Hwa Chong Institution

Project Work

Category 3 Inventions Written Report

(based on the contents of our Invention Logbook)

Title of Project:
Foldable Helmet

Group Name:
Group 6 (Group ID: 3-02)

Group Members:
1) Michael Yeoh Seong Jui (1i2)
2) Philip Tan Pei Feng (1i1)

1. Problem Finding

1. At the very beginning, we just brainstormed freely. We did not bother about the IvP 2018 themes or whether the ideas were good or not. It also did not matter if the ideas were silly or shallow.

2. We just looked at our own lives and asked, "What present task in my life can be done better?" "What do I wish for?" With this method, we came up with many ideas.

3. After this free-flowing brainstorming process, we weeded out ideas which clearly did not fit the IvP 2018 themes. Eventually, we ended up with 6 good problems.

4. Our considerations for selecting problems to work on are set out in the following problem evaluation grid (Decision Matrix):

Considerations for Selection	**6 good problems**					
	Portable bicycle helmet (Note: when we say "portable", what we mean is easily portable.)	**Washing machine which can wash two separate loads in one drum**	**Multi-purpose pot and knife**	**Clothes for fast-growing children**	**Website/app to track children's behaviour**	**Plant health tracker**
#1 Gap in market	5	3	3	3	2	3
#2 Feasibility	3	1	3	3	3	3
#3 Usefulness to target users	6	3	3	3	3	2
#4 Creativity	4	3	3	6	3	3
Total Score	18	10	12	15	11	11

Note:
The matrix is based on a range from 1-6, with 6 being the best, followed by 5,4,3,2 and then 1.

Our justifications for these considerations are set out in Annexe 1.

5. We chose the 3 highest-scoring good problems as our best 3 good problems.

6. We did a PMI analysis for each of these 3 good problems.

7. We used the Decision Matrix and the PMI analysis of our best 3 good problems to decide on our best good problem.

8. We eventually chose the portable bicycle helmet as our best good problem.

2. Define the Problem

1. Cyclists and other personal mobility device (PMD) users should be using helmets for safety reasons. However, based on our observations, many do not.

2. Reto Zanettin from the Swiss Federal Laboratories for Materials Science and Technology reported in April 2016 that, "a survey by the Swiss Council for Accident Prevention (bfu) showed that … 53 percent of cyclists wind their way through traffic without protective headgear."

3. Cycling or using a PMD without a helmet can result in serious head injuries in the unfortunate event of an accident.

4. Statisticians Jake Olivier and Prudence Creighton from the University of New South Wales did a major study of bike helmet use around the world that was published in 2016. They found that helmets reduce the risks of a serious head injury by nearly 70%.

5. It is inconvenient to carry a conventional helmet around when it is not in use. Some people have told us that they will use a helmet if this inconvenience is eliminated.

6. We asked friends and family to answer a short survey questionnaire via Survey Monkey. The purpose of this quick survey was to get an impression on whether people who do not currently use bicycle helmets would do so if they had a helmet that is easily portable. The majority of respondents answered "yes". For more information on our survey, please see Annexe 1A.

7. For a list of the existing foldable bicycle helmets and other protective helmets that we considered, please see Annexe 2.

8. Some problems with existing portable bicycle helmets on the market are as follows:
   a. the foldables and collapsibles are not thin enough when they are compressed for storage. The thinnest that we are aware of are the models which fold to a thickness of 2.5 to 3 inches;
   b. the use of a collar containing an airbag is not practical for sunny, hot and humid Singapore; and
   c. there are problems with the idea of the airbag – airbags do not work in all situations and they can also be dangerous.

3. Your BIG IDEA

1. We propose to invent a portable bicycle helmet which is slimmer than existing solutions.

2. More and more people are using bicycles and other PMDs these days. It is relatively cheap and simple to get around in bicycles and other PMDs. The Singapore government is currently also promoting a 'car lite' society.

3. The purpose of inventing a portable bicycle helmet which is slimmer than existing solutions is to facilitate greater use of bicycle helmets.

4. At present, despite existing solutions, it is still common to see helmet-less cyclists on Singapore roads. We hope that greater bicycle helmet usage will result in a reduction in head injuries sustained in cycling accidents and that this will, in turn, encourage greater use of bicycles.

5. If more people cycle instead of driving cars, there will be less carbon emissions and less demand for fossil fuels.

6. The potential benefit of our invention to users would be the fact that it is slimmer than existing solutions and hence easier to carry around when not in use. We hope that our helmet will enable

more people to use an environmentally friendly mode of transport and keep their heads safe at the same time.

7. The key and essential idea underlying our proposed invention is to try to compress our helmet as much as possible. Folding results in twice the bulk, hence the focus on compressibility.

8. We propose to do so by creating a helmet comprising of an outer shell of hard material which is, at most, as thick as existing solutions and an inner layer which is not folded but compressed such that it is flatter than existing compressed helmets.

9. We used a Decision Matrix to compare our idea with existing solutions. Please see Annexe 3 for this Decision Matrix.

10. Two of the problems that we expected to encounter in the course of our work were getting access to materials used to construct helmets for commercial production and conducting safety testing.

11. The project timeline was provided by the school. However, throughout the project, we tried to work ahead of time in a way which suited us.

4. Construction Process

1. The ten considerations that guided the construction of our prototypes are as follows:
    a. Consideration #1 - our original sources of inspiration;
    b. Consideration #2 – existing foldable helmet solutions;
    c. Consideration #3 – the key biomechanical characteristics of bicycle helmets (Teach Engineering (n.d.));
    d. Consideration #4 – type of biking activity;
    e. Consideration #5 – safety standards and safety testing of bicycle helmets;
    f. Consideration #6 – other types of protective helmets;
    g. Consideration #7 – existing patent documents;
    h. Consideration #8 – ideas and solutions beyond the realm of protective helmets;
    i. Consideration #9 – type of prototype we aimed to make and materials available to us to make the prototype; and
    j. Consideration #10 - the need to strike a balance between conflicting considerations.

    Please see Annexe 4 for more information on these considerations.

2. The **two constraints** we faced when constructing our prototypes and how we attempted to deal with them are set out below.

3. The material introducing Category III Inventions which was distributed to us at the start of the year states that we have to construct a "working prototype" of our invention. Based on our research, a "working prototype" is an actual working model in terms of size and functionality. We aimed to construct a foldable helmet which is slimmer than existing solutions. Our final and most 'advanced' prototype is an actual working model in terms of size and in terms of the function of foldability. As far as we know, it is slimmer than existing solutions (i.e. we achieved our aim). However, it is not constructed out of the actual materials used to make helmets for commercial sale. We do not have access to such materials. We also do not have access to the processes that are used to make helmets for commercial sale.

4. Therefore, our **<u>FIRST CONSTRAINT</u>** is that **we cannot produce a prototype using actual materials and processes used to make helmets for commercial sale.**

5. As a result, our final prototype is functional in some – but not all – respects. Based on our research, it seems that that a partially functional prototype is called a "proof-of-principle prototype", a "rough prototype" a "crude prototype", a "representational model" or a "mock-up". In our invention log book and in this written report, we have used the word "mock-up".

6. Our **<u>SECOND CONSTRAINT</u>** is related to our first constraint. Right from the start of our project, we wondered **how to go about safety testing our invention**. We wondered whether we would have access to the laboratories that conduct safety testing of bicycle helmets.

7. Our starting point was to do some research on how safety testing is conducted and some safety standards applicable to bicycle helmets. Details are set out under the heading "Consideration #5" in Annexe 4. As we were trying to deal with this second constraint, we were concurrently trying to figure out what to do about the first constraint. Not being able to make a prototype using actual materials and processes used to make helmets for commercial sale meant that we would not have a prototype which was fit for sending to a laboratory for safety testing.

8. After doing more research, we found out that physical testing of helmets in laboratories is usually supplemented by computer-based (virtual) testing. In theory, it is possible to do 100% virtual testing.

9. We therefore considered if we could make a computerised version of our helmet and safety test it virtually. However, even at the final stages of product development for this IvP project, we would not have all the necessary information and specifications that need to be inputted into the relevant computer programme. For example, we would not be able to input the all technical details of the characteristics of the actual materials used to make helmets for commercial sale. Thus, we did not pursue the idea of virtual safety testing and the whole idea of safety testing.

10. We felt that it was alright to abandon the whole idea of safety testing because the aim of this project is to try to build a portable helmet that can be compressed so that it is thinner than existing solutions. We therefore targeted to test our mock-up only for the function of compressibility and slimness.

11. Nonetheless, we tried to account for the issue of safety by bearing in mind the key biomechanical characteristics of a bicycle helmets when designing our prototypes. Details of the key biomechanical characteristics of a bicycle helmet are set out under the heading "Consideration #3" in Annexe 4.

12. For our early prototypes, we used materials that we had easy access to at home and in school, such as Post-Its, A4 sized paper, sticky tape and masking tape. For our mock-up, we chose materials which appeared to us to share key characteristics of the actual materials used to make helmets for commercial sale. Please see Annexe 5 for details on how and why we chose the materials used to construct our prototypes.

13. We documented our products development stages in the form of photographs and notes that we took as we worked on our invention. Our photographs and notes are presented in Annexe 5.

5. Modification and Evaluation

1. The aim of this project is to construct a ‘working prototype’ which compresses so that it is slimmer than existing foldable helmets on the market.

2. Based on our research, we believe that the slimmest models available on the market are between 2.5 to 3 inches thick. Thus, our main test criteria was compressibility of our invention to a thickness less than 2.5 inches.

3. Another test criteria was fit. We checked whether or not our mock-up would fit snugly onto a life-sized polystyrene head.

4. We had to conduct four test iterations involving three mock-ups in order to finalise our product design. Details of all four test iterations and the results of these tests are set out in Annexe 6.

5. From the group of people we approached to conduct our needs analysis, we received some positive feedback. For example:
   “I would use this helmet if it is produced commercially and passes safety tests.”
   “I like the design. It is stylish and I will consider buying it if it is not too expensive.”
   “It is very hot to wear a helmet. I like this helmet because there is more air ventilation.

6. However, from one of our Project Work Mid-term Evaluation judges, we received negative feedback on one design feature of our helmet. The judge fedback to us that safety is of utmost importance and that she would not want any gaps at all in a helmet that she wears.

7. We therefore decided to include in our presentation slides for our Project Work Final Evaluation, an explanation of one of the considerations we had to bear in mind when constructing our prototypes - the need to strike a balance between conflicting considerations.

8. A visual representation of the conflicting considerations, how we dealt with the issue and our proposed solution to address that judge’s concerns are explained in our slides for our Project Work Final Evaluation presentation. These slides are reproduced in Annexe 7.

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Annexe 1

Considerations for selecting problems to work on and the justification for these considerations

Considerations	Justification
Consideration #1 - Gap in market	We aim to fill an existing gap in the market. We therefore need to determine if there is an existing gap in the market in the first place.
Consideration #2 - Feasibility (including commercial potential)	One aspect of feasibility is that our idea must have commercial potential. Another aspect of feasibility is that we need to be able to convert our idea into a prototype.
Consideration #3 - Usefulness to target users (utility)	Our product must be useful to target users so that they would buy it.
Consideration #4 – Creativity	We need to come up with a creative solution to an existing problem. Novel solutions may be more attractive to target users.
Consideration #5 - Purpose fulfilment (‘How well does it solve the problem?’)	This is a practical consideration which is self-explanatory. We applied this consideration in the design process but not earlier.
Consideration #6 - Ease in use (‘Will the users have problems operating it?’)	This is a practical consideration which is self-explanatory. We applied this consideration in the design process but not earlier.

Annexe 1A

Our preliminary market survey

Survey Monkey questionnaire entitled "Cycling Safer". Created on 25 March 2018 and open from 25 to 31 March 2018.

We asked a total of three questions. We received 27 responses.

First question:

Have you ever cycled without wearing a bicycle helmet?

Respondents were given a choice of two answers: yes or no.

26 out of the 27 respondents (**96.3%**) answered yes**.**

Second question (to be answered only by the respondents who said that they have cycled without wearing a bicycle helmet before):

Our initial research suggests that lack of easy access to bicycle helmets is one reason why people cycle without wearing them. If you had a slim, light, foldable, portable bicycle helmet that could fit into your bag/handbag, would you use it every time you cycle?

Respondents were given a choice of two answers: yes or no.

Out of the 26 respondents who answered this question**, 20** (**76.92%**) said that they would use such a helmet every time they cycle.

Third question (to be answered by the 6 respondents who answered "no" to the second question):

If you answered "No" to Question 2, what would make you use a bicycle helmet every time you cycle?

This was a free response question.

We received the following comments from the 6 respondents. We have grouped the comments according to the themes that they fall under.

<u>First type of responses - responses which indicated that solutions other than a well-designed helmet were required</u>

"Regulation."
"Mandatory wearing laws."
"Enforced laws."

<u>Second type of responses - responses which indicated that raising awareness of the dangers of riding without a helmet may be required. There is also the need to understand the thinking of the respondents (why do hold these opinions?)</u>

"Nothing. I hate wearing anything on my head."
"Nothing."
"If I had an accident that scared me."

Some respondents who had answered "Yes" to question 2 voluntarily shared what sort of foldable helmet would appeal to them

"Light."

"Cool and tiny helmet which can be folded and has protective qualities."

"One that suits the hot and humid weather in the tropics ... or one that comes out like an airbag in an emergency. Saw something like that on the Internet. And it must be affordable."

"The key thing is our humid weather. We sweat so much wearing the helmet."

"Make it affordable in a material that doesn't stink after sweating so much into it."

One respondent who had answered "Yes" to question 2 also gave the following comment

"Just wondering why the need for helmet when cyclists cycle on pavements? The pedestrians need more protection becos the PMD which is battery operated is now on the pavement."

Annexe 2

List of foldable bicycle helmets and other protective helmets that we looked up during the early stages of this project

S/No.	Brand/Model/Description	Type of protective helmet	Notes/Comments
1	Motorika Snapit	Foldable bicycle helmet	
2	Biologic Pango	Foldable bicycle helmet	Uses Fidlock® fastener. Downloaded photographs of the fastener are in Michael's individual logbook entry dated 8 April 2018.
3	Carrera Accordion/Foldable	Foldable bicycle helmet	This is the foldable helmet that one group member uses.
4	Closca	Foldable bicycle helmet	
5	Morpher	Foldable bicycle helmet	Uses Fidlock® fastener.
6	Overade Plixi	Foldable bicycle helmet	
7	Weshine	Foldable bicycle helmet	
8	HeadKayse	Foldable bicycle helmet	
9	Spitfire Industry EcoHelmet	Foldable bicycle helmet	
10	Golem Innovation Alpha	Foldable bicycle helmet	
11	FEND	Foldable bicycle helmet	
12	Tatoo by Julien Bergignat and Patrice Mouille	Foldable bicycle helmet	This design comes closest to what we ourselves were thinking of. However, this invention does not feature the key biomechanical features of a bicycle helmet. It received positive reviews but also one scathing, negative one: "This one … neglects the way bike helmets actually work. It's not simply that they're padded … Rather, helmets protect you because they're monolithic and rigid – that allows the force of an impact to [be] transmitted along their length, rather than directly into your head. They're made of foam both to be

			lightweight and so that they can easily crack – just like a racecar, they're meant to break-up upon impact, to further disperse kinetic energy. When wearing the Tatoo, you might feel the warm glow of future-forward design. You also won't feel your legs, after you are paralysed." Actually, it was this review which made us consider what key safety features a bicycle helmet must have.
13	Coroflot The Fractal Bike Helmet	Foldable bicycle helmet	This invention does not feature the key biomechanical features of a bicycle helmet.
14	Tatamet Designer Foldable Safety Helmet	Foldable bicycle helmet	This invention does not feature the key biomechanical features of a bicycle helmet.
15	Hövding	Air bag collar	
16	Bell X-Ray	Mountain biking bicycle helmet	
17	Kalli City	Bicycle helmet for city riding	This is the helmet used by one group member for city cycling.
18	Etto City Safe	Bicycle helmet for leisure riding	Uses Fidlock® fastener.
19	Scorpion EXO AT950	Motorcycle helmet ("jack-of-all-trades" motorcycle helmet)	
20	Etto Explore	Ski helmet	
21	Giro Combyn	Ski and snowboarding helmet	
22	VICIS Zero 1	Football helmet	Instead of a rigid outer shell, the Zero 1 has a soft, deformable outer skin with a harder plastic core inside. It has two sets of two chin-straps. Two of the four chin-straps fasten to the inner shell rather than the outer one; VICIS engineers think

			that this will curb energy flowing through the jaw.
23	Troxel Intrepid	All-purpose equestrian helmet	
24	U.S. Army helmet systems circa 2005	Ballistic helmets	

We think that existing foldable bicycle helmets can be classified into three categories:

a. collapsibles (i.e. helmets which reduce in height as they are compressed from the top/bottom);
b. foldables (i.e. helmets which reduce in width as they are compressed from the sides); and
c. the airbag collar.

We chose the Closca as an example to represent the category of collapsibles.

Figure 1. Side view of the Closca. Source: https://helmets.org/folding.htm

Figure 2. Closca in collapsed state. Source: https://helmets.org/folding.htm

We chose the Morpher as an example to represent the category of foldables.

Figure 3. Side view of the Morpher. Source: https://helmets.org/folding.htm

Figure 4. Morpher in collapsed state. Source: https://helmets.org/folding.htm

The only airbag collar we found was the Hovding.

Figure 5. The collar containing in the uninflated airbag is shown on the left. The airbag deploys in the event of a crash and the inflated airbag is shown on the right. Source: https://hovding.com/

Annexe 3

Problem evaluation grid (Decision Matrix) to compare our idea with existing solutions

We used one type of helmet from each of the three categories of existing solutions (collapsible, foldable, airbag) for our comparison.

Considerations for Selection	Closca	Morpher	Hovding	Our idea
#1 Gap in market	3	3	3	3
#2 Feasibility	3	3	2	3
#3 Usefulness to target users	3	3	2	3
#4 Creativity	3	3	3	3
#5 Purpose fulfilment	3	3	2	3
#6 Ease in use	3	3	2	3
#7 Flatness for storage	2	2	3	3
#8 Breathability	2	2	3	2
#9 Maintenance	2	2	3	3
Total Score	24	24	23	26

Note:
The matrix is based on a range from 1-3, with 3 being the best, followed by 2 and then 1.

Annexe 4

Details of the ten considerations that guided the construction of our prototypes

1. **Consideration #1 - Our original sources of inspiration**

    a. We experimented with various permutations of our helmet by drawing from our original sources of inspiration for this project – mediaeval armour and nature.

    b. Right from the beginning, we were attracted to the following occurrences in nature:

        i. how an armadillo rolls itself up into a ball (folding mechanism); and

        ii. how American cockroaches can squish themselves flat to navigate through cracks and crevices and to avoid being killed when stomped on (compressibility).

        The American cockroach inspired the invention of the CRAM robot cockroach by scientists at University of California, Berkeley (CRAM = Compressible Robot with Articulated Mechanisms). We were inspired by the photos and diagrams of the CRAM robot cockroach that we found on the Internet.

    c. At a later stage, we also looked into:

        i. the defence mechanism of pangolins (folding mechanism); and

        ii. ladybird wings (compact storage of inner wings which can be folded or released very rapidly).

2. **Consideration #2 – Existing foldable helmet solutions**

    As mentioned in Section 2 of this report, we looked at existing models of foldable bicycle helmets.

3. **Consideration #3 – the key biomechanical characteristics of bicycle helmets**

    a. We did some research on the key biomechanical characteristics of bicycle helmets. These would be the key safety features of a bicycle helmet.

    b. In order to understand what these key safety features are and why they are needed, we also had to be aware of some science principles at work during a typical bicycle crash.

    c. The website www.consumerreports.org describes "the details of the physics and biomechanics that occur" during a bicycle crash and the function of a bicycle helmet as follows:

    "Think of a bike accident as a chain of events transferring kinetic energy that starts with a cyclist on a bike and ends with the possible microscopic jostling of brain cells. Wearing a bike helmet is important in minimizing the damage. Here's how:

The bike stops suddenly because it hits a solid object, such as a car, **or more gradually in a sliding fall**. The first milliseconds of the crash are important because some of the energy is dissipated when the frame or wheel crumples, or by the friction of the slide.

The rider is still in motion, even though the bike has stopped. The rider might take a dive over the handlebars or simply tumble sideways to the ground. An unprotected human skull can withstand modest impacts—for example, if you fell while running and hit your head on soft ground or a tree. But the force involved in a bicycle accident is much greater. Many factors affect the outcome of a fall. But in general, depending on the rider's height, in a free fall from a bike the head could hit at anywhere from 9.5 to 13.4 mph. The Consumer Product Safety Commission helmet test simulates impact speeds of 10.7 and 13.9 mph.

[Note: Newton's second law of motion states that force = mass x acceleration. The mass of a cyclist is a constant but the helmet can slow down acceleration in order to reduce force. The helmet also absorbs and distributes force to minimise the force that reaches the rider's head.]

The bike helmet goes through several changes on impact that can save your life. The smooth, thin outer shell helps prevent minor punctures from sharp objects and allows your head to glide as it moves, which reduces the wrenching of your head and neck. That lengthens the time it takes for your head to come to a complete stop, usually dissipating enough energy to prevent a skull fracture or damage to a major blood vessel, which can crush the brain as the sealed skull fills with blood. The dense expanded polystyrene foam core [note: this is what we call the "inner layer" in this log book] compresses or breaks, spreading the force over a wider area.

The brain is suspended in a bath of cerebrospinal fluid, and when the acceleration of the head comes to a stop, it might continue to move. Even if the helmet did its job and prevented a skull fracture, the rider might still suffer a concussion. If the impact is largely linear—right between the eyes or across the head from one ear to the other—the brain sloshes back and forth inside the skull until the energy dissipates. If the impact is off-center, rotational forces come into play. The brain no longer simply moves back and forth—it also rotates inside the skull, increasing the chance of damage to the delicate tissues.

The brain cells might twist, stretch, or rupture, causing chemical changes that prevent them from transmitting information the way they are meant to. This metabolic crisis going on within a cell—as head-injury specialist Robert Cantu, M.D., a clinical professor of neurology and neurosurgery at Boston University Medical School describes what happens at a granular level inside the brain during a concussion—results in confusion, memory problems, trouble concentrating and other cognitive deficits. Those are the signs that doctors check for during a neurological exam."

d. Figure 6 below shows how a helmet protects the brain and skull by absorbing linear force in the event that the cyclist's head hits a hard surface.

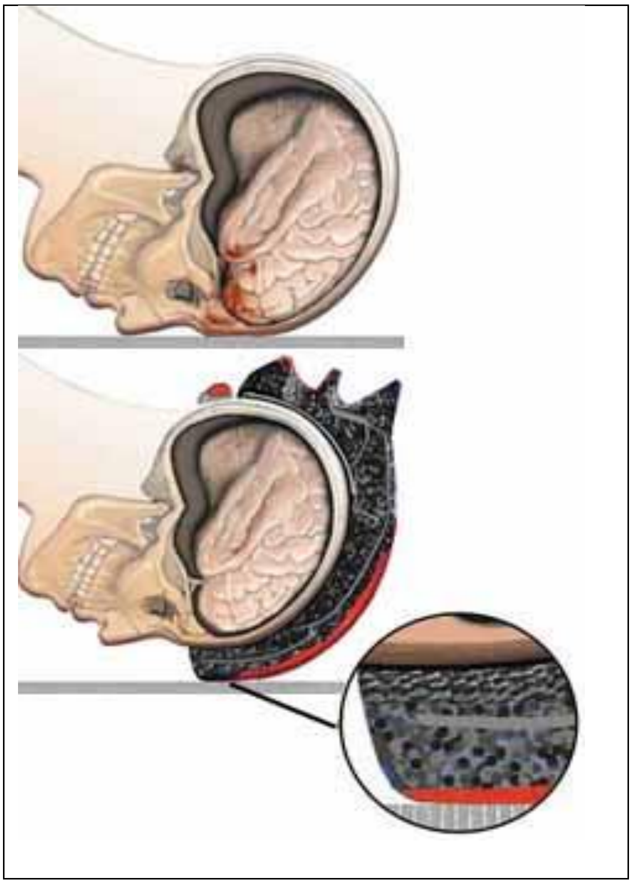


Figure 6. How a helmet protects the brain and skull by absorbing linear force in the event that the cyclist's head hits a hard surface.
Source: http://cozybeehive.blogspot.sg/2008/03/how-bicycle-helmet-works.html

e. A Youtube video which we thought clearly illustrated the linear and rotational forces acting on a cyclist's head in the event of a crash can be accessed via the following link:

https://www.youtube.com/watch?v=kQ9jRxOp1S0

It is entitled, "The Mechanics of a Crash". Please note, however, that the video was produced by a manufacturer of a component used in bicycle helmets (the slip plane), so the information in the video about the slip plane and its purported benefits may be biased.

f. Key features of a typical bicycle helmet which meets accepted industry safety standards are as follows.

i. A hard and smooth outer shell

aa. The outer shell has several purposes. As mentioned earlier, it protects against minor punctures from sharp objects and allows the rider's head to glide as it moves on the road upon impact, which reduces wrenching of the head and neck. Wrenching can add to the severity of impact. Sliding also causes a slower deceleration due to friction. The outer shell also distributes the force of the collision over a large area. It holds the inner liner together as the inner liner absorbs the force of the collision and starts to compress or break up.

bb. The rounder and smoother the outer shell, and the more surface area of the outer shell (achieved, for example, by having less ventilation holes), the better.

Roundness and smoothness promotes ‘slideability’. This feature (‘slideability’) was described in one of the patent documents that we found as “very low friction coefficient with potential contact surfaces” (United States Patent Application Publication No. US2009/0260133 A1, Pub. Date: Oct. 22, 2009)).

More surface area results in a better spread of force.

ii. A soft inner liner

aa. This is also commonly known as the inner liner. In this log book, we have used the term “inner layer”. As mentioned earlier, the inner layer absorbs force. It also spreads force over a wider area. It is commonly made out of dense expanded polystyrene foam and is usually 15 mm to 20mm thick.

bb. The greater the surface area of the inner layer, the better. This is because the more foam is in contact with the rider’s head, the better force can be spread out.

iii. Straps which keep the helmet on when the rider flies through the air.

In this log book, we have referred to the straps as “the strap system”.

g. We found a nice diagram on the Internet which illustrates the above-mentioned three key features of a bicycle helmet:

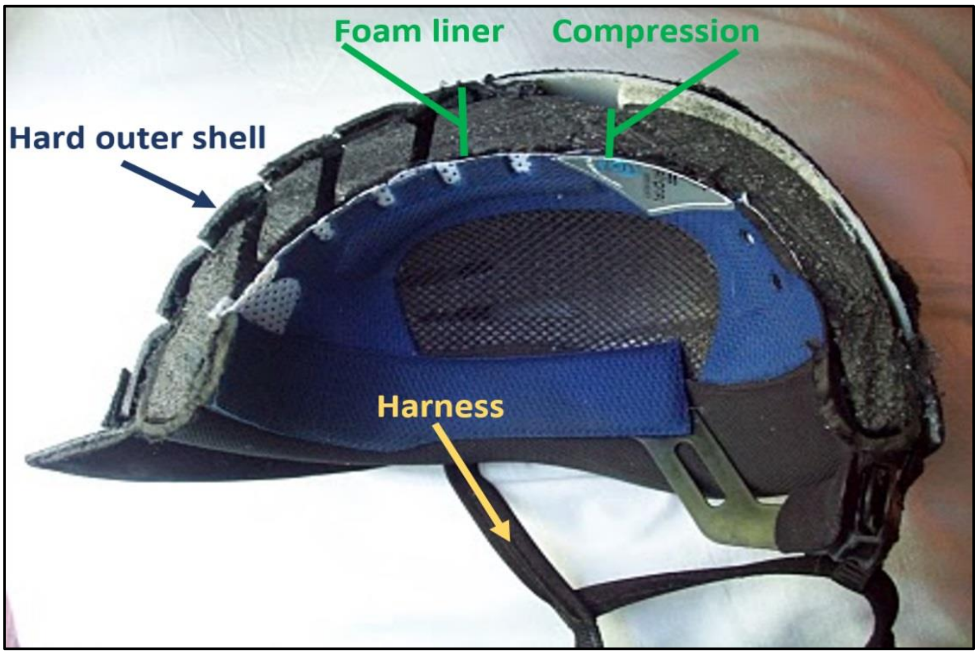


Figure 7. This helmet was sawed in half after a fall and shows the compression of the foam. *Credit: S. Kotow, labeled by S. Mastellar.*
Source: http://igrow.org/up/articles/12195-1-orig.png.

Note:
igrow.org is a website related to horse-riding and the helmet featured in Figure 7 is actually an equestrian helmet. We have used this photograph because the key features of an equestrian helmet are the same as that of a bicycle helmet and these key features are clearly illustrated in this photograph.

h. Two relatively recent developments in the field of protective helmets have introduced variations to the three key features discussed above:

   i. Movement away from hard to flexible outer shell in favour of relatively soft outer shell

      Instead of a hard and smooth outer shell, some protective helmets now sport a tough but flexible outer shell that is designed to crumple. Such helmets are designed to work the way car bonnets crumple upon impact, i.e., absorb and distribute force by crumpling. Manufacturers who agree with this theory believe that a hard shell may actually aggravate injury. For example, because the hard shell is more likely than a softer shell to bounce on impact in the event of an accident.

   ii. Efforts to reduce rotational force

      aa. The traditional bicycle helmet does not deal with the damaging effect of rotational force well enough.

      bb. More recent designs attempt to reduce rotation of the head due to change of momentum in the event of a collision. For example, some manufacturers have introduced a slip plane between the outer shell and the inner layer of their helmet. The efficacy of the slip plane has yet to be proven (The Bicycle Helmet Safety Institute (n.d.)).

      cc. Other solutions to date include the development of a technology that changes the structure of an EPS liner to permit movement on impact and pads which promote lateral movement of the helmet in a crash (The Bicycle Helmet Safety Institute (n.d.)).

         The Bicycle Helmet Safety Institute expressed the view that, “although unbiased test results are very hard to find, any spur to innovation in what has been a long stagnant period for new helmet technology is very welcome.” (The Bicycle Helmet Safety Institute (n.d.)).

i. Implications of the above-mentioned developments on the design and construction of our prototypes:

   i. We considered the option of constructing a hard outer shell as well as the option of constructing a tough but flexible outer shell.

   ii. We bore in mind that we should try to deal with the problem of rotational force if possible. [Note: in the end, we could not figure out what to do with this problem at all. Our proposed solution to the rotational force problem is therefore to use a material or method of construction to make an inner layer which addresses the problem instead of solving the problem with a design-related solution. An example of such material or method would be "technology that changes the structure of an EPS liner to permit movement on impact" (The Bicycle Helmet Safety Institute (n.d.)) previously mentioned.]

4. **Consideration #4 – type of biking activity**

   a. When we were looking up the various different types of protective helmets, we realised that it is not ideal to design one helmet for multiple types of target users. Different activities involve different types of risks. The different types of risks result in different considerations when designing a helmet.

   b. We therefore restricted ourselves to constructing a helmet for urban cyclists, despite our original idea to target all cyclists and, also, other PMD users.

   c. Helmets worn by urban cyclists are designed for use at lower speeds than helmets used by racers and mountain bikers. They also do not have to be aerodynamically shaped because speed is not a consideration. The cycling terrain would be relatively flat and uniform. For example, cemented pavements, dedicated cycling tracks and asphalt roads shared with cars and other motorised vehicles.

5. **Consideration #5 – safety standards and safety testing of bicycle helmets**

   a. As the whole point of wearing a bicycle helmet is to keep one's head safe in the event of an accident, we researched safety standards and safety testing, even though we had no idea at the time we were doing the research, how we would deal with safety testing. As mentioned earlier, we eventually decided that it is not possible to safety test our invention at this stage of its development. However, because we have already done the work, we present below what we found out about these topics.

   b. The articles we found were hard to understand. However, we found several Youtube videos which were easy to understand. One such Youtube video is entitled, "Science Behind Safe Bike Helmets & How They Fit". It can be accessed via the following link:

      https://www.youtube.com/watch?v=pBV4DOJoqDk.

   c. Safety testing is mostly done in laboratories which put actual helmets to the test.

   d. Safety testing is done to ensure compliance with safety standards specifications (The Bicycle Helmet Safety Institute (n.d.)).

   e. Standards are developed and published by various standard-setting organizations (The Bicycle Helmet Safety Institute (n.d.)).

   f. A typical standard specifies impact tests, strap tests, characteristics of materials to be used, required coverage, labelling and other requirements. Some have tests to simulate low temperature performance, hot performance, wet performance and sunlight aging (The Bicycle Helmet Safety Institute (n.d.)).

g. There are several accepted safety standard specifications in the market. In Singapore, unlike in the case of motorcycle helmets, there are no local safety standards applicable to bicycle helmets. The safety standards listed in the Sport Singapore's Safe Cycling Guide are those of the Snell Memorial Foundation, the American National Standard Institute (ANSI), the US Consumer Product Safety Commission (CPSC), and the American Society for Testing and Materials (ASTM), EN078 and ANSA Z-90.4.

h. Unlike in some other countries such as Australia, there are no laws in Singapore which make the wearing of bicycle helmets compulsory. However, Sport Singapore recommends that cyclists be helmeted when they cycle and that the helmets comply with accepted industry safety standards.

i. Singapore also does not make safety testing and certification of bicycle helmets mandatory (though such testing and certification is required for motorcycle helmets).

j. Strangely, we discovered that current safety tests for bicycle helmets do not test the efficacy of a helmet in reducing rotational force, even though rotational force is one of the two main forces acting on a bicyclist's head which result in injury (Stigson, et al. (2017), Curnow (2008), Carnall (1999)). Current impact tests are limited to testing for "perpendicular impact" (Stigson, et al. (2017)).

(Random but interesting fact: This is a point often cited by people who are against the wearing of bicycle helmets and making the wearing of bicycle helmets compulsory.)

k. A second way of safety testing is to use the computer. A virtual helmet is created and tested in virtual simulated crashes.

l. Both methods (testing of the actual helmet in a physical laboratory or facility and computer simulation) are often combined.

6. **Consideration #6 – Other types of protective helmets**

a. In addition to existing foldable bicycle helmet solutions, we also looked at protective helmets worn in activities which we though involve risks which were similar or greater than risks associated with cycling.

A list of these other types of protective helmets are set out in Annexe 2.

b. We wanted to see if we could get any ideas for use in the context of our foldable bicycle helmet.

c. One helmet which we found interesting was the VICIS impact reducing football helmet. A diagram of the cross section of a VICIS helmet is reproduced below:

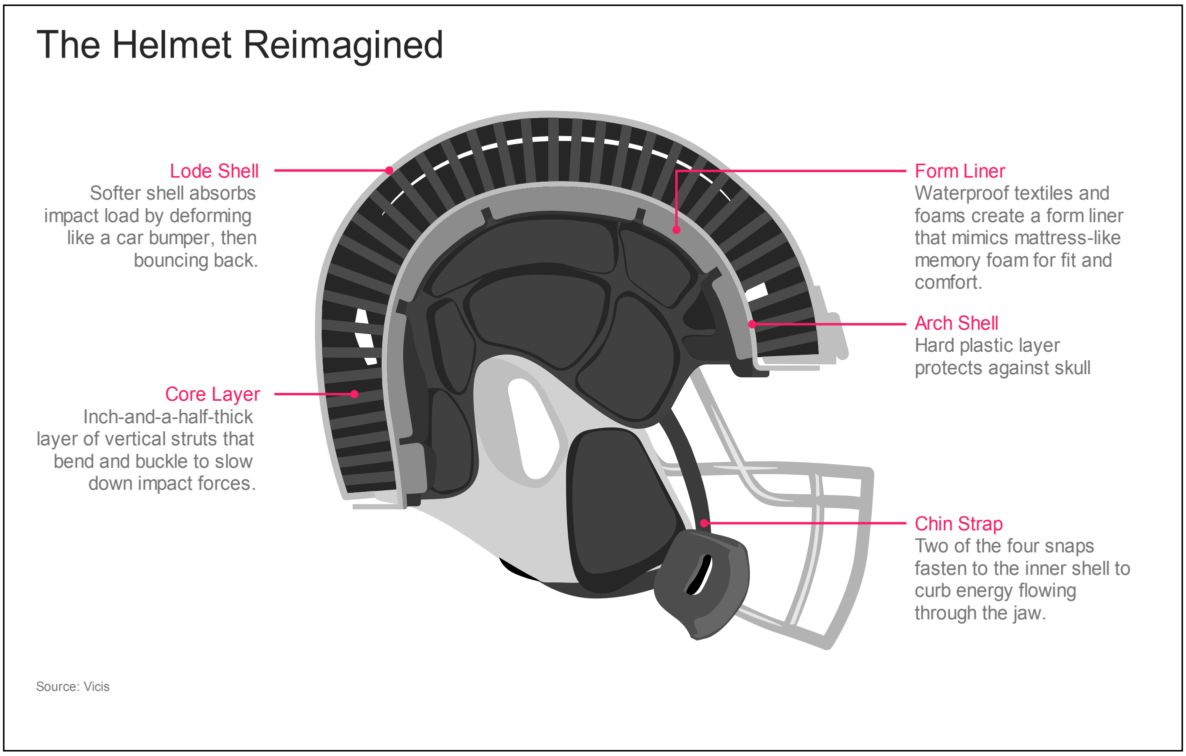


Figure 8. Cross section of a VICIS helmet
Source: https://www.bloomberg.com/features/2016-vicis-football-helmet/

d. As can be seen from Figure 8, the outer shell deforms like a car bumper and, in that way, absorbs and distributes force. A cool video showing how the VICIS outer shell compresses upon linear impact can be found by accessing the following link:

https://www.bloomberg.com/features/2016-vicis-football-helmet/

e. Protective helmets like this one made it possible for us to consider the idea of a tough but flexible compressible outer shell instead of a hard outer shell.

7. **Consideration #7 – existing patent documents**

a. We also looked to existing patent documents to help us to solve some problems that we faced.

b. One question we asked ourselves during the design process is as follows:

Our helmet will be made of several pieces. Is there any optimum location to place the joints?

c. The design of our robot cockroach inspired outer shell contains a seam right down the mid-line of the helmet. We wondered if the helmet would split apart like pea pods, durians and the fruit of kapok plants in the event of a frontal collision which struck that mid-line seam.

d. An existing solution - the Morpher – comprises of a number of panels joined to each other. It folds down its mid-line. The manufacturer's website states that this helmet exceeds the applicable safety standards (but does not state which standards the helmet was tested against). Figures 9 and 10 below show extracts from the patent documents of the Morpher, which illustrate and describe its mid-line seam. Figure 11 below shows photographs of the Morpher when fully opened and when compressed.

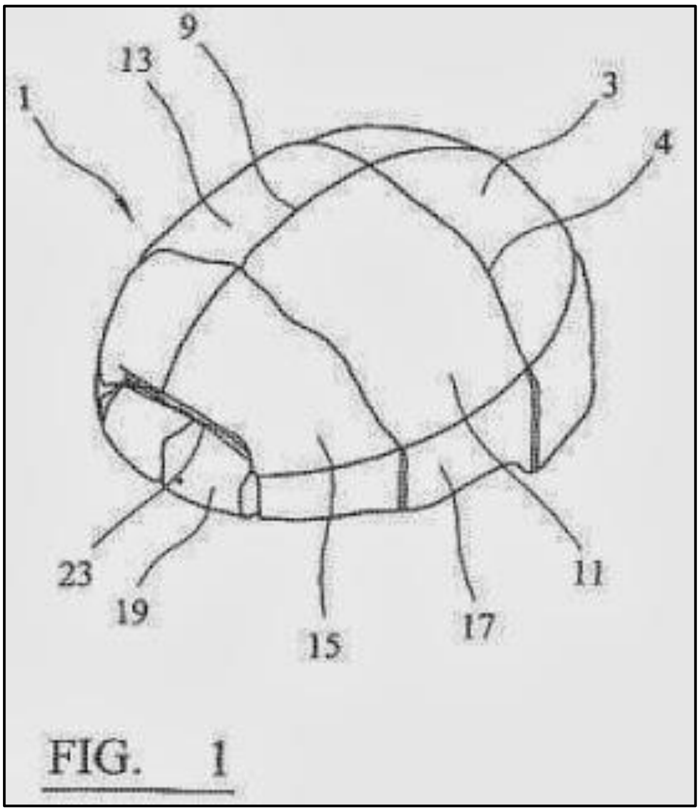


Figure 9. Sketch extracted from the patent documents of the Morpher.
Source: http://stephenvandulken.blogspot.sg/2013/11/the-morpher-folding-helmet.html

(57) Abstract: A collapsible helmet comprises a shell 1 having two or more components which are hingedly connected together about fold lines extending across the shell. Each component comprises a plurality of panels 3 with each panel being hingedly connected to at least one adjacent panel. The shell may be adjustable between a first configuration in which the helmet may be placed over the head of the user and a second configuration in which said components are flattened and are arranged in a substantially overlying relationship.

Figure 10. Abstract from the patent documents of the Morpher.
Source:
https://worldwide.espacenet.com/publicationDetails/originalDocument?FT=D&date=20120419&DB=&locale=en_EP&CC=WO&NR=2012049463A1&KC=A1&ND=1#

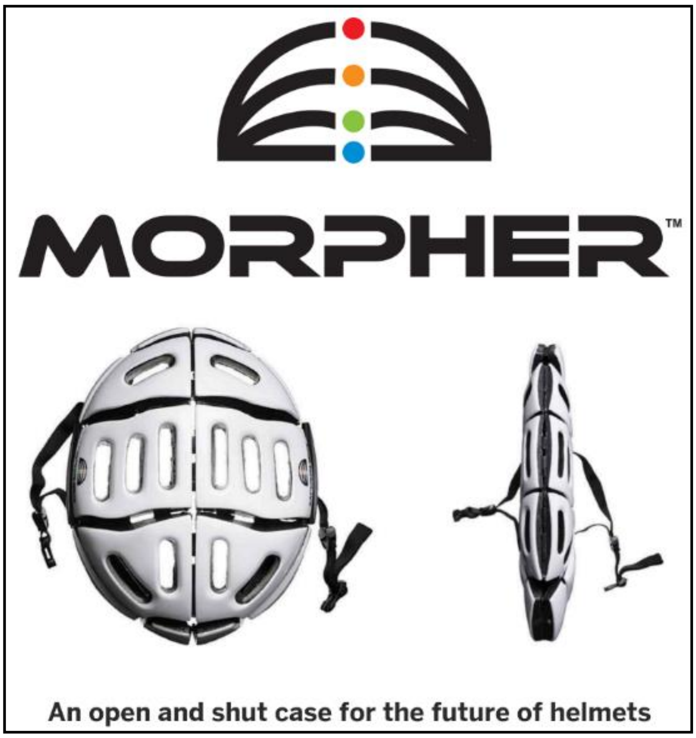


Figure 11. Images of the Morpher and the brand logo from the manufacturer's website.
Source: https://www.morpherhelmet.com/products/gift-card?variant=2721953480728

e. We also found other patents of protective helmets with midline splits, for example, United States Patent Application Publication No.: US2016/0120255 A1 Pub. Date: May 5, 2016.

f. We felt encouraged that a split down the mid-line of a helmet may not be an issue. However, our cockroach inspired outer shell consists of plates which we may not be able to join in a streamlined way. This is because the edges of the plates have to be relatively thick (instead of tapering) so that they do not break off upon impact in the event of an accident. We have tried to show this problem via the sketches in Figure 11A below.

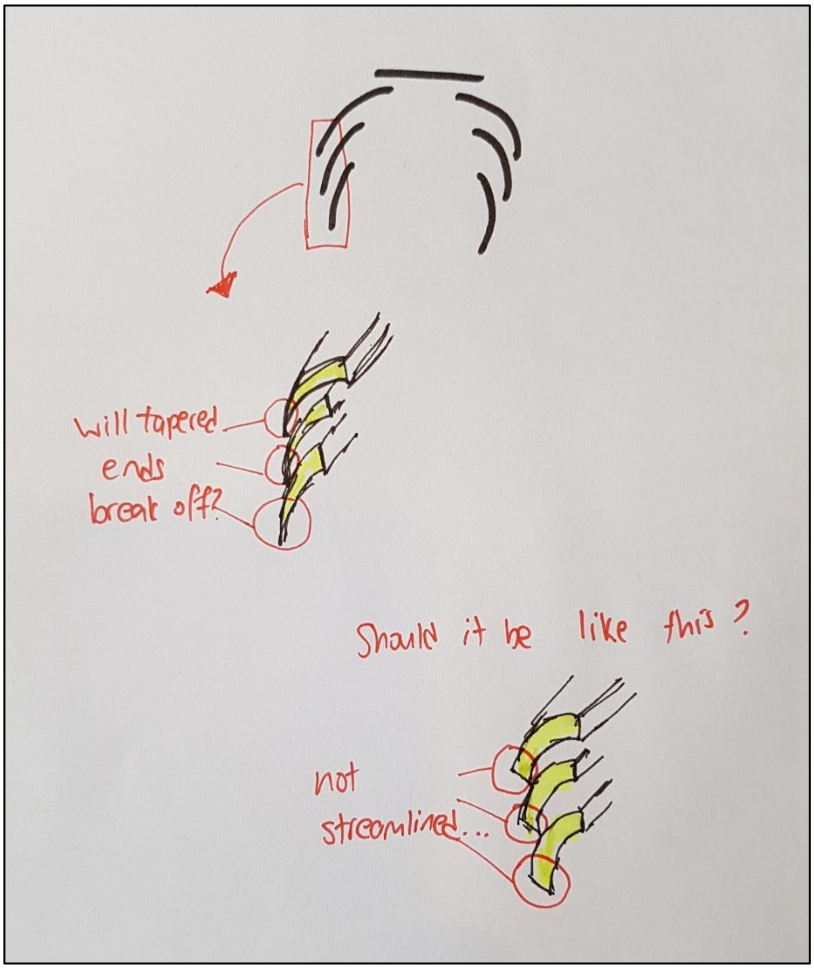


Figure 11A. In our robot inspired outer shell, we may not be able to construct the plates such that they form a smooth, streamlined outer surface.

g. We therefore bore in mind our alternative designs as we trawled through the patents databases.

h. Some patent documents which supported our ideas/features of our designs or which contained useful information are as follows:

i. Design-related points:

aa. multi-plate helmet – United States Patent Application Publication No.: US2007/017370 A1 Pub. Date: Jul. 12, 2007, United States Patent Application Publication No.: US2016/0120255 A1 Pub. Date: May 5, 2016, U.S. Pat No. 4,404,690 and U.S. Pat No. 4,903,346, both referred to in United States Patent Application Publication No.: US2016/0120255 A1 Pub. Date: May 5, 2016.

bb. tough but flexible outer shell - United States Patent Application Publication No.: US2016/0120255 A1 Pub. Date: May 5, 2016 ("a more yielding external surface"). United States Patent Application Publication No.: US2009/0260133 A1 Pub. Date: Oct. 22, 2009 ("strong yet flexible" outer shell).

cc. outer shell and inner layer of the helmet having ventilation holes at different points - United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12, 2007.

dd. strap systems - United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12, 2007, Grant US5469583A in favour of Tom Akeley Bell Sports, Inc (helmet strap stabiliser clip), Grant US5608918A in favour of Frank Salvaggio Western State Import Company, Inc. (lockable strap separator for use with bicycle helmets and the like).

ii. Materials for use in actual protective helmets

aa. materials to construct tough but flexible outer shell - United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12, 2007

bb. materials to construct inner layer - United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12, 2007, United States Patent Application Publication No.: US2009/0260133 A1 Pub. Date: Oct. 22, 2009.

cc. materials to construct strap system and material to join the multiple plates - United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12, 2007. Material to join multiple plates is to be “flexible material of elastomer nature”, “flexible elastic material” or “flexible elastic textile” but such materials must not overstretch. If they overstretch, safety is compromised.

8. **Consideration #8 – ideas and solutions beyond the realm of protective helmets**

a. We looked at other safety products (children’s car seats and inflatable structures to cushion falls at home and at the workplace) to see if we could get any ideas for use in the context of our foldable bicycle helmet.

b. We also looked at specific contraptions and materials which we thought could help us to solve some problems that we faced when designing and constructing our prototypes.

c. Living hinge

i. Typical protective helmets have a hard and smooth “monoblock external shell” (United States Patent Application Publication No. US2007/0157370 A1, Pub. Date: Jul. 12, 2007) which slides easily on the road (or other hard surface) in the event of an accident.

ii. However, in order to fold, all the foldable helmets we managed to look up had a “plurality of shell segments” (United States Patent Application Publication No. US2007/0157370 A1, Pub. Date: Jul. 12, 2007).

iii. Our question therefore was: how do we join several pieces of outer shell together yet maintain a streamlined surface which would not compromise on the helmet's ability to slide on the road (or other hard surface) in the event of an accident?

iv. As previously mentioned, we were not confident that our robot cockroach inspired design would be safe enough, so we examined our armadillo inspired design more closely.

v. As can be seen in Figure 12 below, we had originally thought of an outer shell that folds in the middle the same way that the armadillo folds itself. We later abandoned the idea of folding in favour of the idea of compressing.

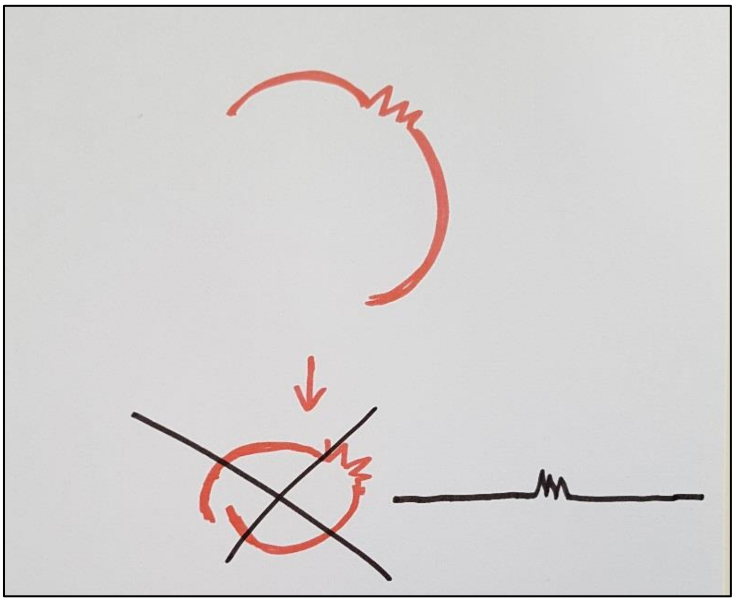


Figure 12. Sketches of armadillo inspired outer shells – the compressible version is sketched in black. The foldable version is the sketch in red which has been crossed out.

vi. The problem was that the armadillo inspired hinge is a protrusion which would hinder 'slideablity' of the shell.

vii. We needed a hinge which does not hamper 'slideability'.

viii. After some research, we discovered that our idea could be realised using a living hinge as shown in Figure 13 below. A living hinge can be designed such that it will not constitute a protrusion which would hinder 'slideability'.

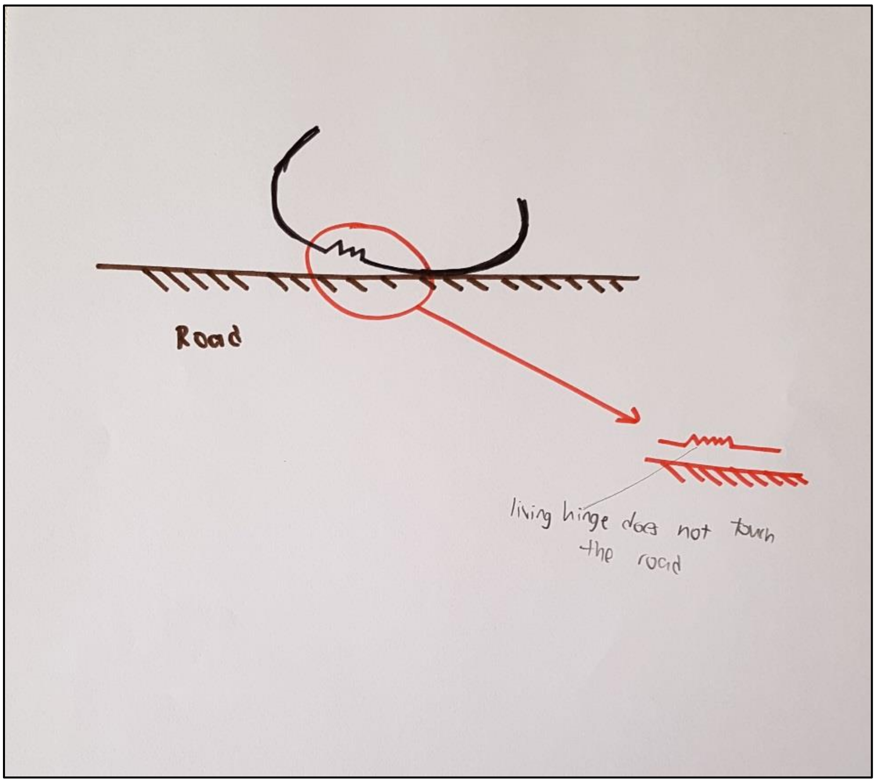


Figure 13. Incorporating a living hinge into the design of the armadillo inspired outer shell.

ix. However, there were problems with living hinges which we could not overcome, most of all, the fact that living hinges may not be able to withstand the impact of a bicycle crash.

d. Stretchable hydrogel

i. In our search for an alternative to living hinges, we were looking for a flexible material (to flex and stretch when the helmet is compressed) which is strong enough to withstand the impact of a bicycle crash. As mentioned earlier, existing patent documents contained some information on this point. However, we were looking for more detailed solutions.

iii. Our search led us to the stretchable hydrogel. This “tough gel stretches to 21 times its length, recoils and heals itself” (Harvard John A. Paulson School of Engineering and Applied Sciences (2012)). It also does not dry out.

iii. Stretchable hydrogel seems to be a relatively new material. It has been described as being suitable for a “wide range of … technological applications” (Harvard John A. Paulson School of Engineering and Applied Sciences (2012)). Based on its properties (or, at least, the ones that we have read about and understood), we think that stretchable hydrogels could potentially be used in the construction of foldable bicycle helmets.

9. **Consideration #9 – type of prototype we aimed to make and materials available to us to make the prototype**

   a. We constructed two types of prototypes: paper prototypes (we made several) and three mock-ups.

   b. A paper prototype is the first step to reduce ideas to physical form. Simple materials such as cardboard are used. There are no working parts. Our paper prototypes enabled us to explore concepts, potential problems and possible solutions in a fast, simple and cheap way. We found it useful to be able to see and feel our ideas in 3D.

   c. Once we decided on the actual design of our helmet, we proceeded to build our mock-ups.

   d. A mock-up is a prototype which shows key features and ideas and is functional in some but not all respects. When constructing our mock-ups, we focussed on the function of compressibility and slimness.

10. **Consideration #10 - the need to strike a balance between conflicting considerations**

   a. A bicycle helmet has to be protective, wearable and marketable at the same time. These goals are not necessarily compatible.

   b. For example, an outer shell with no perforations at all potentially offers maximum protection. However, the helmet would be hot to wear (due to lack of ventilation) and therefore not so wearable and marketable.

   c. Another example is as follows: a helmet made of premium materials may have better protective qualities but may be too costly to be marketable.

   d. In designing and constructing our mock-up, we bore in mind the feedback that we received from our market survey. We therefore factored in wearability (specifically, ventilation). We also bore in mind the comments of our industry mentors that was conveyed to us during the IvP Seminar that:

      i. it is important to have a hard outer shell; and

      ii. breathability (ventilation) is important.

Annexe 5

Explanation on how and why materials were chosen for use to construct our prototypes

1. For our early prototypes, we used materials that we had easy access to at home and in school, such as Post-Its, A4 sized paper, sticky tape and masking tape.

2. For our mock-up, we chose materials which appeared to us to share key characteristics of the actual materials used to make helmets for commercial sale.

3. First, we researched materials used in actual helmets. Next, based on the relevant characteristics of such materials, we identified materials that we could use to construct our prototype.

    a. Actual materials used to make the outer shell

        i. The shell for inexpensive helmets is just stamped PET (the material used for bottled water containers) or a similar plastic (Bicycle Helmet Safety Institute (n.d.)). For more expensive helmets, the shell is made of higher quality plastic, commonly, polycarbonate or acrylonitrite butadiene styrene (ABS) or composite materials such as fiberglass, lightweight carbon fibre (Bicycle Helmet Safety Institute (n.d.)).

        ii. Other materials include:

            aa. fibre-reinforced composites or thermoplastics (United States Patent Application Publication No.: US2009/0260133 A1 Pub. Date: Oct. 22, 2009 and United States Patent Application Publication No.: US2007/0157370 A1 Pub. Date: Jul. 12 2007) to make a strong yet flexible outer shell. Kevlar Mark III (a registered trademark of Honeywell) and Spectra Shield (Du Pont proprietary material) seem to fall within this category of materials (Walsh, Scott and Spagmodo (2005)); and

            bb. in more recent times, materials designed to crumple upon impact. For example, XRD (registered trademark of XRD Rogers Corporation).

    b. Inner layer

    Inner layers are usually made of expanded polystyrene (EPS)(Bicycle Helmet Safety Institute (n.d.)). Other materials used are expanded polypropylene (EPP), expanded polyurethane (EPU or PU) (Bicycle Helmet Safety Institute (n.d.)) and, in more recent times, energy absorbing plastics such as D30® (Bicycle Helmet Safety Institute (n.d.)).

    c. Other materials which have been identified as being suitable for use in safety/protective devices, and which could potentially be used for outer and/or inner layers of bicycle helmet

        i. A material which fascinates us is metallic microlattice, which one team member read about when he was researching investigations into aircraft collisions.

ii. Schaedler, Ro, Sorensen, Eckel, Yang, Carter and Jacobson (2013) wrote that, "metallic microlattices can be designed to maximise energy absorption while not transmitting a stress greater than the injury or damage threshold."

iii. Figure 13A below shows a photograph that we took of a metallic microlattice sample during a visit to the Singapore Science Centre earlier this year.

Figure 13A. A photograph of a metallic microlattice sample. This sample was exhibited at the Singapore Science Centre earlier this year.

d. Straps

Helmet straps are generally made of nylon or polypropylene (Bicycle Helmet Safety Institute (n.d.)).

e. Buckles

i. Most current bicycle helmets are plastic or nylon of the Fastex type (a trademarked ITW/Nexus band) with side pinch release (Bicycle Helmet Safety Institute (n.d.)).

ii. We were attracted to the Fidlock® magnetic fastener used in the Morpher, Biologic Pango and Etto City Safe helmets (existing foldable helmets in the market). We tried to use the underlying concept when constructing the strap system of our mock-up.

4. For constructing our mock-ups, we looked for easy-to-find /easy-to-access materials which appear to have characteristics similar to that of materials used to make actual helmets for commercial sale.

5. For example, in an actual bicycle helmet for commercial sale, polycarbonate or ABS is commonly used to make the outer shell. We identified hardness and smoothness of surface as key characteristics of these materials. We then sourced for materials accessible to us which appeared to share these key characteristics. Our final choice of material to make the outer shell of our mock-up was pelletized polycaprolactone, which we purchased from a hobby shop in Woodlands which caters to robotics enthusiasts.

6. A table of the materials we shortlisted to build our final prototype and the materials that we ultimately use is as follows:

Part of helmet	Relevant characteristics of actual materials used to construct helmets for commercial sale	Materials shortlisted to build our final prototype	Material ultimately used to build our final prototype
Outer shell (Rigid)	Hard and smooth	• Flexible 3D printing filaments • Papier-mache • Polypropylene sheets • Fimo® Air Light Modelling clay • Pelletized polycaprolactone (InstaMorph®)	Pelletized polycaprolactone (InstaMorph®)
Outer shell (Tough but flexible)	Hard, flexible and smooth	• Sculpey® Bake and Bend • Silk Clay® • Polypropylene sheets	Not applicable (we did not pursue this variation of the outer shell)

Material to join parts	Flexible material which does not overstretch	• Thin silicone sheets used in kitchen • Commercial ultra- thin silicon sheets • Elastic band used in tailoring • Cloth ribbon • Press studs • Velcro • Plastic buckles	• Elastic band used in tailoring (all 3 mock-ups) • Cloth ribbon (1st and 3rd mock-ups) • Plastic buckles (1st mock-up) • Press studs (2nd mock-up) • Velcro (2nd and 3rd mock-ups)
Inner layer	• Foam-like, able to compress upon impact (may or may not bounce back) • 15-20 mm thick	• Kitchen sponges • Foam sheets • Foam strips • Felt sheets • Modelling clay	For the prototype of the inner layer: • Kitchen sponges For all three mock-ups: • Modelling clay • Foam strips
Strap system	• Straps: Flexible and will not snap under pressure • Conventional plastic buckle: Holds the straps together and will not break under pressure. • Fidlock magnetic buckle  (Source of photo: http://www.thinkbiologic.com/products/pango-folding-helmet)	• Elastic band used in tailoring • Cloth ribbon • Plastic tape • Plastic buckles •Magnetic material • Velcro	• Elastic band used in tailoring (all 3 mock-ups) • Plastic tape (3rd mock-up) • Plastic buckles (1st and 2nd mock-up) • Velcro to simulate the effect of a Fidlock® magnetic buckle (3rd mock-up)

<u>**Annexe 5**</u>

Documentation of the prototype/ product development stages. You may use drawings, photographs or videos

Stage 1: Generating ideas – research, early sketches, inspiration from daily life

Main sources of inspiration

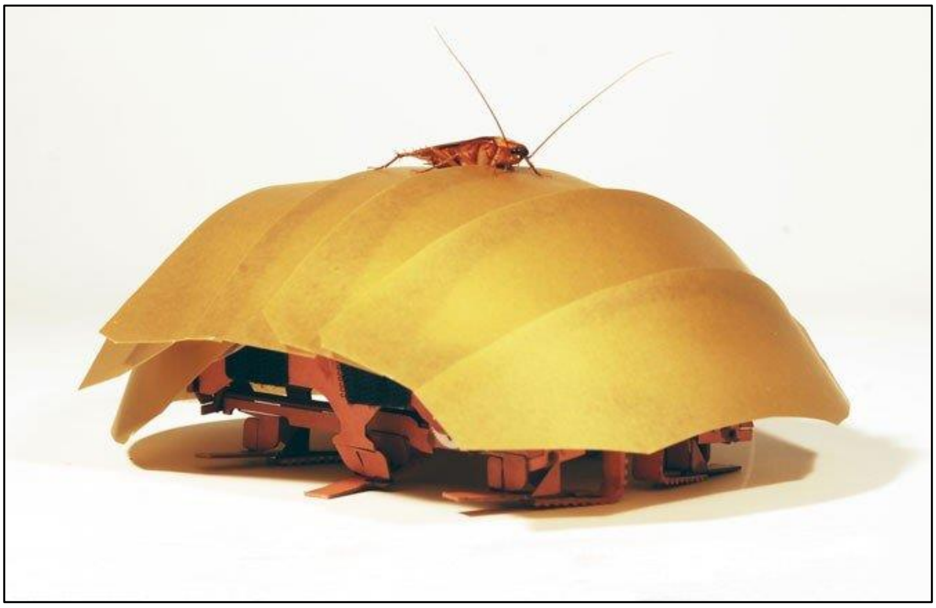


Figure 14. Robot cockroach inspired by the American cockroach. A live American cockroach sits on top.
Source:https://www.seeker.com/cockroach-robot-squishes-flat-to-get-through-cracks1770858062.html

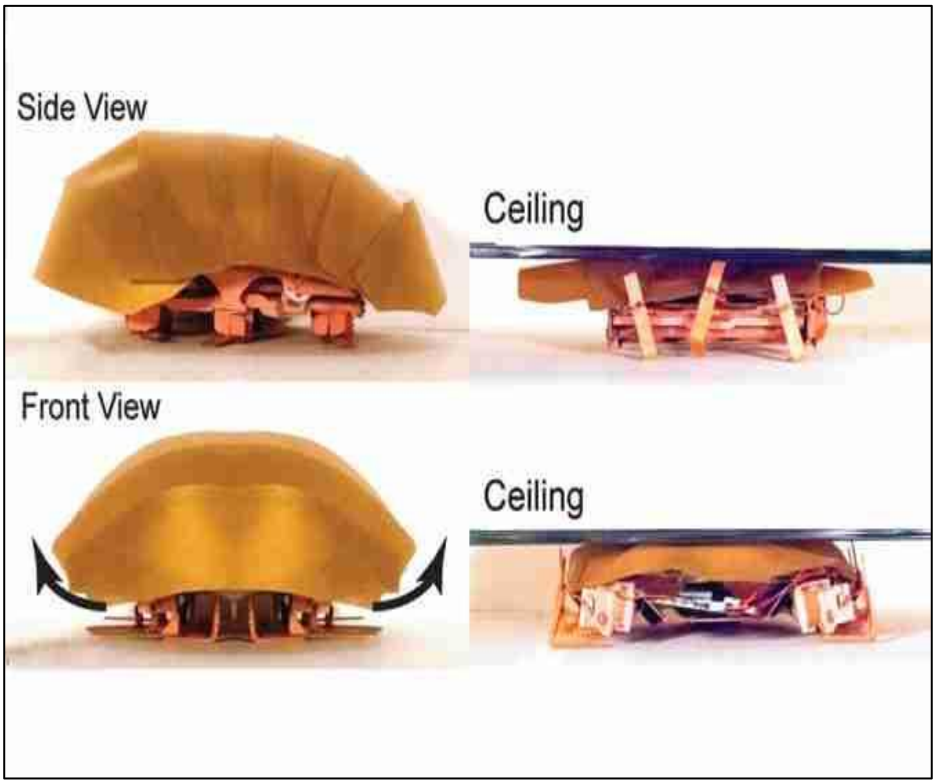


Figure 15. How a robot cockroach can compress to navigate narrow spaces.
Source:https://www.seeker.com/cockroach-robot-squishes-flat-to-get-through-cracks1770858062.html

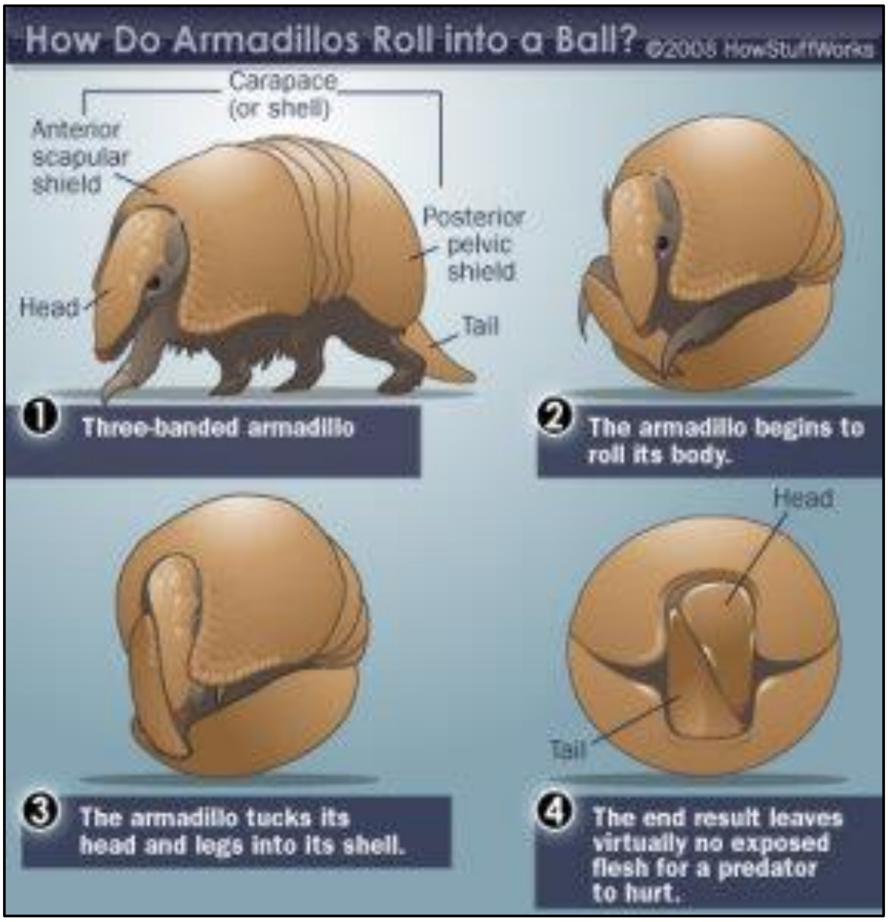


Figure 16. How an armadillo turns itself into a ball.
Source: https://animals.howstuffworks.com/mammals/armadillo-ball1.htm

Sketches of some ideas during the early days

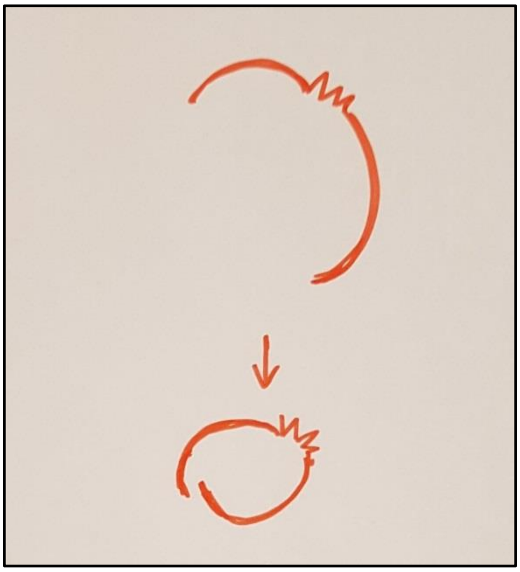


Figure 17. Side view of armadillo-inspired outer shell – sketch 1

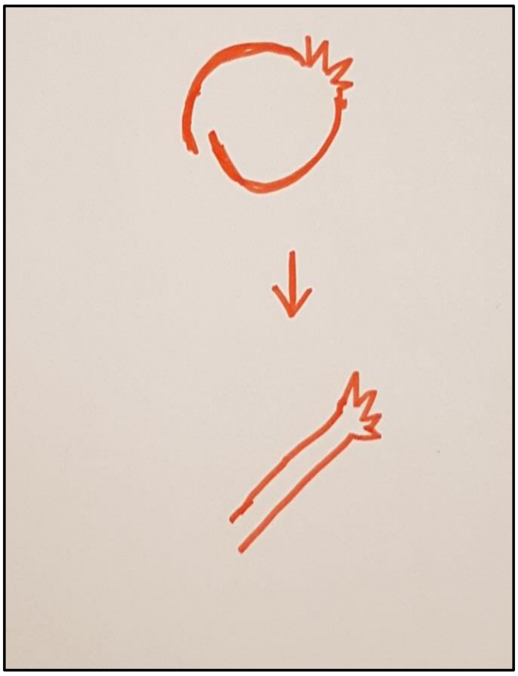


Figure 18. Side view of armadillo-inspired outer shell - sketch 2

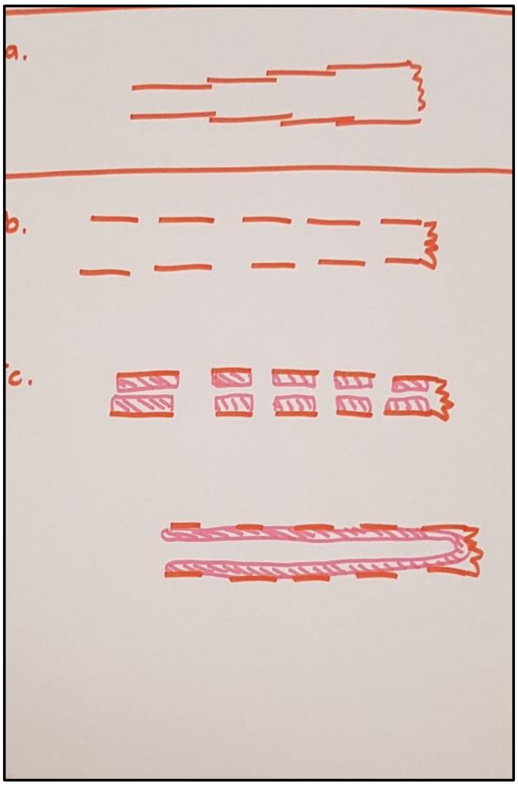


Figure 19. Side view of armadillo-inspired outer shells which are not made of out a single solid piece of material.

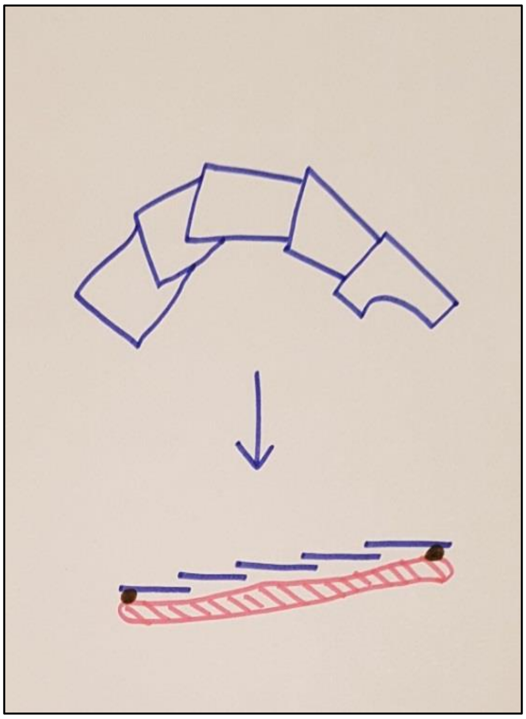


Figure 20. Robot cockroach-inspired outer shell – side views

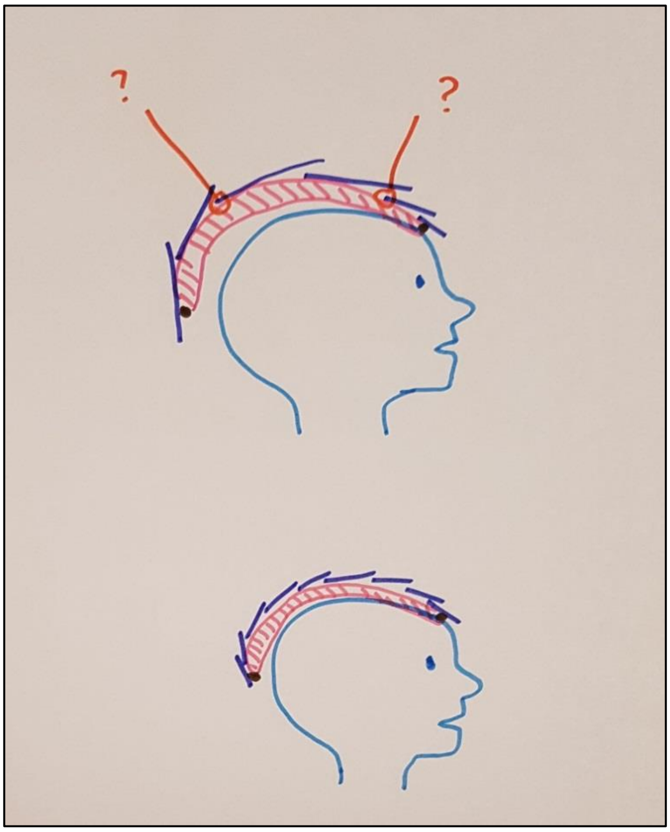


Figure 21. Side view of robot cockroach-inspired outer shell atop a human head.

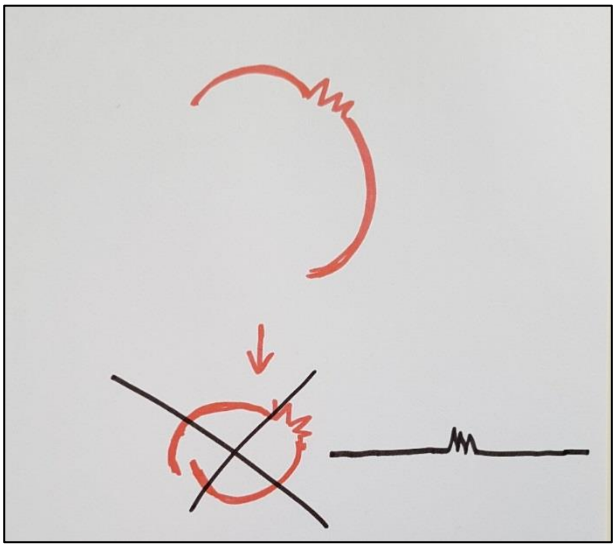


Figure 22. Corrections to original armadillo-inspired helmet (side view).

Figure 23. Photograph of the underside of a Carrera foldable helmet belonging to one group member. The design of this foldable helmet was one source of inspiration for the sketch shown in Figure 24 below.

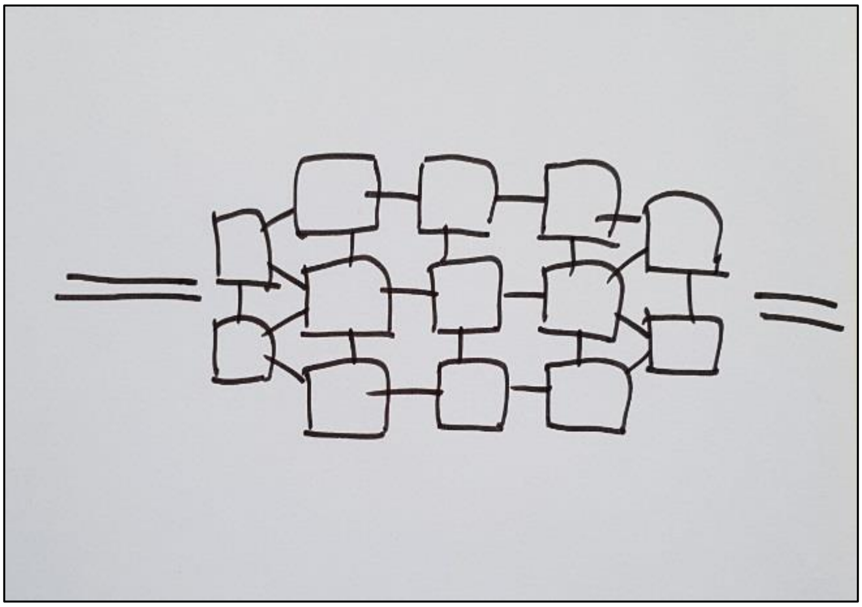


Figure 24. An early sketch of the inner layer of our group's folding helmet.

Stage 2: Exploring possibilities, working with our ten considerations, addressing problems – paper prototypes, sketches, notes

Sketches of the robot cockroach inspired outer shell, the armadillo inspired outer shell and the inner layer

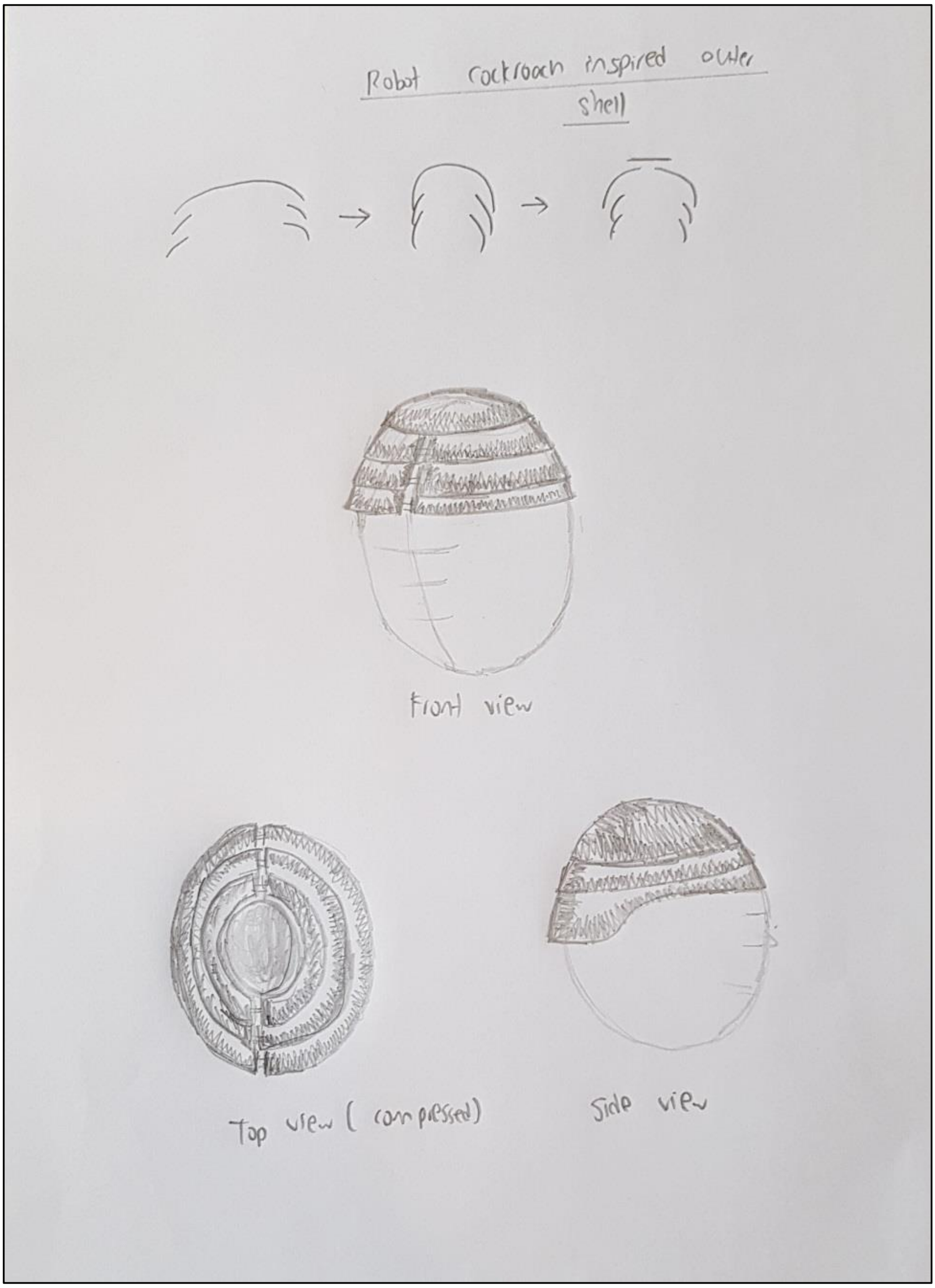


Figure 25. Sketches of our robot cockroach inspired outer shell.

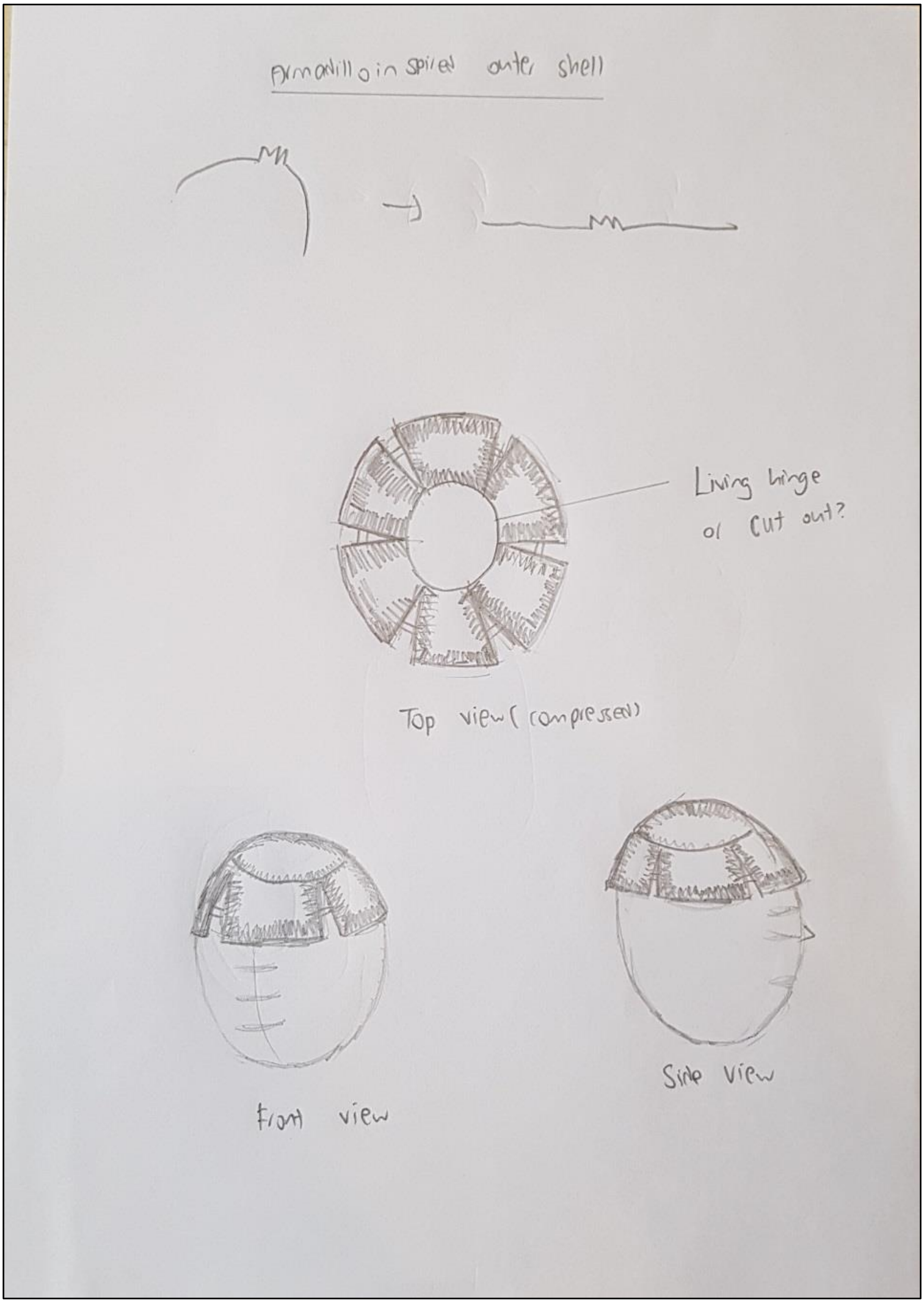


Figure 26. Sketches of our armadillo inspired outer shell.

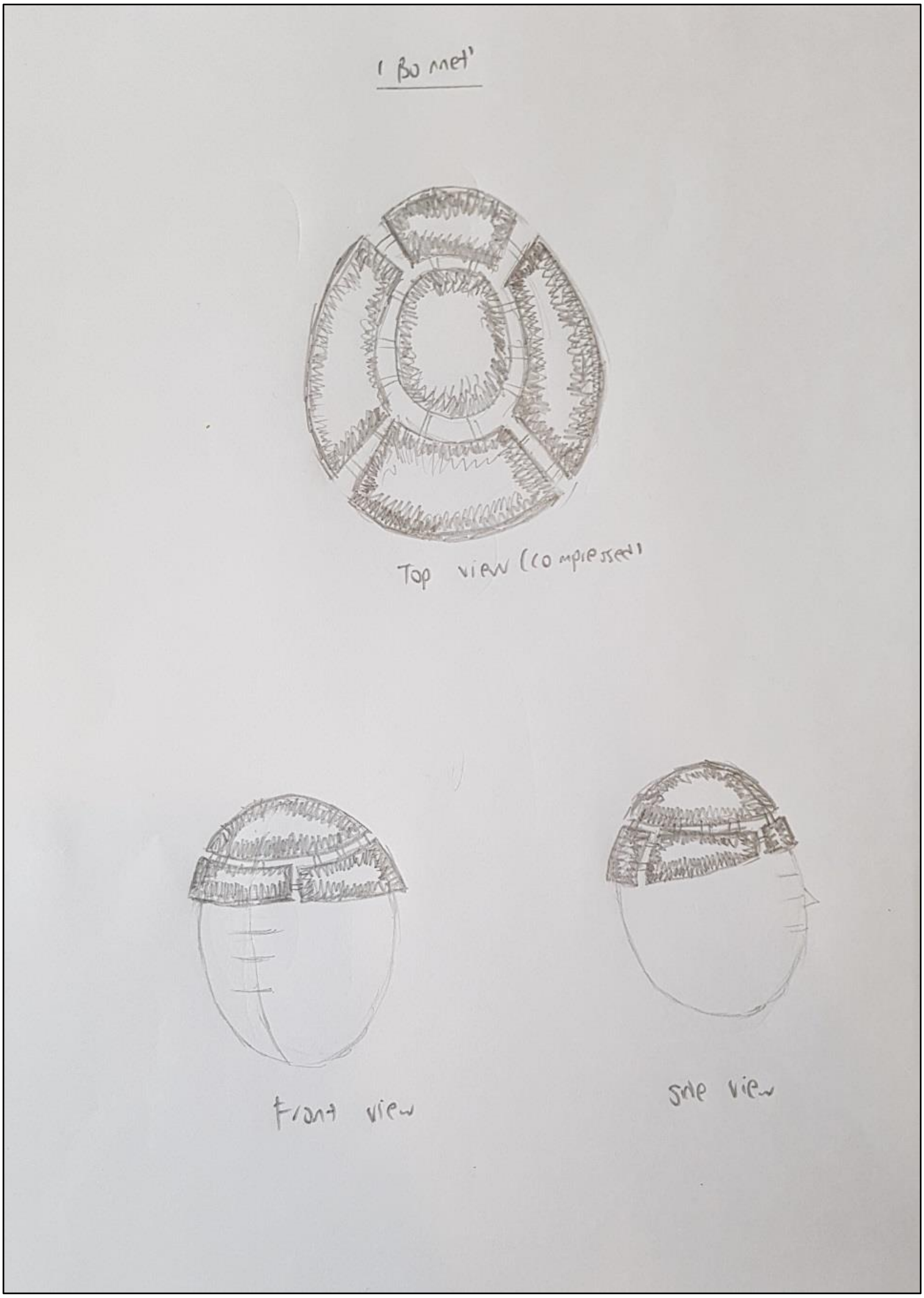


Figure 27. Sketches of our inner layer 'bonnet', which could potentially also be used for the outer shell.

First paper prototype – robot cockroach inspired outer shell

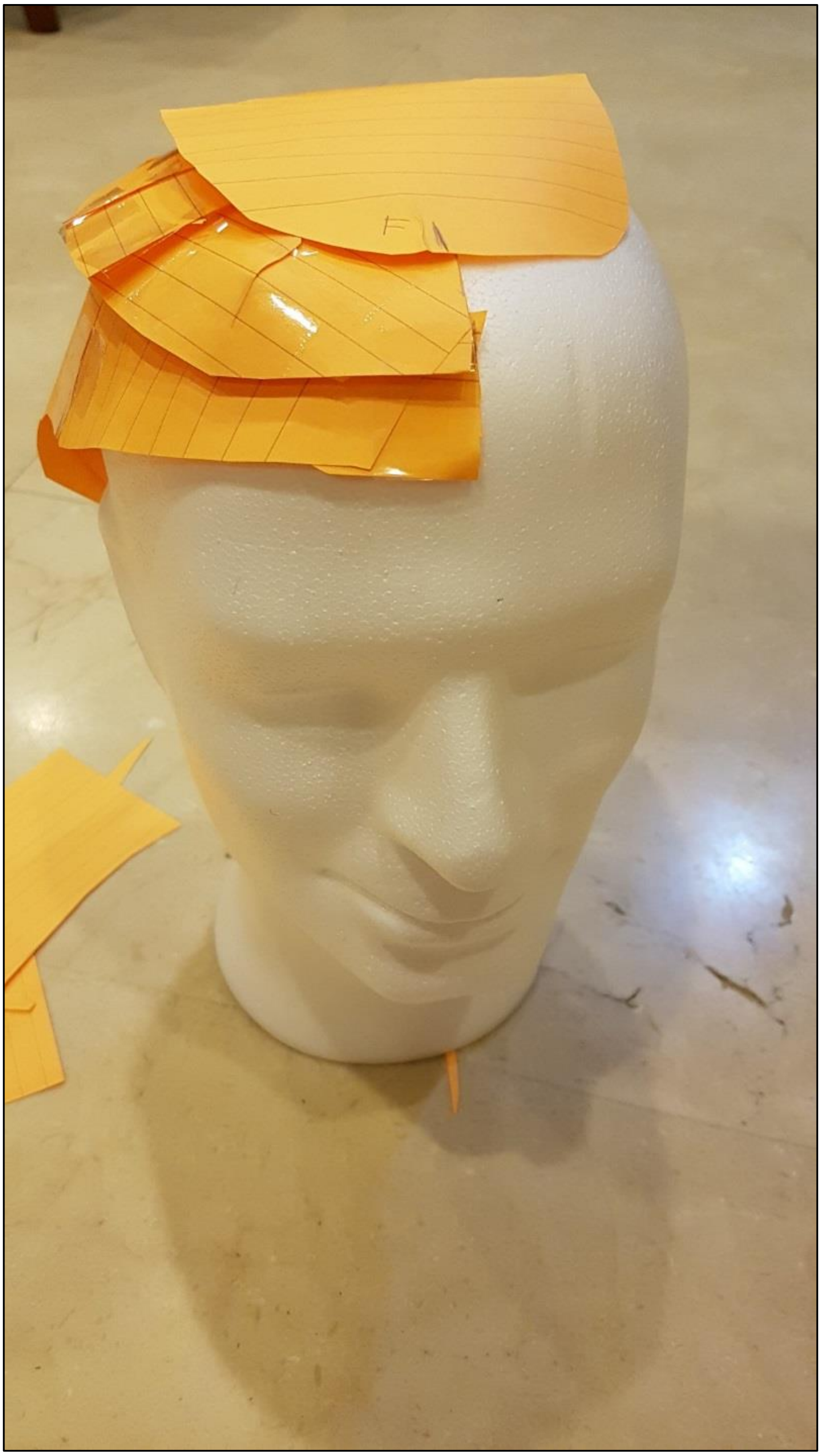


Figure 28. Photograph of first paper prototype inspired by robot cockroach – front view.

Figure 29. Photograph of first paper prototype inspired by robot cockroach – side view.

Figure 30. Photograph of first paper prototype inspired by robot cockroach – the different plates (one side only)

First paper prototype – armadillo inspired outer shell

Figure 31. Post-Its (cut into shape), cellophane tape, double-sided tape and Blu-tack were some of the materials used to make our first paper prototypes.

Figure 32. Photograph of first paper prototype inspired by the armadillo – side view.

Figure 33. Photograph of first paper prototype inspired by the armadillo – top view (compressed).

First and second paper prototypes – inner layer

Figure 34. Photograph of first paper prototype of 'bonnet' – top view (compressed).
What actually turned out in real life was very different from what we had first imagined!

Figure 35. Photograph of first paper prototype of 'bonnet' – top view (not compressed).

Figure 36. Photograph of first paper prototype of ‘bonnet’ – side view.

Figure 37. We used our first paper prototype to make 'stencils' of the various parts of the bonnet.

Figure 38. We then used the 'stencils' to cut out the parts for our second paper prototype.

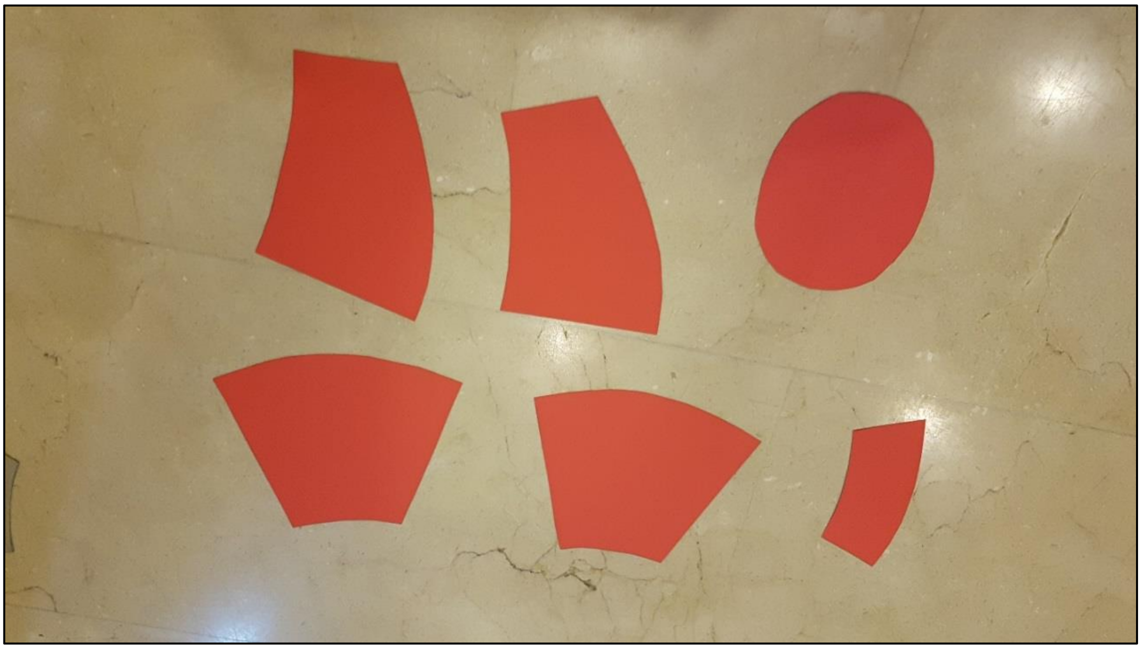


Figure 39. Parts cut out from the ‘stencils’ for use to construct our second paper prototype. For the second prototype, we cut each part into sub-parts.

Figure 40. Photograph of second paper prototype of ‘bonnet’ under construction.

Figure 41. Photograph of second paper prototype of ‘bonnet’ – side view.

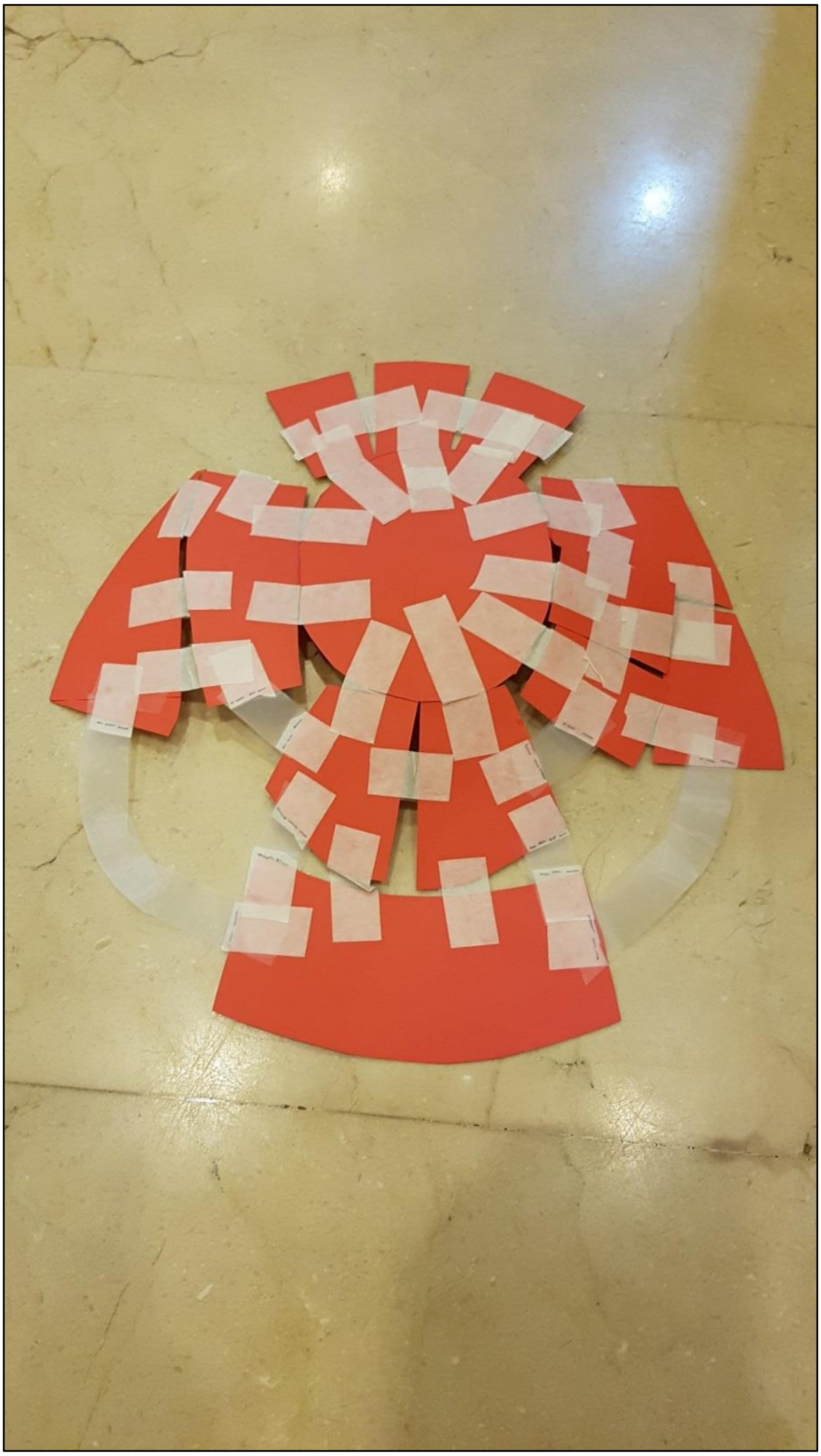


Figure 42. Photograph of second paper prototype of 'bonnet' – top view (compressed).

Two failed paper prototypes and the sketches from which they were produced. These were done when we were exploring design options other than the robot cockroach, armadillo and 'bonnet' ones

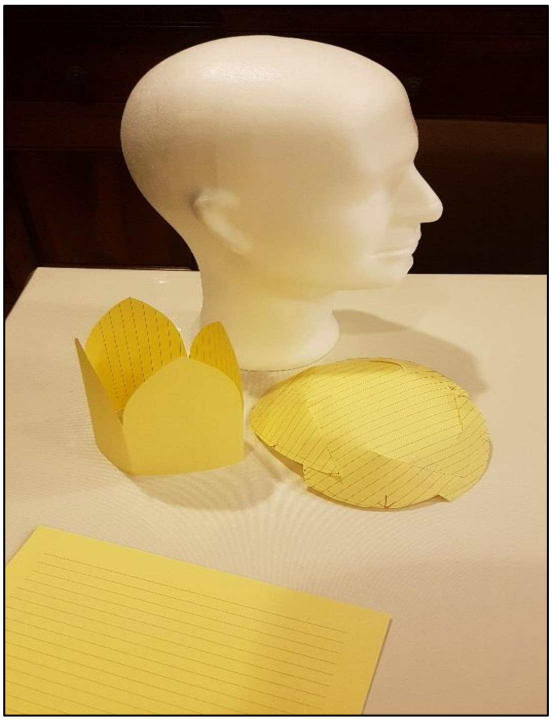


Figure 43. Two paper prototypes which showed why the underlying ideas we thought of do not work.

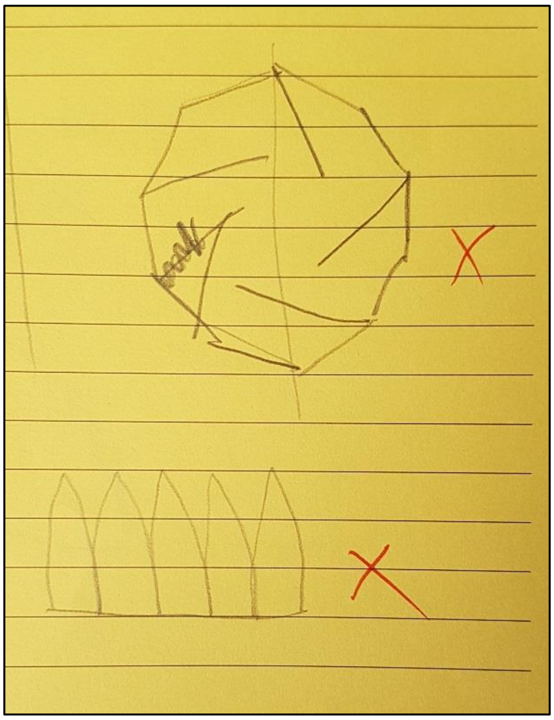


Figure 44. The design on top was used to make the 3D paper prototype on the right in Figure 43. The design at the bottom was used to make the 3D paper prototype on the left in Figure 43.

Failed experiment with Sculpey's Bake and Bend – this was our attempt at making the mock-up of a flexible outer shell, using the robot cockroach inspired design

Figure 45. Material and equipment used to make small versions of two robot cockroach inspired plates.

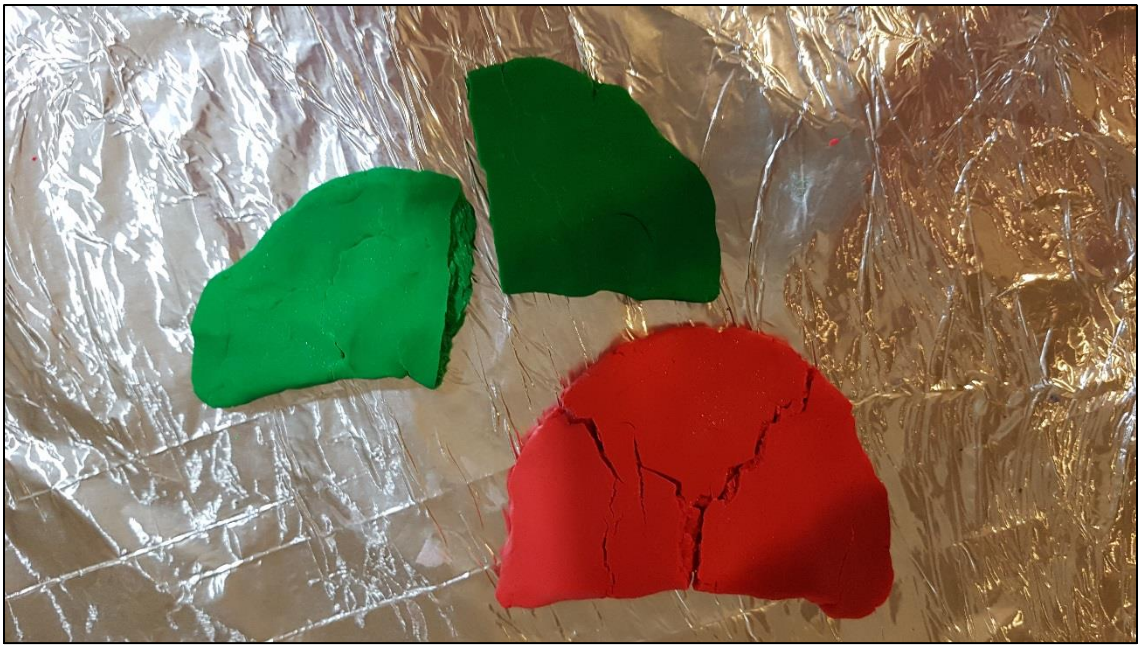


Figure 46. The baked plates broke (they were supposed to bend).

Stage 3: Making final and life-sized paper prototypes of our helmet in our finalised design (armadillo inspired outershell + inner layer in the form of a 'bonnet'/cap)

Preparing a paper cap to mark out the parts of a rider's head which have to be covered by the helmet

Figure 47. Sticking the first row of Post Its onto the polystyrene head

Figure 48. Sticking on the next row of Post Its and covering the top of the polystyrene head

The completed paper cap

Figure 49. Front view

Figure 50. Back view

Figure 51. Right side – straight edge above the ear

Figure 52. Left side – curved edge above the ear.

Using the paper cap to prepare a ≈ 20mm thick foam cap in order to enable the preparation of a life-sized paper prototype of the outer shell

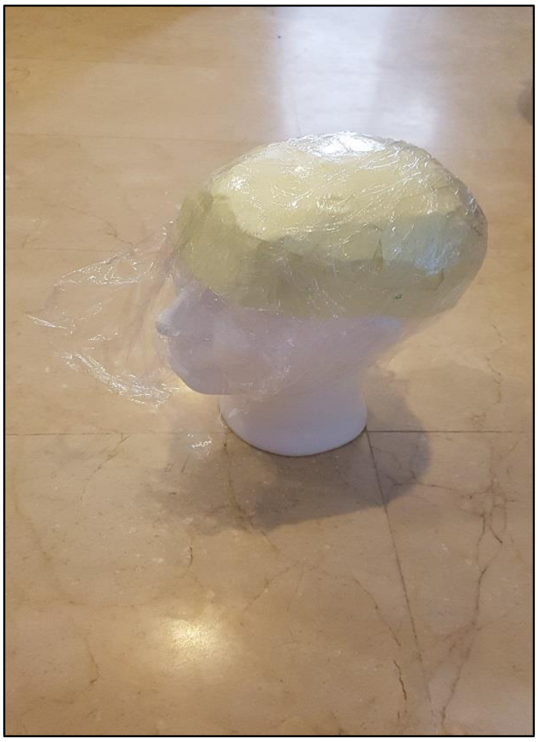


Figure 53. Placing cling film over the paper cap. The paper cap is to guide the making of the foam cap. The foam cap would be stuck onto the cling film. The cling film would make it easy to remove the foam cap from the top of the paper cap.

Figure 54. Sticking on layer upon layer of foam sheets.

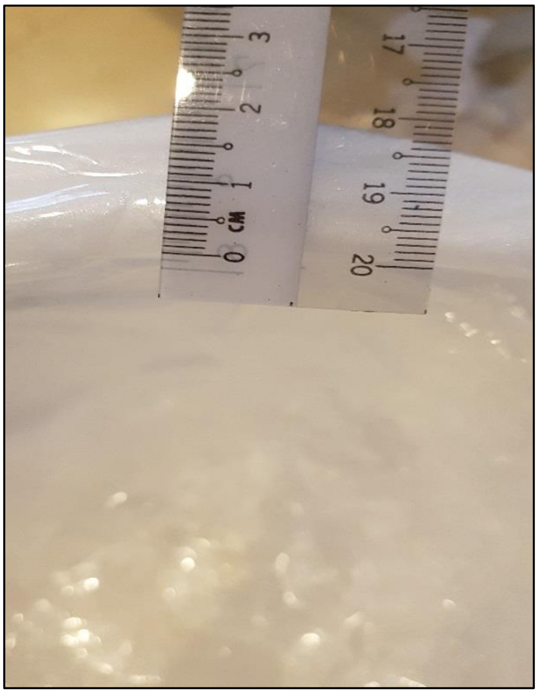


Figure 55. Aiming for a thickness of about 20mm.

Figure 56. Almost completed foam cap.

Using the foam cap to prepare a life-sized paper prototype of the outer shell

Figure 57. Sticking on Post Its (no need for cling film because the foam cap is held together by masking tape).

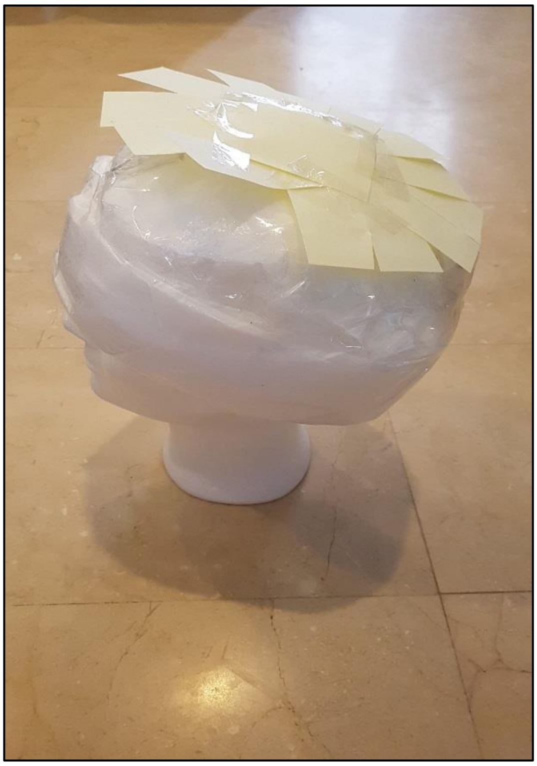


Figure 58. Sticking on more Post Its.

Figure 59. Completed life-sized outer shell on the right. The foam cap used as a guide to construct it sits atop the polystyrene head on the left.

Figure 60. The paper cap that was used as a guide to make the foam cap is on the left. The completed life-sized outer shell is on the right.

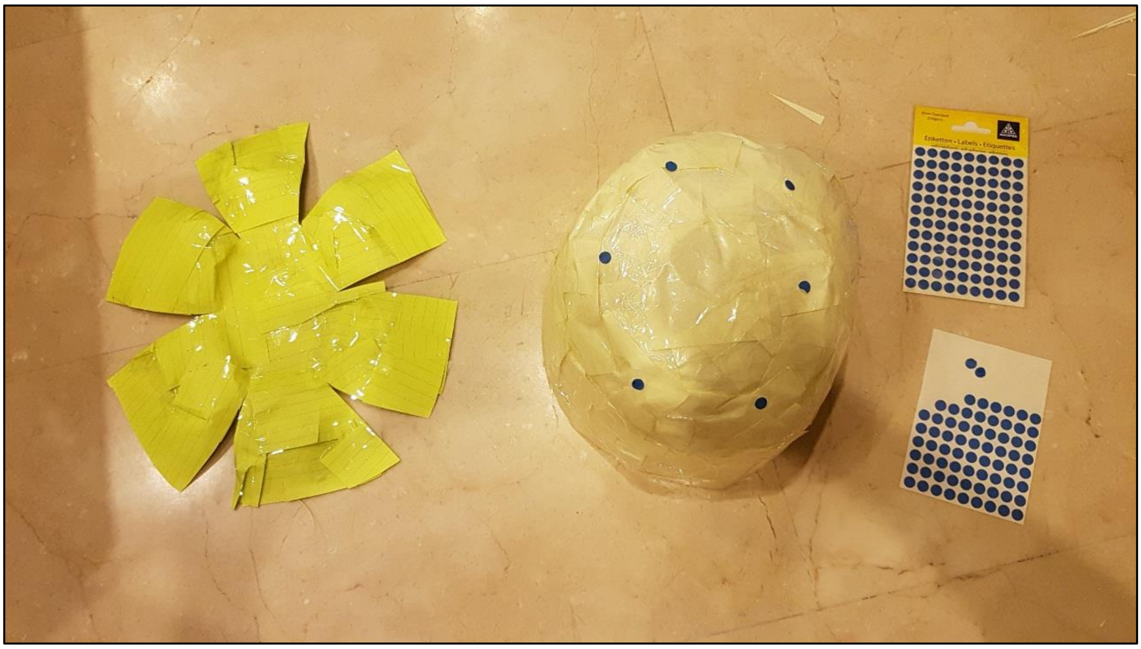


Figure 61. Preparing to cut open the life-sized outer shell according to the pattern of our first paper prototype.

Figure 62. The life size outer shell (on the right) after it has been cut open according to the pattern of our first paper prototype (on the left).

Figure 63. Sticking fabric tape onto underside of outer shell in order to make 'belt holders' to thread a strap through.

Figure 64. Threading the strap through the 'belt holders'.

Figure 65. Threading of strap into 'belt holders' completed and plastic buckle attached onto the ends.

Figure 66. Buckle fastened and outer shell turned right side up. This is how the outer shell looks like in non-compressed state.

Making more refined, life-sized versions of the inner 'bonnet'

Figure 67. Starting the process of putting cling film on top of paper cap, then sticking on the Post Its.

Figure 68. Sticking on more Post Its.

Figure 69. First version in the process of construction.

Figure 70. Completed first version. We purposely made only one side, because it was difficult to achieve symmetry. Our plan was to just use the side that had been made in mirror image to make the mock-up if this version in chosen.

Figure 71. First version cut up for compressibility.

Figure 72. Completed second version. As in the case of the first version, we purposely made only one side of this version.

Figure 73. Completed second version, cut open to show compressibility.

Figure 74. Clockwise from the top: Completed second version (cut open), completed first version (cut open) and a third version (incomplete and cut open).

Working on paper prototypes of the strap system

Figure 75. Using raffia string to decide on where to place the two sets of strap systems.

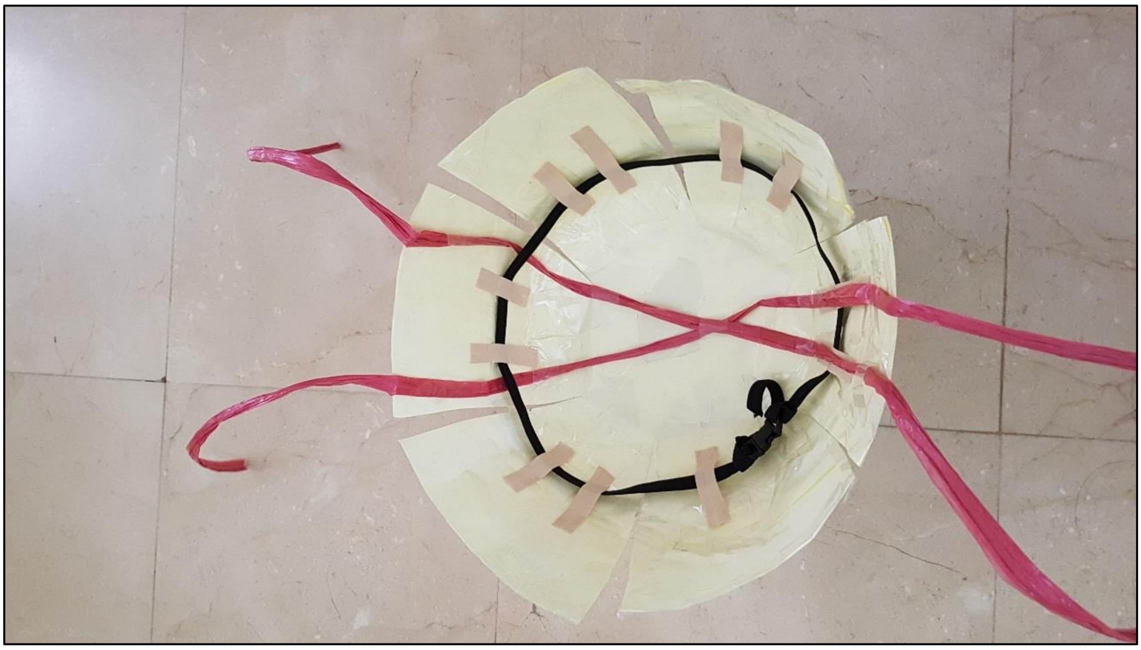


Figure 76. Underside of the outer layer showing how the strap system will be attached to each layer; in criss-cross fashion.

Stage 4: Making the mock-up – first attempt at the inner layer

<u>Making templates to enable us to cut sponge shapes which would be the parts for the inner layer</u>

Figure 77. Using the second version of our life-sized paper prototype of the inner layer to prepare templates of the various parts of the prototype.

Figure 78. Using the templates to cut out pieces of sponge to make the inner layer.

Making the inner layer

Figure 79. We used two layers of 10 mm thick sponge. We put the straps in between the layers to secure them.

Figure 80. We tried to used glue to stick the layers together.

Figure 81. Attaching the panels.

Figure 82. Side view of completed inner layer.

Figure 83. Top view of the completed inner layer (compressed state).

Stage 5: Modifying the design of our helmet

We presented this first prototype of our inner layer (the prototype made of sponge mentioned above) at the IvP Seminar. We received the following feedback from industry mentors:

A hard outer layer is important.

We should use two colours to distinguish the inner and the outer layers.

Breathability is important.

Bearing in mind this feedback, we adopted the design of our sponge prototype but modified the construction of the outer shell and inner layer by merging both layers, instead of making a two-layer helmet. The outer layer was fastened directly on top of the inner layer.

Stage 6: Constructing mock-up #1

Figure 84. We used our sponge prototype to create thin base plates out of Silk Clay, a brand of air drying clay which feels foam-like when dry.

Figure 85. Using double-sided sticky tape to position the straps onto the thin base plates before adding on the small pieces of thick foam tape.

Figure 86. We used multiple pieces of hard foam tape of 10mm thickness to fill up the plates before using Silk Clay to fill up the gaps. The purpose of using the hard foam tape was to ensure that the thickness of the shell was 10 mm. We made two shells (one on top of the other) in order to achieve the desired thickness of 20mm. The thickness of the inner foam layer of a typical bicycle helmet ranges from 15mm to 20mm.

Figure 87. Another photo showing the addition of multiple pieces of hard foam tape. After a while, we realized that it was easier to work with smaller rather than larger pieces of the hard foam tape. After putting on all these pieces of hard foam tape, we filled the gaps with Silk Clay. We also used Silk Clay to shape the sides and surfaces of the plates.

Figure 88. The inner layer after the gaps had been filled out with Silk Clay and the surfaces smoothened and shaped.

Figure 89. Attaching the plastic chin buckle. This was done only after the hard outer layer was added.

Figure 90. Experimenting with Instamorph before starting the construction of the hard outer layer of the helmet.

Figure 91. Applying warm Instamorph directly onto the Silk Clay plates so that the Instamorph would stick to the Silk Clay. We had difficulty making sheets of Instamorph (see front plate) and applying the Instamorph in small batches also did not work (see top plate). Both techniques resulted in unevenly coated and bumpy surfaces.

Figure 92. Hard, white Instamorph outer layer of our helmet stuck directly onto the black Silk Clay foam-like inner layer.

Figure 93. Working on the strap system to hold the helmet together when worn – photo 1.

Figure 94. Working on the strap system to hold the helmet together when worn – photo 2.

Figure 95. Working on the strap system to hold the helmet together when worn – photo 3.

Figure 96. Working on the strap system to hold the helmet together when worn – photo 4.

Figure 97. Completed mock-up #1.

Stage 7: Constructing mock-up #2

Figure 98. Attaching straps and joining parts to the top of the bottom half of the inner layer.

Figure 99. For our mock-up #2, we made the top half of the inner layer as stand-alone pieces (i.e. not fused to the bottom half of the inner layer). We felt it would be easier to apply the Instamorph this way.

Figure 100. Using some clay to ‘glue’ the bottom and top halves of the inner layer together. At the stage, the hard outer shell represented by the Instamorph has already been fused onto the top half of the inner layer.

Figure 101. This method of construction (constructing the bottom and top halves of the inner layer separately) resulted in a problem. The clay shrinks a bit and also curls up at the sides when it dries out. Therefore, the shapes of the bottom and top halves of the inner layer were not identical. The two halves also could not be stacked without gaps. The problem can be seen in this photograph - see where the red arrow is pointing to. There are gaps between the bottom and top halves of that clay plate. It was possible to fill in the gaps with more clay and smoothen out the shape to make it look even. However, this resulted in plates which were thicker than necessary. That is why our mock-up #2 is thicker than our mock-up #1. For mock-up #1, we had fused the bottom and the top halves of the inner layer and let the fused layer dry out before we added the Instamorph.

Figure 102. This is the underside of our mock-up #2. We were working on an alternative strap system to hold the helmet plates together in a compressed position (i.e. when worn). For mock up #1, we made 'belt loops' attached to the plates and threaded a 'belt' through the loops. For mock-up #2, we experimented with press studs and Velcro. In this photograph, there are two belts on the polystyrene head. On top is a black belt with press studs for pressing into corresponding press studs glued to underside of the helmet plates. Below the black belt is a white Velcro strip for attaching onto Velcro bits glued to the underside of the helmet plates.

We concluded that 'belt loops' (what we did for mock-up #1) are the best. We will make 'belt loops' for our third and final mock-up.

Figure 103. Completed mock-up #2.

Figure 104. Completed mock-up #1 in compressed state and sitting in a plastic document carry case (left) and completed mock-up #2 on polystyrene head (right).

Stage 8: Construction of mock-up #3 (the final mock-up)

Figure 105. Making a 'mould' out of white Velcro strips in order to make a trough in the underside of the bottom half of the inner layer.

Figure 106. Using the sponge prototype of the inner layer as a stencil to create base plates for mock-up #3.

Figure 107. Work-in-progress (photo 1).

Figure 108. Work-in-progress (photo 2).

Figure 109. Work-in-progress (photo 3).

Figure 110. Work-in-progress (photo 4).

Figure 111. Work-in-progress (photo 5).

Figure 112. Work-in-progress (photo 6).

Figure 113. Work-in-progress (photo 7).

Figure 114. Work-in-progress (photo 8).

Figure 115. Completed mock-up #3 (compressed state, outer layer)

Figure 116. Completed mock-up #3 (compressed state, underside of inner layer)

Figure 117. Completed mock-up #3 on life-sized polystyrene head.

Figure 118. Use of Velcro to simulate the Fidlock® magnetic buckle.

Annexe 6

Details and results of test iterations

Instructions from the school:
"Write down your prototype/ product test criteria and check against it if it works. Identify areas of weakness for modification. Indicate the test iteration and date of test."

Test Iteration: 1 Item tested: Prototype of inner layer	Tick			Remarks
Test Date: 10 May 2018	Pass	Fail	Potential Failure	
Test Criteria 1 Compressibility of the inner shell	√			We fixed problems at the paper prototyping stage, hence we expected to fulfil this test criteria 1.
Test Criteria 2 Fit – whether the prototype fits snugly onto a life-sized polystyrene head		√		The inner layer constructed out of sponges does not follow the contours of the polystyrene head.

Test Iteration: 2 Item tested: Mock-up #1	Tick			Remarks
Test Date: 2 July 2018	Pass	Fail	Potential Failure	
Test Criteria 1 Compressibility of the fused inner layer and outer shell to a total thickness of less than 2.5 inches	√			When compressed, our mock-up #1 is approximately 1 inch thick.
Test Criteria 2 Fit – whether the prototype fits snugly onto a life-sized polystyrene head			√	We made some errors in construction, so the fit was not as good as it could get. The fit was also affected by difficulties using Instamorph. If we cannot overcome these difficulties, we will use a different material to construct the hard outer layer.
Design flaw highlighted by industry mentor		√		Our industry mentor pointed out that the plastic buckle we used in the strap system to hold to helmet plates together when the helmet is in use may cause damage to the wearer in the event of an accident.

Test Iteration: 3 Item tested: Mock-up #2	Tick			Remarks
Test Date: 8 July 2018	Pass	Fail	Potential Failure	
Test Criteria 1 Compressibility of the fused inner layer and outer shell to a total thickness of less than 2.5 inches	√			When compressed, our mock-up #2 is approximately 1 .25 to 1.5 inches thick.
Test Criteria 2 Fit – whether the prototype fits snugly onto a life-sized polystyrene head			√	We replaced the buckle in the strap system to hold to helmet plates together with press studs. However, this still resulted in slight protrusions that may lead to safety issues. It was also difficult to position the press studs to ensure that the strap fitted the underside of the inner layer smoothly. We tried to construct a second strap system on this prototype using Velcro. While the fit was better, it was difficult to position and handle the Velcro strap.

Test Iteration: 4 Item tested: Mock-up #3	Tick			Remarks
Test Date: 26 July 2018	Pass	Fail	Potential Failure	
Test Criteria 1 Compressibility of the fused inner layer and outer shell to a total thickness of less than 2.5 inches	√			When compressed, our mock-up #3 is approximately 1 inch thick (specifically, between 2 to 2.5 cm thick).
Test Criteria 2 Fit – whether the prototype fits snugly onto a life-sized polystyrene head	√			We built a 'trough' into the underside of the inner layer into which we placed the strap intended to hold the plates together. We also used Velcro to simulate a Fidlock® magnetic buckle. In this way, the strap system to hold to helmet plates together was flush with the underside of the inner layer. No protruding parts which may injure the wearer in the event of an accident.

Annexe 7

Ventilation vs. safety

One of the considerations that guided the design of our helmet

- Need to strike a balance between conflicting considerations.

- We have explained this point in our log book as follows:

"A bicycle helmet has to be protective, wearable and marketable at the same time. These goals are not necessarily compatible. For example, an outer shell with no perforations at all potentially offers maximum protection. However, the helmet would be hot to wear (due to lack of ventilation) and therefore not so wearable and marketable. A helmet made of premium materials may have better protective qualities but may be too costly to be marketable."

Ventilation vs. safety

More 'breathability' — Midpoint — Potential for more safety

Do not wear a helmet.

Safety of utmost importance. No gaps at all in helmet.

There are possible problems with an outer shell of greater surface area or size. For example, increased mass may result in increased force upon impact (Newton's Second Law of Motion).

"A major theme in the helmet market since 1997 has been more and larger air vents. All major manufacturers now have hyper-ventilated models."
- The Bicycle Helmet Safety Institute

Sources of photographs are acknowledged on slide 28.

Designing our helmet:
Striking a balance between ventilation & safety

More breathability — Midpoint — Potential for more safety

- Breathability is an important factor for several of the people we surveyed. Our industry mentors also highlighted to us that breathability is important.

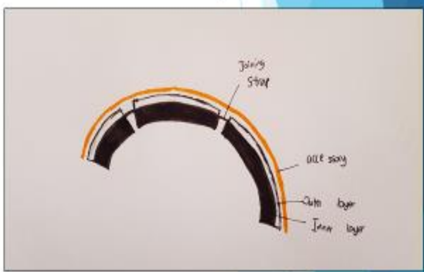
- "[I]mproving thermal wear comfort [is important and is] a goal which cycling helmet manufacturers have been working on for some time."
  - Reto Zanettin, Swiss Federal Laboratories for Materials Science and Technology (2016)

- We benchmarked against existing solutions. Our helmet design does not have gaps larger than the Carrera, which has passed safety tests and is available for sale commercially.

- We feel that our current balance between breathability and safety can be maintained.

Our helmet: how to increase safety if required?

More breathability — Midpoint — Potential for more safety



- We propose the addition of an optional accessory known in the cycling world as an 'aeroshell' for users who want more safety. A sketch of our proposed aeroshell from side view is shown in the photograph above.

Example of an aeroshell which has been produced commercially and is currently available for sale as an optional accessory

Lazer Z1 (left) & aeroshell (right)

"The element of the Lazer Z1 that stands out most is that it has been designed with ventilation in mind, with 30 vents throughout the body. ... [It] also comes with an aeroshell, which covers the top to improve the aerodynamics or keep you warm in cold weather, depending on how you look at it."

Source of photograph and quote:
https://road.cc/content/buyers-guide/214305-17-best-high-performance-helmets-combine-light-weight-aerodynamics-and

How our proposed aeroshell would differ from existing ones on the market

- Existing aeroshells
  - Intended to help prevent loss of body heat from the wearer's head, protect against rain and snow or to improve aerodynamics.
- Our proposed aeroshell
  - Intended to provide additional protection in the event of an accident.
  - Customizable so that users can decide how many (or how few) ventilating holes they want.
  - Foldable (existing aeroshells are for use with non-foldable helmets. Like the helmets, they are rigid and cannot be folded).

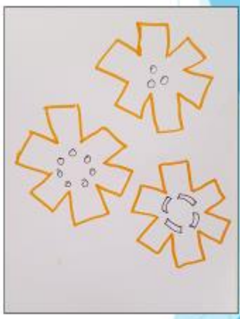
Paper prototype of our proposed aeroshell

Aeroshell is worn over the helmet, functions as additional outer layer.

Above: Aeroshell atop helmet.
Right: Aeroshell in compressed state.

Possible ways to customize the accessory:

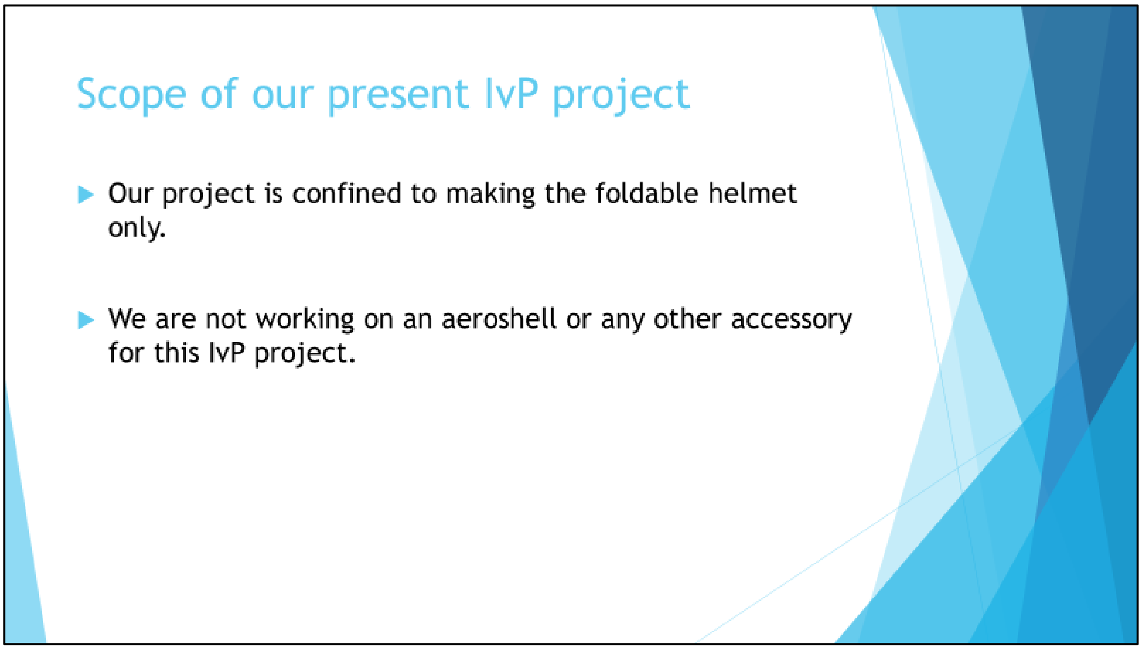
- number, location & shape of ventilating holes
- choice of colour
- addition of reflectors
- make it glow-in-the-dark?



Future work – some things to think about

- How to attach accessory to helmet?
  - Possibility #1: clip-on (like existing aeroshells)
  - Possibility #2: use of embedded magnets? (idea inspired by the Fidlock® magnetic fastener)
  - Possibility #3: second set of chin straps (idea borrowed from the VICIS Zero 1)
- Material to make working prototype of accessory?
  - Proposed starting point: materials used to make a strong but flexible outer shell.

PLEASE NOTE:


Scope of our present IvP project
Our project is confined to making the foldable helmet only.
We are not working on an aeroshell or any other accessory for this IvP project.