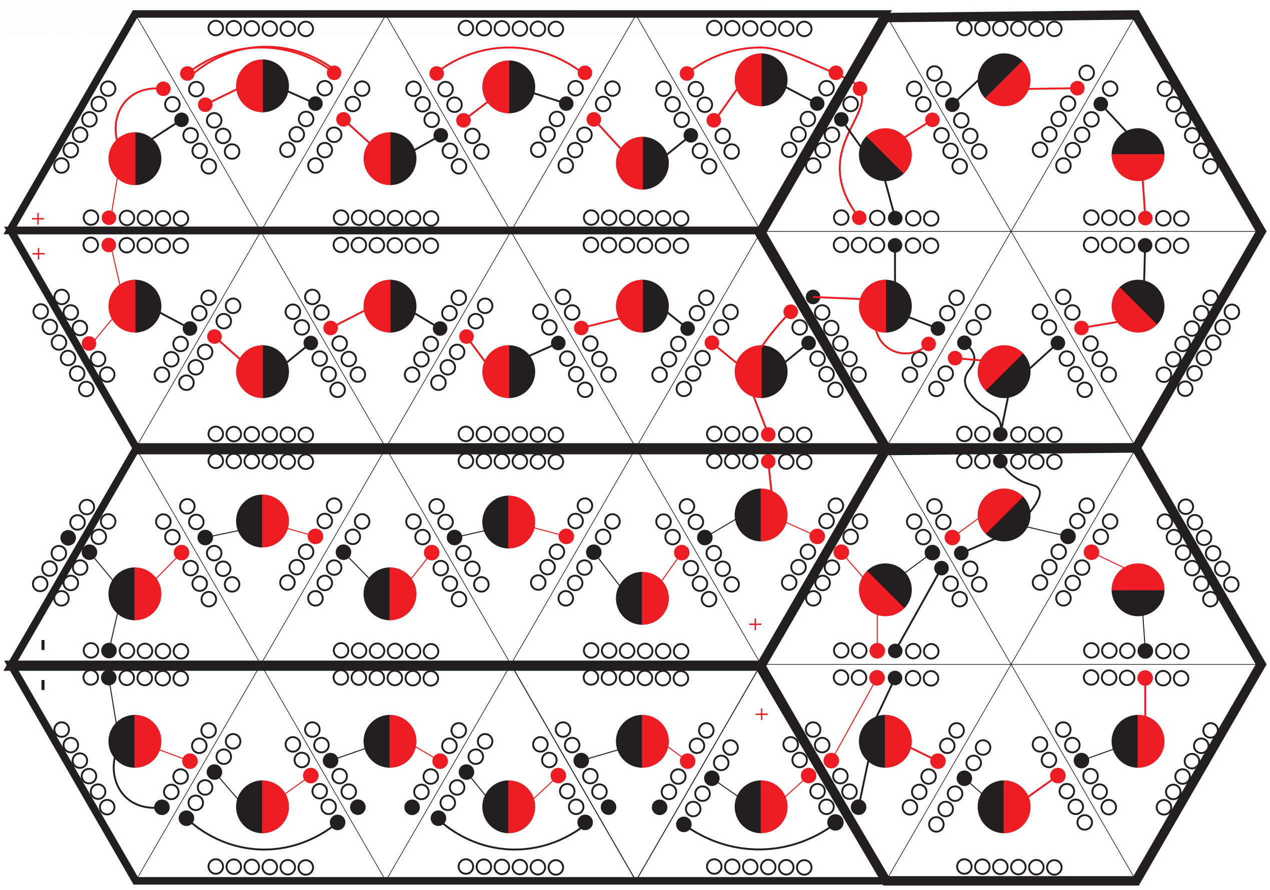
6.03

WIRING DIAGRAM

The modules were designed with customisation in mind. The reason for having 6 possible channels per face of the triangles is so that any possible layout of panels could be wired in. Each solar cell needs a + in and - out, Then each battery needs a + and - line. Then any rewiring lines need a channel to be routed through. This could all be accomplished with a custom PCB on the reverse of the panels to help minimise the wasted space inside the modules. Below is the wiring diagram for the prototype showing the channel layout for 6x6 parallel series strings. Without the wiring lines for the batteries as these had to be relocated to the control box as described in the following section. The renders below shows the possible arrangement of a custom PCB and terminal block to replace the wiring nests.



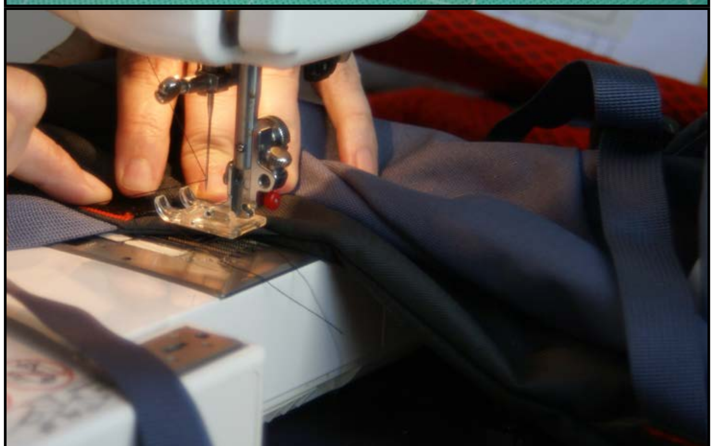




6.04

BAG INTEGRATION

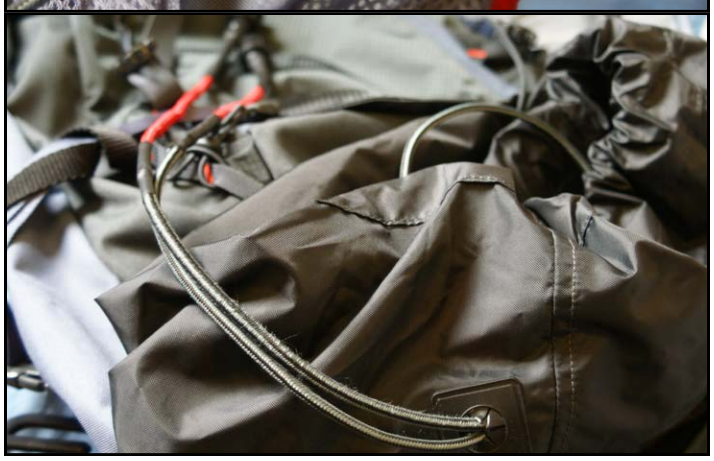
The way the back is secured to the pack is through traditional webbing and attaching buckles. This allows for quick and easy removal and installation onto the pack when needed. The webbing is 18mm Nylon and all the wiring is braided and built using waterproofed connectors and ports.



The webbing and buckles were stitched onto places on the pack where it could be easily accessed.

The stitching was all backstitched to prevent unthreading.

In order to waterproof the output ports a rubber grommet was used at all entrance and exit points, Whilst this isn't fully waterproof it would provide an appropriate level of protection from water ingress. During large downpours, a rain cover would be used anyway.



The bag has 2 cables integrated into it. One going down to the hip strap to allow for charging on the go and the other is a USB type A female which allows for battery bank expansion if needed for power users or professionals.

6.05

PROTOTYPE VS DESIGN

There are some key differences between the decisions made in order to produce a working prototype in the budget and timeframe of a major project.

Primarily the route of these is the cost. Components had to be sourced and edited to fit and as such won’t perform to the same level as those specifically built for the product.

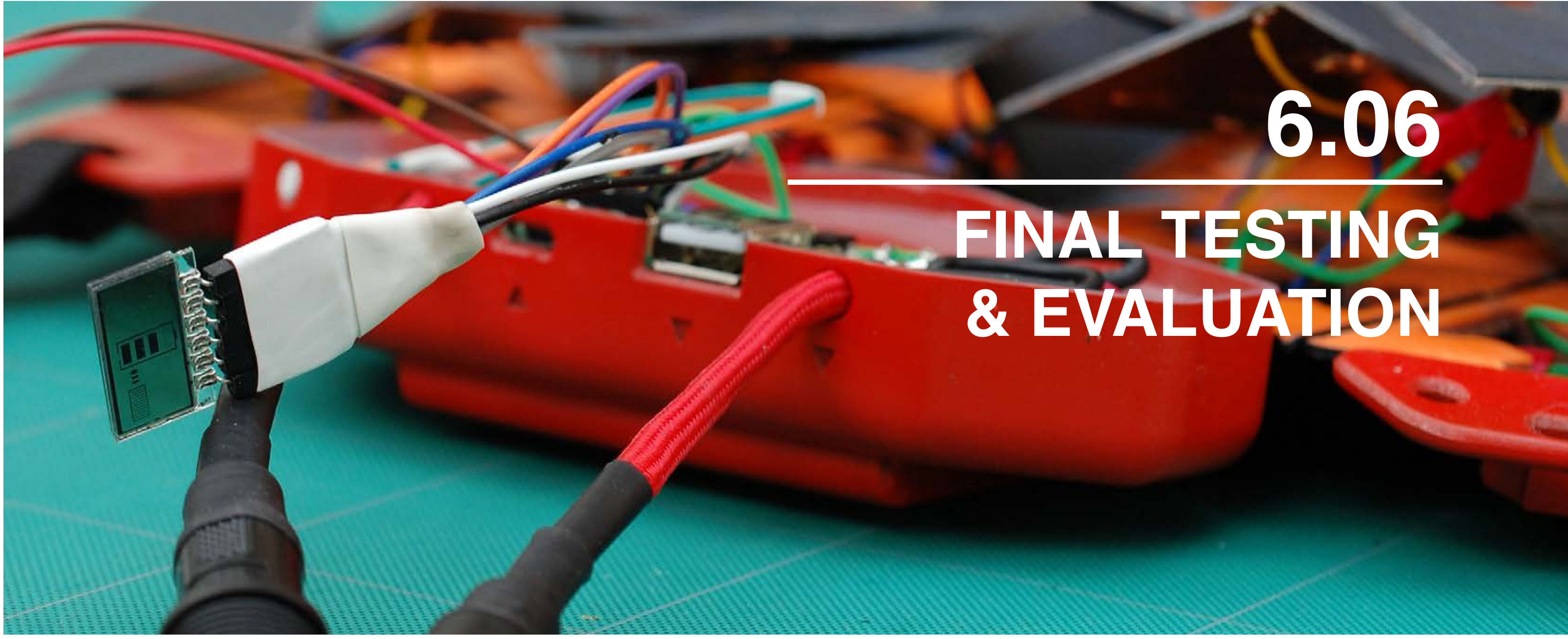
The solar panels, for example, are cut down from existing monocrystalline panels scavenged from dead solar chargers kindly donated by Solar Technology International. Whilst these are the same type of high-quality monocrystalline panel the author recommends for the final product the PCB traces on the back had to be rewired to match the new cut down the profile. This also means there is more wasted space on the modules as the alignment of the crystalline panels are not designed for the prototype. Fortunately, the wasted space is less than 10% however the final product would greatly benefit from total usage of the triangular space.

Another area is the thickness, due to the prototype using existing ring terminals to emulate the plate connectors the thickness of them was limited by the outside diameter of terminals. By custom building the connectors it would be possible to reduce the overall thickness by up to 15/20%.

The interface and battery management systems are also a generic off the shelf model rather than one custom tailored to the panels and batteries, whilst this won’t affect matters much as no features were compromised on when selecting the PCB it could have incorporated more custom features like software emulated MPPT for the final design.

Another area where the prototype had to be edited away from the original design was in the placement of the batteries. In the case of the real product, the batteries were designed to fit within the modules themselves as shown in the wiring diagram. However due to availability and sizing issues with the batteries they were moved to inside the control box. This means a slightly reduced overall capacity for the prototype to the real product however it still functions exactly as expected. For the prototype 2x 18650 3.7V 2000mAh cells were used giving a total capacity of 4000mAh which is less than the designed total storage capacity of (40x120mAh LIR2450) 4320mAh but not by much however this should be noted when reviewing the evaluation stages.

Another aspect that would be different on the final product would be custom built cells rather than cutting larger panels to fit and rewriting them. This would mean a much higher module efficiency as explained in the sections to follow.



6.06

FINAL TESTING & EVALUATION

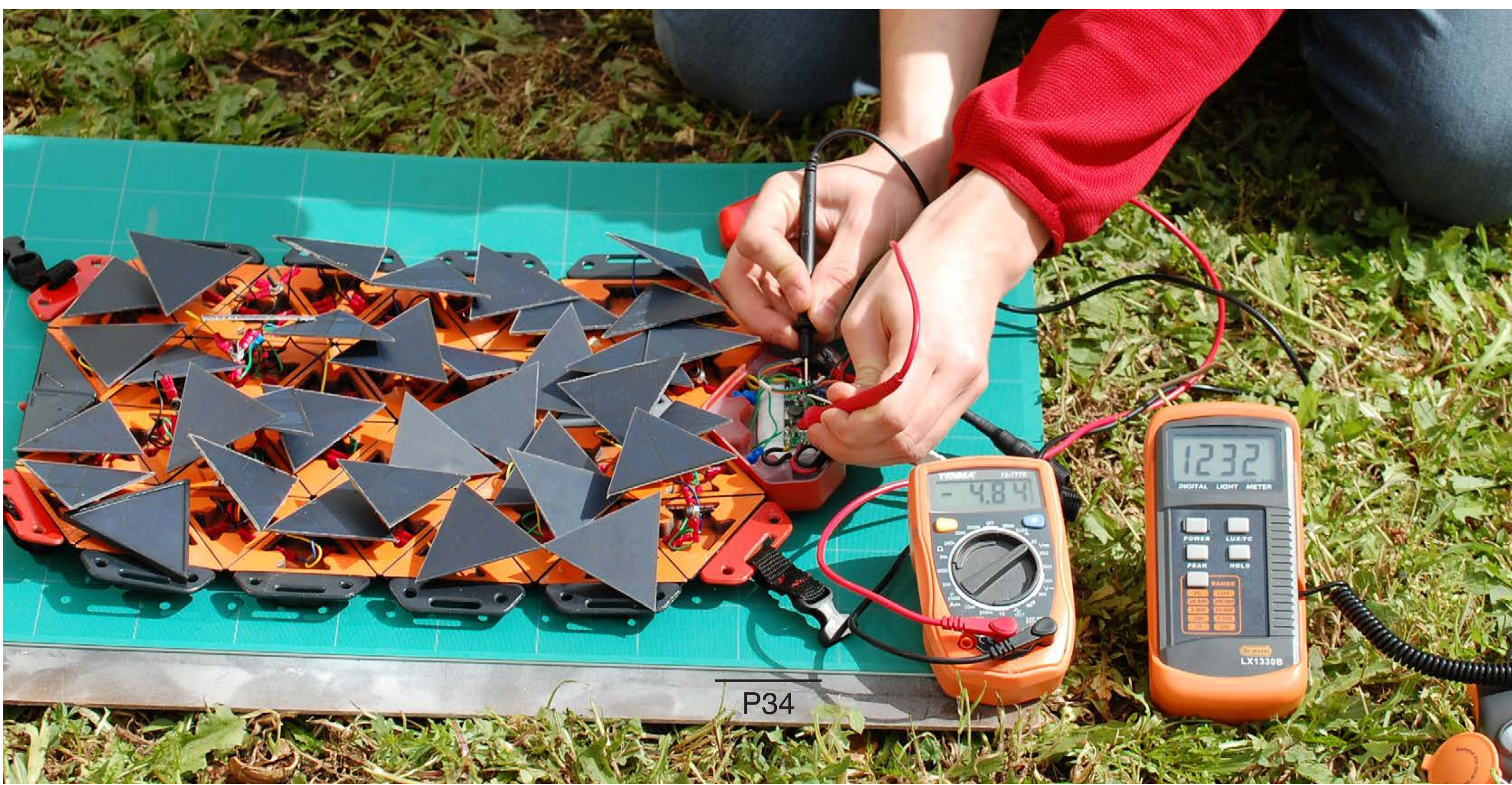
For the final testing, the bag was left fully discharged and then timed how long it took to fully charge in overcast sunlight with a starting luminosity of 123,200 lux. The voltage provided by the panels was around 5V consistently, increasing to around 6V when placed in direct sunlight.

Unfortunately for the testing phase, no opportunity was available to test the functionality of the system on a long distance hike or trail due to time constraints.

From fully depleted the pack took 9h 23mins to fully charge with inconsistent bright spells, well under the expected time for similar sized TF panels and in line with other rigid panels.

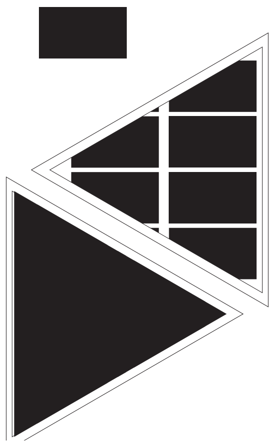
From this we can work out the time taken to fully charge a phone would be 6 h 45 mins and as such falls well within the average time people would be active hiking for. From these previously established specifications, the author can mark this proof of concept project as a success.

During some brief shock, bend and drop testing the product showed no sign of damage although sustaining minor scratches which were then touched up for the final presentation. Although this wasn't carried out with any scientific rigour so should be taken as anecdotal evidence only.



6.07

MODULE VS CELL EFFICIENCY



= 21%
Cell Efficiency

= 15.25%
Module Efficiency

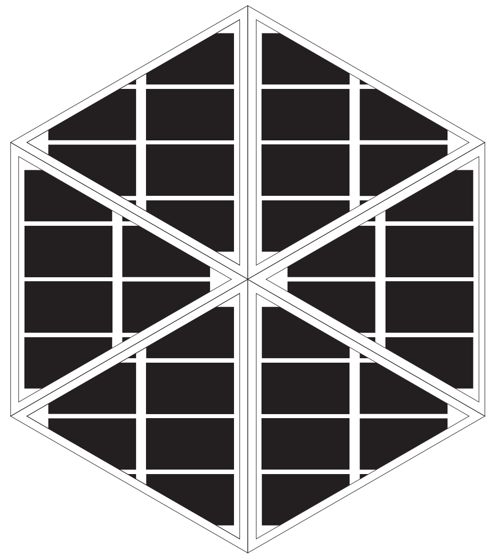
= 18.46%
Module Efficiency

Area 2/Area 1 x 100
= Percentage active

Cell efficiency x
Percentage Active
= Module efficiency

Prototype Active Area
= $4176mm^2$

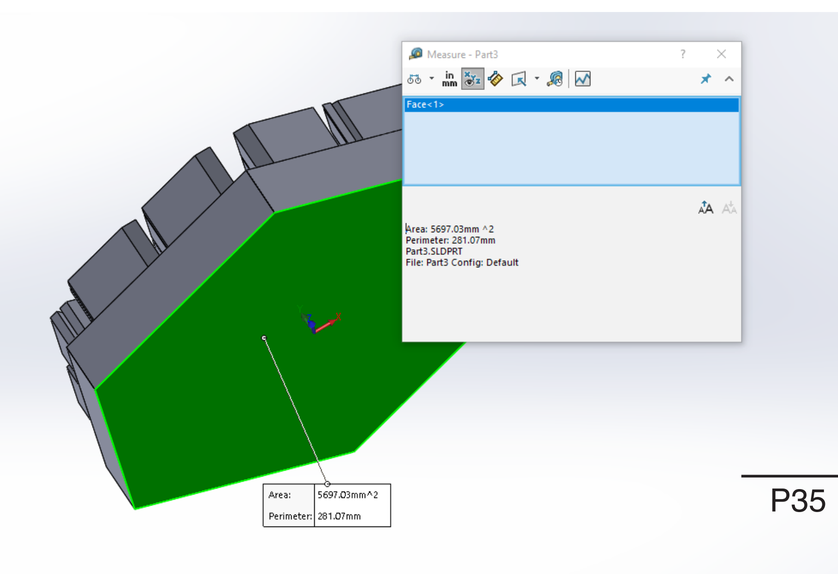
Final Product Active Area
= $5009mm^2$



A trick that a lot of manufacturers use when advertising solar panels is by quoting the cell efficiency rather than the overall module efficiency. The Module Efficiency takes into account the total surface area of the product not just the active areas with solar panels. For the project a target of no less than 75%active areas. In order to minimise the areas affected by this the bezels of the product were made as thin as possible.

An unavoidable area of wasted space is the blank areas on the cells themselves. Each cell triangle is made up of lots of rectangular cells cut down to size. This means there is a large amount of wasted space in the gaps between each rectangle. One advantage of mass manufacturing this product would be the ability to create custom panels with prebuilt PCB traces on the reverse. This would eliminate a large efficiency drop the prototype has to suffer through.

The final sizing of the shape yielded an 87% surface coverage of the modules meaning that each assembled triangle has an efficiency of 18.46% for the final product.



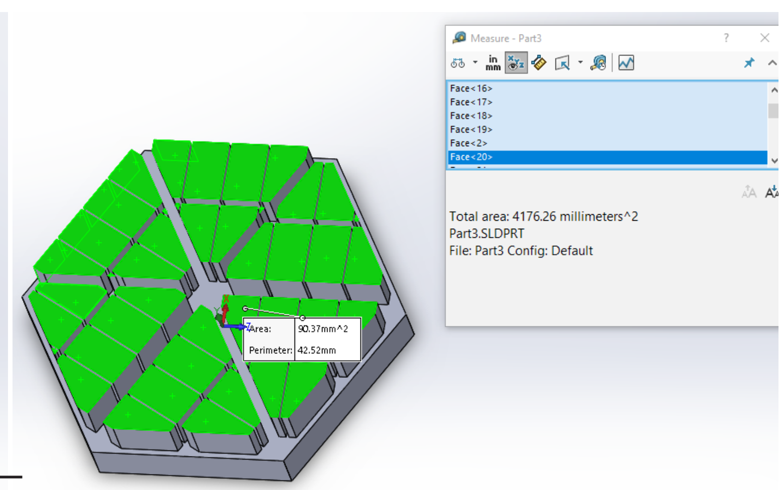


Fig 32. Brister, B (2019) Area calculation Screenshots

6.08

MANUFACTURING CONSIDERATIONS

In regards to the manufacturability of the device, I reached out to Protomould to receive quotes for batch production of 5000 units. The full quotes could be found in Appendix C however they charged £1.05 per base section. It does, however, have large amounts of undercutting geometry so for the purposes of injection moulding further modification would be required in order to get the product ready for mass production. When designing for the injection moulded variant the base triangular sections would need a draft angle adding.

If the final manufacturing process was additive manufacturing however it would be perfectly suited to this geometry, a quote from Protolabs put that at £25 per unit which wouldn't be the case for large quantity manufacturing however it must be worth noting that the scale of manufacture would inform the method better than this study can.

If for example it is being produced in large quantities it would be recommended to pursue the injection moulding route however if the purpose of the product was a limit run for specialists then additive manufacturing would produce equally functional parts and with a significantly reduced set up cost.

Another key aspect to consider is the assembly time. The complexity has been greatly minimised already to help reduce assembly time but the biggest factor currently is the wiring. The suggested design for the final product uses a custom PCB and connector blocks which slot into place so all the rewiring is done at the PCB level. This also allows direct soldering of the battery to the panel and PCB. This, in turn, reduces the space needed internally allowing for a thinner design.

As you can see from Fig 33. the injection moulding analysis reveals areas of concern. As expected the internal regions of the hinge teeth would need a complicated multipart mould in order to get the geometry. It could prove more appropriate to mould those parts separately and use ultrasonic welding to mount the teethed sections to the main body.

In terms of final assembly, all the internals should be sealed and coated in a water-resistant silicone and permanently glued closed to help prevent water ingress.

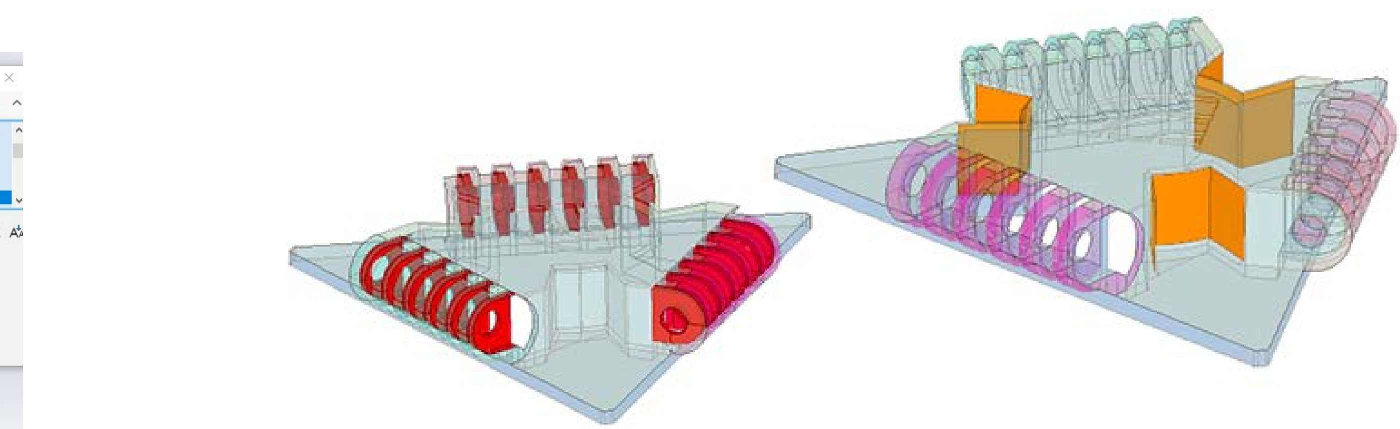
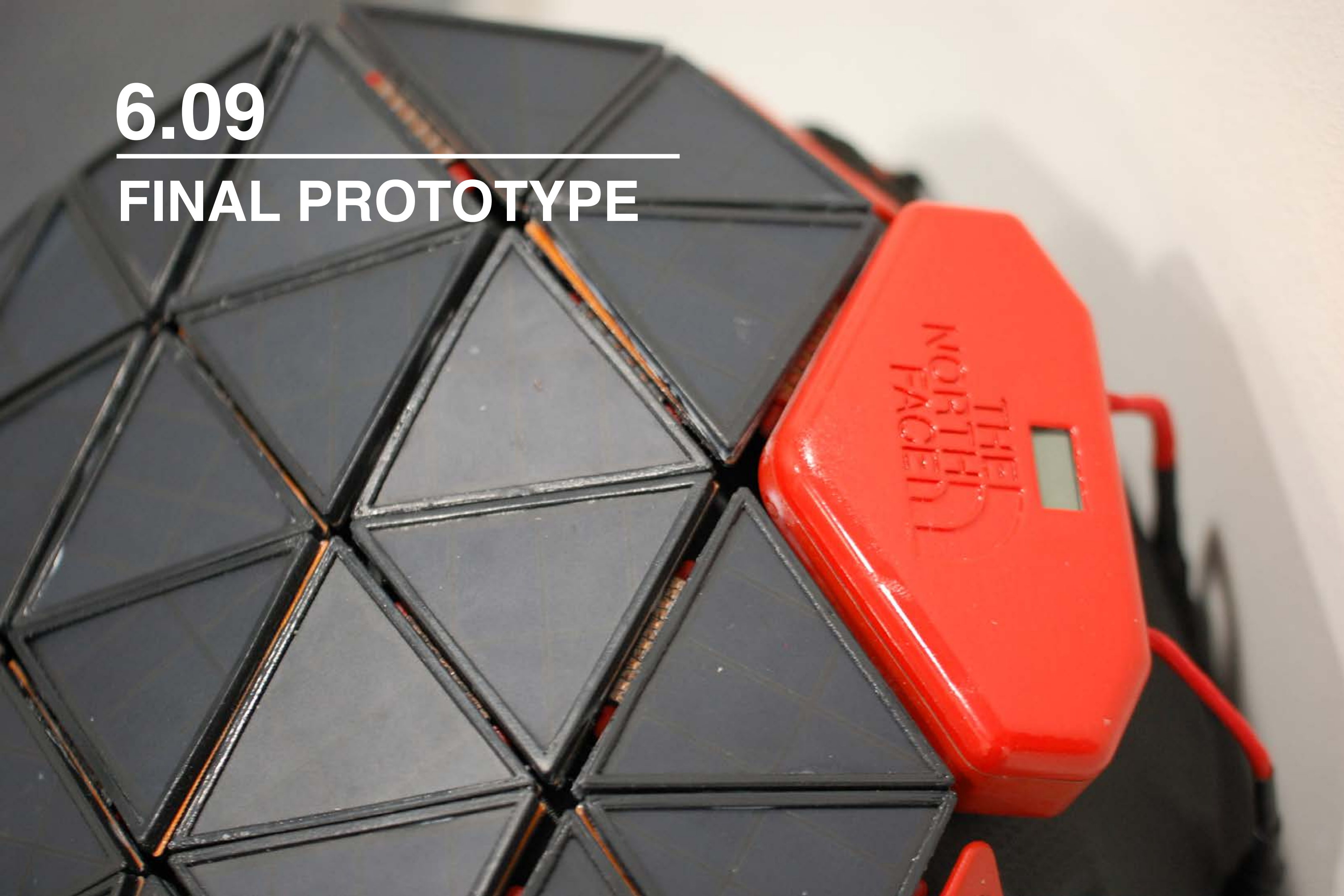


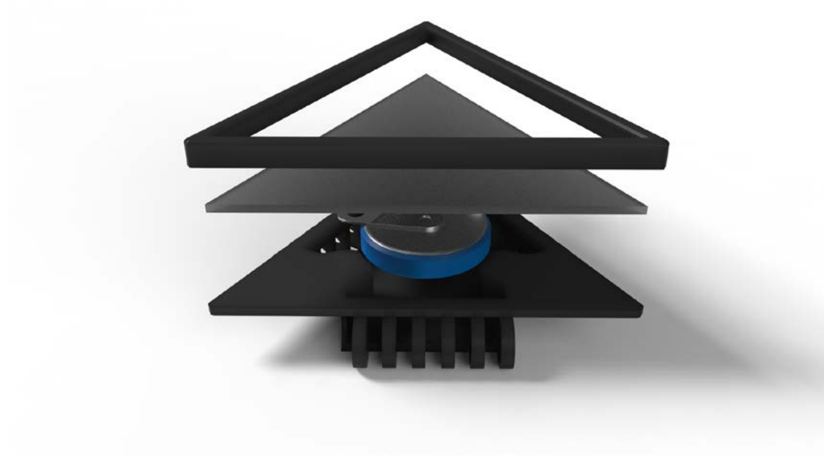
Fig 33. Protomould (2019) Moulding Evaluation Analysis.

6.09
FINAL PROTOTYPE



6.10

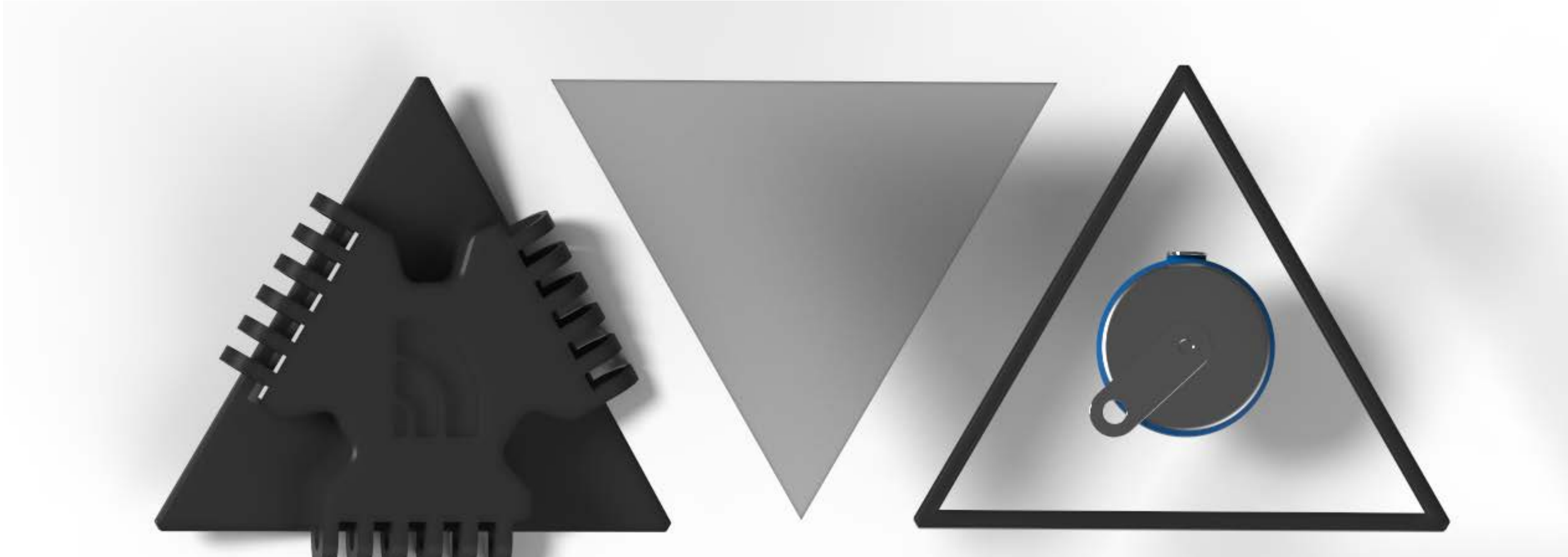
DESIGN EVALUATION



The final design was reduced into as few components as possible. The main system comprises of 4 components. The Solar Panel/PCB, The Panel Cap, The Base Section and the battery. This is done in order to reduce the overall assembly time and reduce the number of components. The main issue with the design will be in the complicated nature of assembling that many modules.

The purpose of this prototype is to fully investigate areas for improvement in this area. The main way to reduce the complexity and assembly time would be the introduction of a PCB to wire up the solar panels and the batteries to the proposed connector blocks. This way no internal space is wasted on wiring and it becomes significantly quicker to assemble in the factory. It also removes one of the highlighted points of breakage which is the solder joints. Traditionally parts fail where the solder meets the main PCB if there is movement on the parts consistently.

Along with a more critical viewpoint whilst the project has been a success the level of cost involved in this design would require a large scale of production to be reasonable. The panels would need to be manufactured specifically for the product again raising prices. However, if produced in large enough quantities the overall cost would fall into line with the higher end solar equipment on the market.



6.11

CONCLUSION

Overall this project has successfully bridged the gap between low efficiency, highly flexible, thin film amorphous panels and the high efficiency, inflexible, Polycrystalline/Monocrystalline Panels.

The final artefact demonstrates the principles behind an articulating solar array and acts as a proof of concept for the design. The hinge mechanism provides a conductive joint with little to no loss of signal when articulating.

The integration with the pack shows how it could be added to an existing line of the pack and how easily it would lend itself to being installed in a new line of packs.

The author proposes it may be more appropriate for VFC and The North Face to explore this design further as part of a joint venture with a solar company in a similar respect to their Surge II Charged Backpack designed in collaboration with Joey Energy.

The user experience with a well-integrated system differs hugely from the standard underpowered, poorly attached solar system. By adding internal cable management the system prevents anything getting tangled or caught and also provides the user with the ability to use their panel whilst moving. A feature seldom presents in stand-alone panels. Unlike most panels on the market, the SunUp Articulating panel is designed specifically with a moving user scenario.

The SunUp project has provided a fantastic opportunity to gain a more in-depth understanding of how a project would be managed in the industry rather than just going through the motions of a traditional major project.

To conclude I would deem the project a success with plenty of room for further development. The main area being a terminal block to interface between the PCB and the hinge mechanism, It would greatly reduce assembly times in comparison to the wire and ring connector approach used in the prototype.

The panel contours to the shape of any backpack and will be able to provide power to a plethora of devices when out on the trail. Providing a tether to civilisation and safety, enabling the user to never stop exploring.

7.01

FIGURES

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7.02

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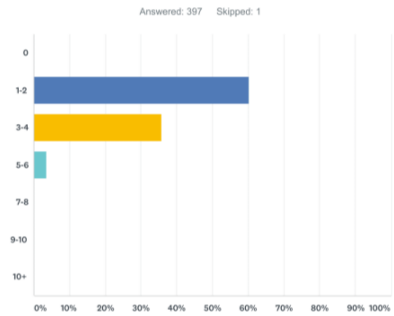
7.0A

APPENDIX A

APPENDIX A

A.1 Key Survey data

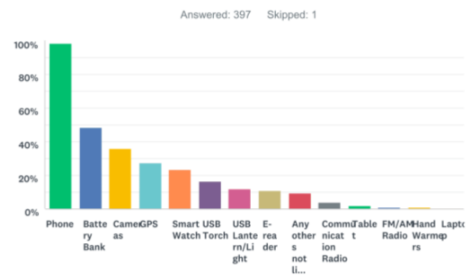
Q1) When you go hiking how many electronic devices do you take with you? (E.g Phones, Tablet, GPS, Smartwatch, USB Rechargeable Lanterns)



ANSWER CHOICES	RESPONSES	
0	0.25%	1
1-2	60.20%	239
3-4	35.77%	142
5-6	3.53%	14
7-8	0.00%	0
9-10	0.25%	1
10+	0.00%	0
TOTAL		397

Figure 11. Survey Monkey Q1 Chart

Q2) What sort of devices do you usually take?



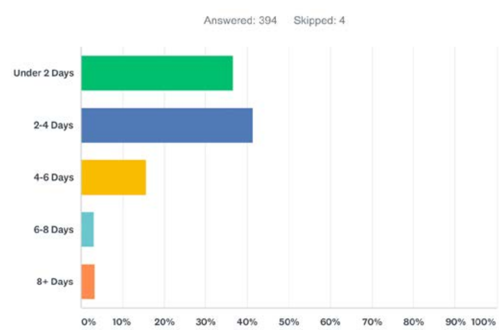
ANSWER CHOICES	RESPONSES	
Phone	98.49%	391
Battery Bank	48.36%	192
Cameras	35.77%	142
GPS	27.46%	109
SmartWatch	23.68%	94
USB Torch	16.62%	66
USB Lantern/Light	11.84%	47
E-reader	10.83%	43
Any others not listed above...	9.57%	38
Communication Radio	4.03%	16
Tablet	1.76%	7
FM/AM Radio	0.76%	3
Hand Warmers	0.76%	3
Laptop	0.50%	2
Total Respondents: 397		

Figure 12. Survey Monkey Q2 Chart

Q3) Predominantly what sort of environments would you be hiking in and still take your electronics/chargers? (Scottish Highlands, Hillside trails, long distance treks, Etc...) Please give as much detail as possible.

Figure 13. Survey Monkey Q3 Wordmap

Q4) On average how many days would you be away from a charging port when out on a hike?

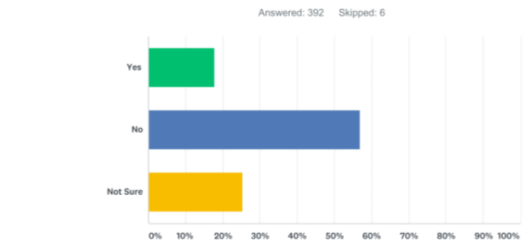


ANSWER CHOICES	RESPONSES	
Under 2 Days	36.55%	144
2-4 Days	41.37%	163
4-6 Days	15.74%	62
6-8 Days	3.05%	12
8+ Days	3.30%	13
TOTAL		394

Figure 14. Survey Monkey Q4 Chart

7

Q5) Would you stay out longer if you didn't have to be near a charging port so frequently?



ANSWER CHOICES	RESPONSES	
Yes	17.86%	70
No	56.89%	223
Not Sure	25.26%	99
TOTAL		392

Figure 15. Survey Monkey Q5 Chart

Q7) What are the main issues with current charging solutions? Please go into as much detail as possible (Weight, Inconvenience, Price, Charging Capacity, Durability, Etc...)

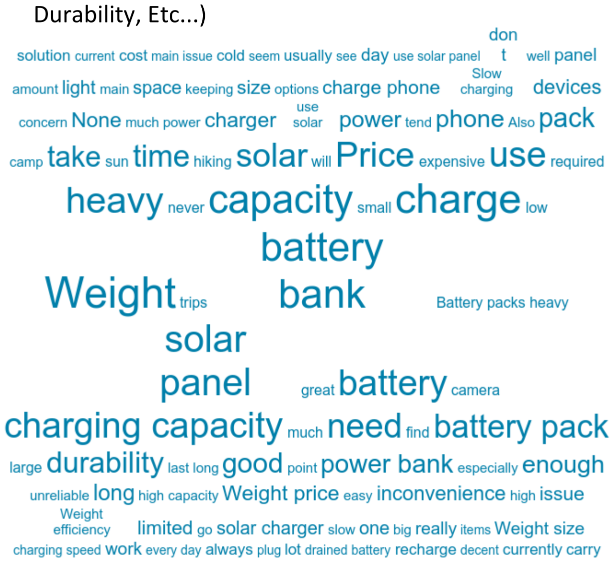
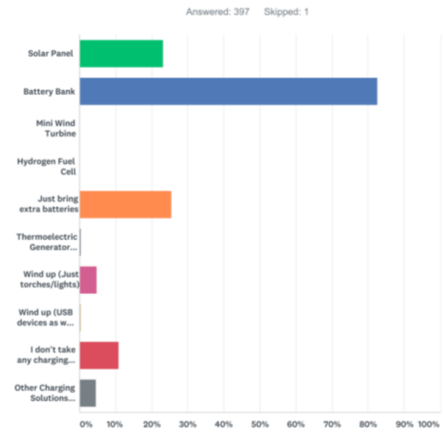


Figure 17. Survey Monkey Q7 Wordmap

Q6) Do you use any charging solutions currently?

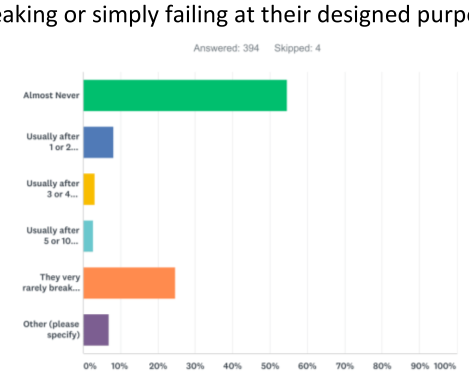


ANSWER CHOICES	RESPONSES	
Solar Panel	23.17%	92
Battery Bank	82.62%	328
Mini Wind Turbine	0.00%	0
Hydrogen Fuel Cell	0.00%	0
Just bring extra batteries	25.44%	101
Thermoelectric Generator (Biolite style stoves systems)	0.50%	2
Wind up (Just torches/lights)	4.79%	19
Wind up (USB devices as well as torches)	0.50%	2
I don't take any charging systems with me	10.83%	43
Other Charging Solutions (Please List in order of frequency used)	4.53%	18
Total Respondents: 397		

Figure 16. Survey Monkey Q6 Chart

With Q6 you can see that the battery bank has a demanding lead in current solutions and as such you can see in Q7 word frequency cloud the largest issue people have with their current solutions is the weight. The use of solar can remove redundant battery capacity. The next biggest issues people had was with the capacity of solar and with the durability of the current offerings. The expanded answers and comment threads in appendix A.2 elaborate on this point.

Q9) How often do you find the current solutions breaking or simply failing at their designed purpose?

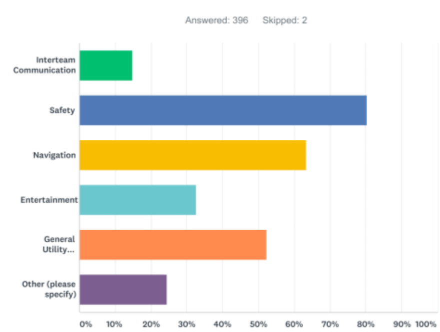


ANSWER CHOICES	RESPONSES	
Almost Never	54.57%	215
Usually after 1 or 2 Expeditions	8.12%	32
Usually after 3 or 4 Expeditions	3.05%	12
Usually after 5 or 10 Expeditions	2.79%	11
They very rarely break on me	24.62%	97
Other (please specify)	6.85%	27
TOTAL		394

Figure 19. Survey Monkey Q9 Chart

Q10 Data Displayed in Table 1.

Q8) What are your reasons for needing electronics when out on expedition?



ANSWER CHOICES	RESPONSES	
Interteam Communication	14.90%	59
Safety	80.30%	318
Navigation	63.38%	251
Entertainment	32.58%	129
General Utility (Lanterns for light, Smartwatches for time, etc...)	52.27%	207
Other (please specify)	24.49%	97
Total Respondents: 396		

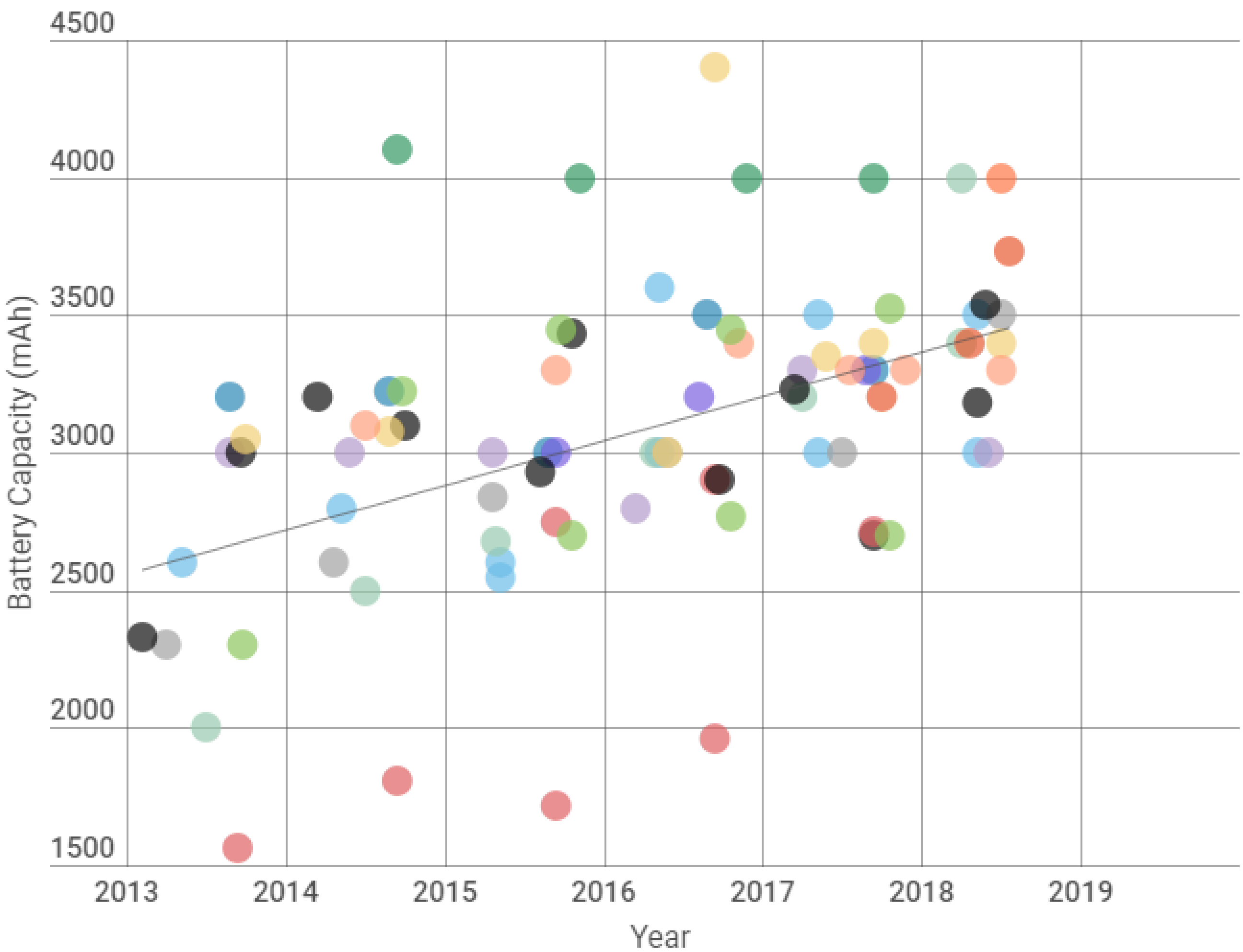
Figure 18. Survey Monkey Q8 Chart

7.0B

APPENDIX B

Below is a graph showing the average battery capacity of phones by year. It shows a steady increase in capacity that is affecting all manufacturers. It does, however, show that the rate of increase isn't quite as steep as you would expect if the technology were advancing at any reasonable rate. Large portions of phones made 5 years ago still have a larger battery than certain phones now.

Points worth mentioning are the red dots near the bottom are the Apple iPhone, notorious for the smaller battery life but thinner phones, this graph shows how they are able to keep the phones so thin.

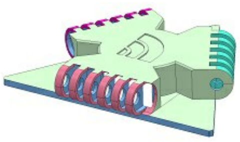


PROTOLABS

ProtoQuote®

Injection Moulding Quote

Prepared for: **Student (Brunel University London)**
Process: **Plastic Injection Moulding**
Quote Number: **254934**
Quote Date: **9-Apr-2019**
Part Name: **Base Hinge section v2 rev 2**
Extents: **74.267 mm x 69.951 mm x 12 mm**



Thank you for the opportunity to quote your parts. We look forward to working with you on this project. If you have any questions, please contact us at +44 (0) 1952 683047.

① Confirm or Modify Specifications and Review Pricing

Cavities:	1 cavity	
A-side (green) finish:	PM-F1 (Low-cosmetic - most toolmarks removed)	
B-side (blue) finish:	PM-F0 (Non-cosmetic - finish to Protomold discretion)	
	Tooling Price:	**£4,840.00**
Sample Quantity:	25 — **Sample Parts 25 @ £1.66:**	**£41.50**
Material:	ABS, Black (Polylac PA-765 Black)	
	Change Material Colour	
	The selected material is not compatible with added colourants	
Manufacturing Time:	Sample parts ship in 15 business days (standard price)	

Total (ex. VAT) **GBP: £4,881.50**

Production Parts Calculator

This calculator shows estimated piece part pricing for future production orders.

Qty 1,000:	£1.51 ea	**Custom Lot Size Pricing**	
Qty 3,500:	£1.28 ea	Enter Lot Size:	5000 Go
Qty 5,000:	£1.05 ea	Qty 5000:	£1.05 ea
Qty 20,000:	£1.02 ea		

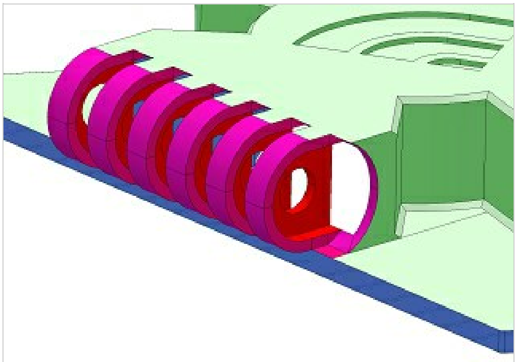
Production pricing in GBP based on the material selected: ABS, Black (Polylac PA-765 Black)

Add £333.00 setup charge to each lot of production parts.

② Manufacturability Analysis (2D View)

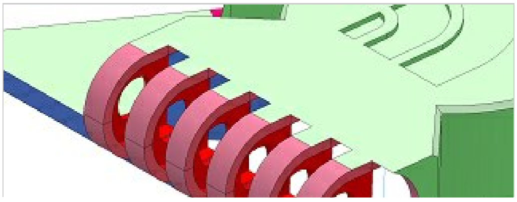
Required Changes (4)

Required Changes
The following illustrations indicate changes to the model which are required for compatibility with the Protomold process.



1. Faces shown in red have undercut portions. Blue lines (if any) indicate undercut regions. We are unable to produce these undercuts with the current Protomold process.

An updated file will be needed to make this part.



2. Faces shown in red have undercut portions. Blue lines (if any) indicate undercut regions. We are unable to produce these undercuts with the current Protomold process.

An updated file will be needed to make this part.

7.0D

APPENDIX D

Ethics Documentation.

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

12 November 2018

LETTER OF APPROVAL

Applicant: Mr Bradley Brister

Project Title: SunUp Solar Backpack

Reference: 12985-LR-Nov/2018- 14732-2

Dear Mr Bradley Brister

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Hua Zhao

Chair

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London

Brunel University London

CONSENT FORM

Title: SunUp VFC Collaborative
Name of Researchers: Bradley Brister
Outline of the Study: The aim of the research is to investigate the current user interactions with electrical devices whilst hiking and how they would generate power for them as well as to inform the design and practical layouts of the product. This independent study is carried out as part of the final year design project at the Design Department, College of Engineering, Design and Physical Sciences, Brunel University London. The information will be used of academic purposes only and treated as highly confidential. All answers will be anonymised.

Please tick the appropriate box

	YES	NO
Have you read the Research Participant Information Sheet?	✓	
Have you had an opportunity to ask questions and discuss this study?	✓	
Have you received satisfactory answers to all your questions?	✓	
Who have you spoken to? Bradley Brister, David Harrison, Yanmeng Xu		
Do you understand that you will not be referred to by name in any report concerning the study?	✓	
Do you understand that you are free to withdraw from the study:		
• **at any time?**	✓	
• **without having to give a reason for withdrawing?**	✓	
• **(where relevant, adapt if necessary) without affecting your future care?**	✓	
(Where relevant) I agree to my interview being recorded.	✓	
(Where relevant) I agree to the use of non-attributable direct quotes when the study is written up or published.	✓	
Do you agree to take part in this study?	✓	

Signature of Research Participant: [signature]

Date: 4 Dec 2018

Name in capitals: JOHN RICHARD FYSON

Witness statement

I am satisfied that the above-named has given informed consent.

Witnessed by: A A Fyson

Date: 4 December 2018.

Name in capitals: ADELA FYSON

Researcher name:	**Signature:**
Supervisor name:	**Signature:**

ACKNOWLEDGEMENTS

DR MARCO CAVALLARO
Without your guidance, this project would never have happened. I greatly appreciate the advice and insight into how a project should be run in the industry regardless of academic requirements.

SOLAR TECHNOLOGY INTERNATIONAL
A massive thank you for providing the high-quality solar cells needed for this project and for an invaluable placement year.

FRIENDS & FAMILY
Thank you to Mum and Sam for his help with the stitching and sewing machine operation. And thank you to the rest for putting up with me incessantly babble on about solar panels for a year.

BRUNEL VFC PROJECT TEAM
To all the other VFC Project members for ensuring we all survive the year.

TECHNICIANS
Obviously, a thank you to all the technicians for helping make the prototype happen.

VFC/THE NORTH FACE
And finally a massive thank you to VFC for letting me work with them for a year.

CONTACT DETAILS

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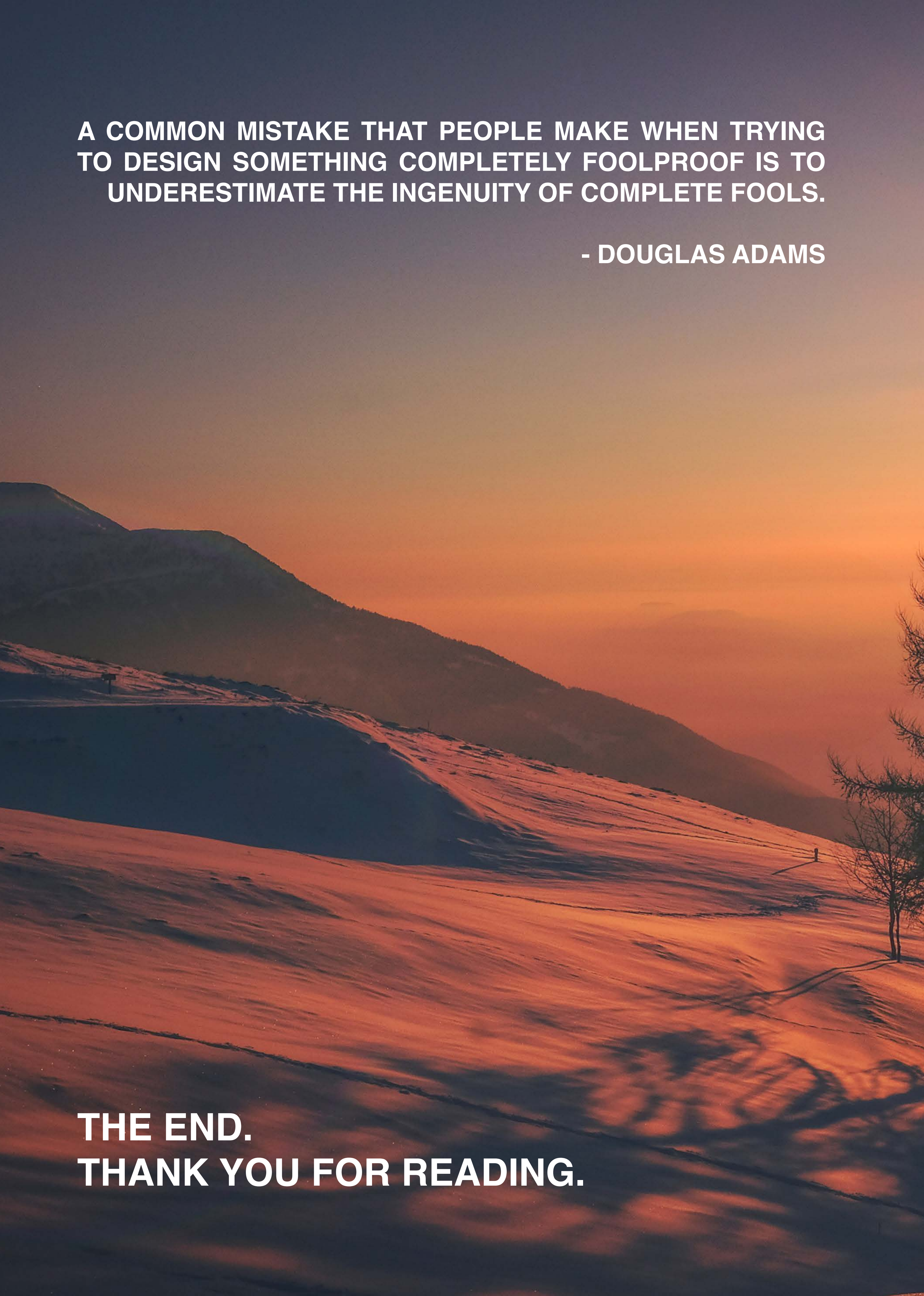
For new and ongoing projects please check out my website through the NFC tag or QR code Below.



A COMMON MISTAKE THAT PEOPLE MAKE WHEN TRYING TO DESIGN SOMETHING COMPLETELY FOOLPROOF IS TO UNDERESTIMATE THE INGENUITY OF COMPLETE FOOLS.

- DOUGLAS ADAMS

THE END.
THANK YOU FOR READING.