Criteria A: Analysis of Design Opportunity

A1: Describe an appropriate problem that leads to a design opportunity

Task/situation

There are **87 million tennis players** worldwide, comprising roughly **1.71% of the global population** (ITF Tennis, 2022), and the global tennis equipment market surged to a valuation of **USD 7.2 billion** in 2021 (MarketWatch, 2023). These numbers underscore the undeniable vitality of the tennis product market, not only as an economic powerhouse but as a thriving center for social and athletic engagement. (RHS Image: Getty Images)

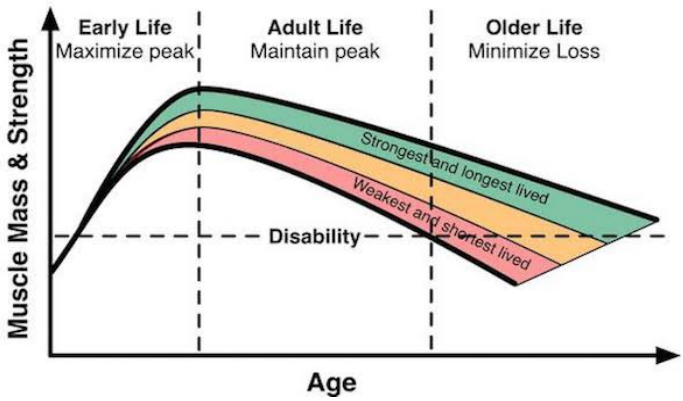
In the game of tennis, **agility is fundamental**. However, agility becomes increasingly harder to develop with age. Inadequate agility leads to late ball arrival, resulting in missed shots or desperate lunges. Consequently, inexperienced adult tennis players require personalized agility training due to **reduced neuro-ability and muscle strength** compared to the younger players. [Milanóvic. Z, 2013 - *Clinical Interventions in Aging*, (online)]

User identification: Primary user

My client (Adrian), age 52, played tennis in his youth and is now trying to get back into the sport.

Research

Muscle mass and strength **decline by 30%–50%** from ages 30 to 80, with an ongoing loss of 12%–14% per decade post-50 [Milanóvic. Z, 2013]. Nonetheless, muscles, like the rest of the body, can be strengthened and maintained. This not only enhances agility in this age group but also fosters tennis skills and overall mobility.



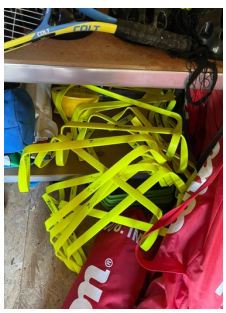
(Figure 1: Sheridan, 2017)

User identification: Expert in field

My adviser is professional tennis coach, Tom Silvia - who has been coaching me for the past 4 years.

Expert Interview:

1. What current equipment do you use to train agility?



- Cones – to represent a target
- Agility ladder – footwork drills
- Silicon spots – cues associated (e.g., touching)
- Hurdles – obstacles for difficulty

2. What are the benefits of using these products?

- Versatility: can be rearranged to make a variety of drills.
- Targets the fundamental agility skills of speed and reaction

3. What problems have you encountered ?

- Learners get disengaged easily due to repetitive nature.
- Hard to tack progress.
- Requires someone to vocally direct which cone to run too.

Existing Agility Product Analysis

KEY
Green – Advantages
Red – Disadvantages
Black – Product explanation

Interactive touch wall

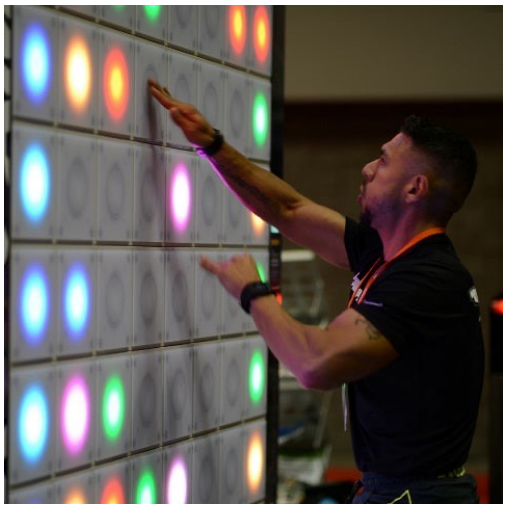
High cost: $8,450

Dynamic, interactive and competitive

Multi-sensory: Tactile (button pressing) and Visual (LED lights)

Unique product - limited competition on the market.

Random sequence - endless sequence until user presses wrong button



Customisable Training - coaches and athletes can adjust the speed, intensity, and pattern of lights or electronic signals to create a training regimen that matches the specific demands of their sport.

Goalkeeper ball deflector:

High cost: £149.99

Lack of portability (2.7m x 1.8m) due to size and weighted bags

If the ball is not kicked at a high speed, the product cannot function

Circular floats deflect football to unpredictable trajectories.

Unforeseeable angles and speeds simulate erratic game play.

Resistance parachute

Only effective in one direction, not for back-and-forth movement across a court.

Easily attaches to the user via a belt buckle

Only effective when ample space is available

Adds 22kg of resistance through drag force.

The additional weight will improve power output as the user will be able to generate more force.

Low cost: £14.99

User Interview

Q. What aspects of agility work best from these existing products?

A. "The interactive touch wall would significantly improve my agility. I've yet to experience a sports product incorporating electronics, but I imagine it to be extremely captivating. The visual cues of flashing lights and electronic signals will engage and motivate me in training. Nonetheless, I feel affordability could be a problem with this, as electronics is often associated with steep prices."

Electronics in Sport Investigation:

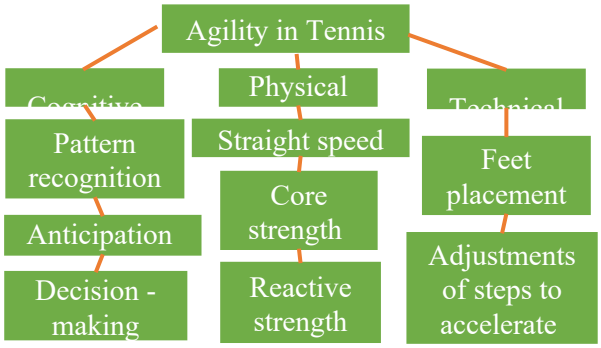
- Heightens neurological reward system –> responsible for motivation and reinforcement training.
- Gamification elements: users experience a sense of achievement when pressing electronics; tapping into the brain's reward circuitry, reinforcing positive behaviours.
- "The athlete sees a stimulus or a trigger and then performs the appropriate action to achieve the goal. This is one of the fundamental core principles in training focus and processing speed." – [Faubert, J. and Sidebottom, L. (2012). *Journal of Clinical Sport Psychology*]

Criteria A: Design Brief

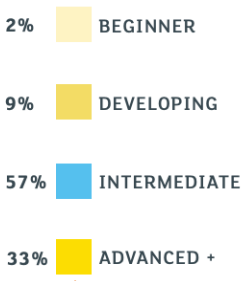
A2: Develop a detailed design brief that identifies relevant parameters of the problem

Product requirements

- **Objective:** Product must improve ALL aspects within agility (see flowchart)
- **Size:** Must fit standard court measurements (see diagram)
- **Environment:** Tennis is both an indoor and outdoor sport – product must be usable in all weather conditions.
- Product must function on all court surfaces: grass, clay and hard.
- **Budget:** product should be more readily available than what's currently offered in the market.



Persona mapping – typical user



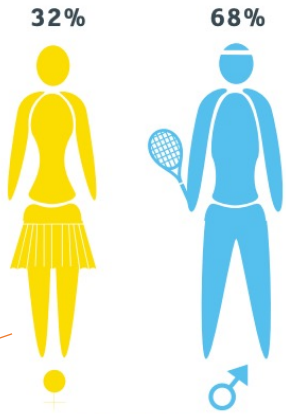
ABILITY

Barriers

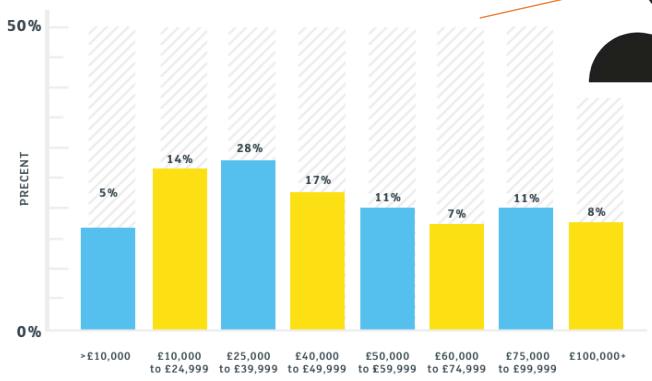
- Lack of time – commitments to family and occupation
- Dissatisfaction with park court surface/facilities

Motivations

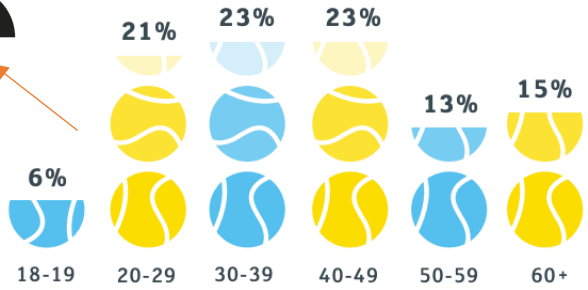
- To be competitive with friends.
- Keeping healthy and being outside in the sunshine.



GENDER



HOUSEHOLD INCOME



AGE
(Average 42)

Data and infographics from LTA British tennis – Adult segmentation study (2016)

Project Scope

Where will the product be used?

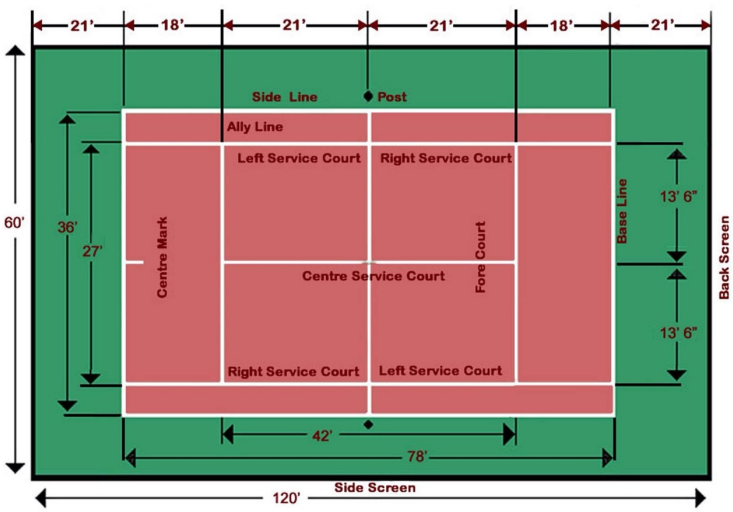
- Product will be used on court; therefore, the product must be safe to use near other players as well as not distracting other players.
- The product must target key playing areas on the court.

Marketing considerations

- Statistically purchase online.
- Predominantly middle age male audience

Method & manufacture approach

- Involvement of programming – utilise the interactive nature of existing products.
- Commonly used material in tennis equipment: carbon Fibre, alumimium, rubber



Criteria A: Design Specification

A3: Develops a design specification that justifies the requirements, based on the outcomes of the research.

H – High priority | M – Medium priority | L – Low priority

*Table prioritised in order of most important to least important category

Category	Specification	Justification	Testing Strategy
Function	1.1 Product must be used without the assistance of a coach/professional. (H) 1.2. Product must improve user's agility to move across the court. (H)	1.1 A product not needing expert explanation allows the user to maximise their agility skills in their own time and their own preferred environment. 1.2 I will model my product off the **bleep test** as it is a proven method to enhance agility and endurance. Therefore, the product must be multiple pieces that gives off visual/audio cues for the user to run to and from.	○ User interviews and trials – repeating with various users and stakeholders.
Target Audience	2.1 Product catered towards amateur middle-aged persons. (M) 2.2 Can be used by other stakeholders in other sports that require fast agility. (H)	2.1 Intermediate middle-aged tennis players lack agility and care the most to improve this skill over teenage and elderly markets. 2.2 The product being functional across all sports extensively opens the potential market, with 23% of the population aged 16 and over actively participated in sporting activities in year ending May 2017 [House of Commons Library, 2017], that's around 15 million people in the UK partaking in sports weekly.	○ Questionnaires ○ Secondary research
Size	3.1 Max size (compact/folded): 75 x 23 x 32 cm (H) 3.2 Max weight of product: 4.8kg (H)	3.1 By researching the vast variety of tennis bags, I chose these measurements as they are from the most used **style tennis bag in adult amateur players**; containing inner compartments to carry many items as well as limited size for easy carry. 3.2 The online data for determining this value was limited. Therefore, I determined this value by filling my own tennis bag with items I would normally take to tennis practice: water bottle, tennis balls, 2 tennis racquets. I then weighed the bag and kept filling it up with weights till the weight of the bag became slightly uncomfortable for my target user.	○ Measuring tape ○ Scales

[Babolat RH X12 Pure Aero]

[Wilson Tour 12 Tennis bag]

References:

- [House of Commons Library, 2017] - *https://researchbriefings.files.parliament.uk/documents/CBP-8181/CBP-8181.pdf*
- [Wilson Tour 12 Tennis bag] - https://www.amazon.co.uk/dp/B08SJSRX6L/ref=twister_B0923JV3CT?th=1
- [Babolat RH X12 Pure Aero] - https://www.prodirectsport.com/tennis/p/babolat-rh-x-12-pure-aero

Category	Specification	Justification	Testing Strategy
Aesthetics	4.1 Colours must be bold and contrast that of the court surface (H) 4.2 Product must not be green or red (M)	4.1 Neon colours are high-octane and energising, which is beneficial in sports products. Paired with black they are an ultra-high-contrast pairing. 4.2 Tennis court surfaces are commonly green or red, however the most common form of colour blindness is red/green blindness [National Eye Institute, 2019]. Having a green product on a red surface (and vice versa) would make the product indistinguishable on a court surface to people with this vision deficiency.	○ User interviews and questionnaires to determine whether aesthetics appeal to my target user and market. ○ Secondary research of existing tennis/ sport related products
Production constraints	5.1 Must be completed by 15/03/2024. (H) 5.2 Must be able to be manufactured in school environment (M) 5.3 Cost no more than £75 (L)	5.1 I am under the time constraint of the IB diploma, the production of this project must be completed within this time frame. 5.2 I have limited access to certain production techniques and material choices at my school. 5.3 Products on the agility aid market range from £40-£150 dependent on the technology involved. Additionally, from the focus group, my target market is willing to spend upwards of £80 for a quality sports product.	○ Gannt chart for time management
Material selection	6.1 Material must be lightweight, strong, weather resistant and sustainable. (M)	6.1 As the product functions with the user running and stepping on it outdoors, the material must be able to withstand the weight of the user and weather conditions. Moreover, my interview highlights how my target audience is willing to pay more for a product made from sustainable materials. However, as the prototype is not final, materials on prototype will not be/might not be ones researched.	○ Material testing: Hardness, toughness and tensile strength ○ Destructive testing
Environmental	7.1 Product must be long lasting (>2 years) and not one-off use (H)	7.1 There are very few sports equipment that are single use, however I will ensure that this product is built to last at least 2 years as that is the typical life span of tennis racquets/equipment [Khaled, 2022 (online – tennismonitor)]	○ Research on recycling electronics. ○ Secondary data on material degredation of sports eqiupment.
Quantity	8.1 Ability to be scaled up commercially (L) 8.2 I will make the prototype suitable for batch production. (L)	8.1 On completion, this product must be able to be commercially viable and taken to investors . However, all elements of my product will be a prototype. 8.2 Batch production allows for new product adaptations in colour and programming to suit another market.	○ N/A

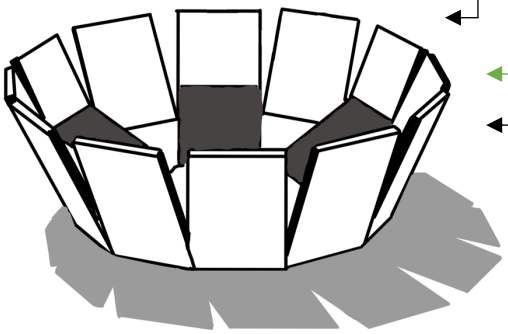
Criteria B: Developing Design Ideas

B1: Develops feasible ideas to meet appropriate specifications that explore solutions to the problem
B2: Use concept modelling and analyse the outcomes to guide design development

Original concepts / Exploration of form:

KEY
Green – Advantages
Red – Disadvantages
Blue - suggested developments from user feedback
Black – Concept design explanation

1.

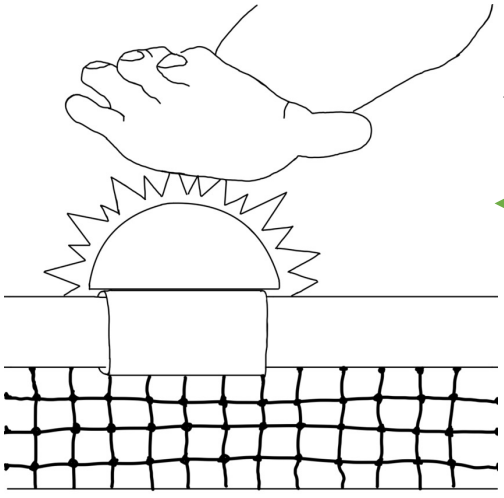


Function: balls throw in and refracted out

Simulates a solo edition of a coach throwing a ball in a random direction (SP1.1)

Inspired by the form of Caribbean Steel pan drums

2.

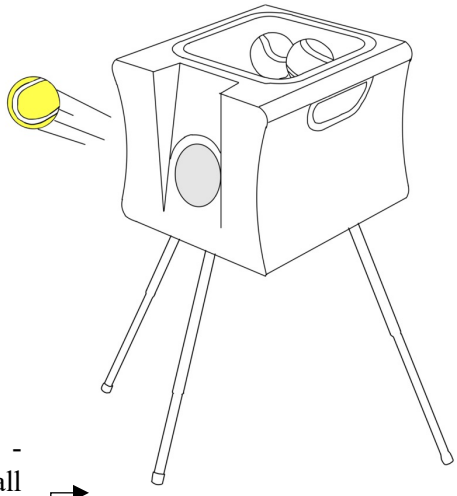


Bluetooth sports adapted game show buttons

Appealing and engaging training method (SP1.1)

Most used + useful agility item in sports: training ladder

3.



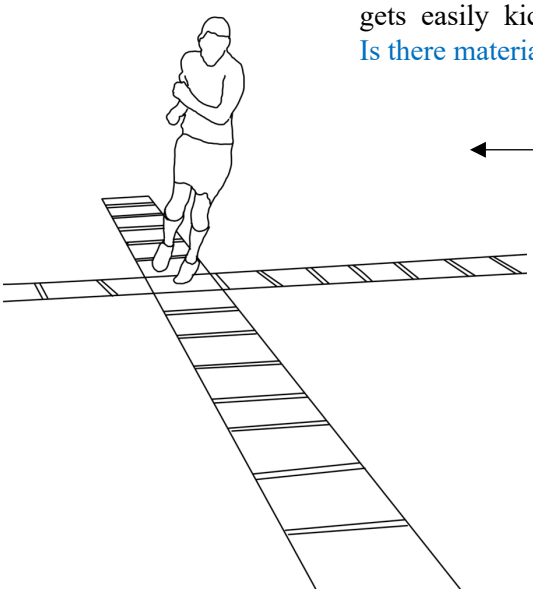
Portable ball thrower - current market they ball machines are massive

Box form and detachable legs allows product to fit in tennis bag (SP3.1)

Extremely complex to manufacture due to monitorised mechanisms (SP5.2)

4.

Issues: textiles material gets easily tangled during set up and gets easily kicked out of place. Is there material alternatives?



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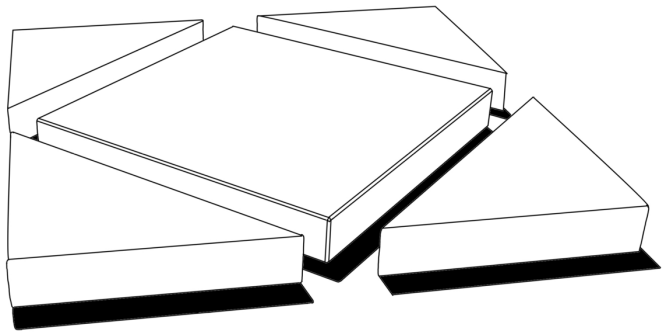
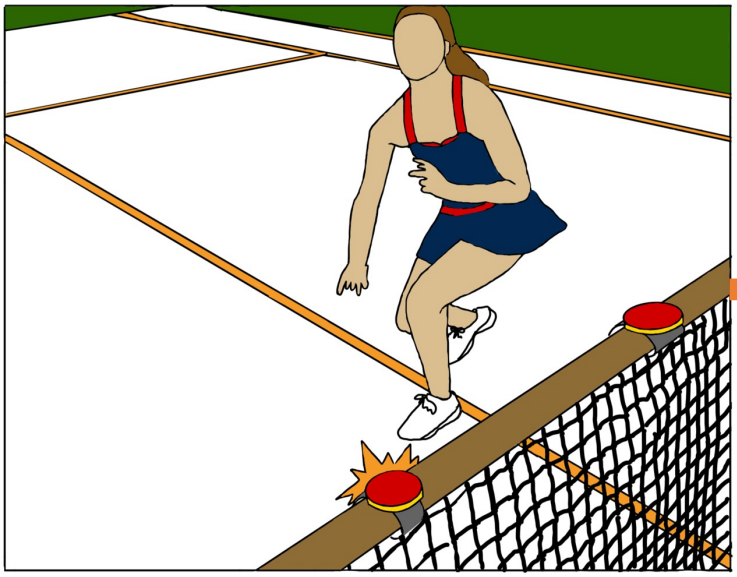
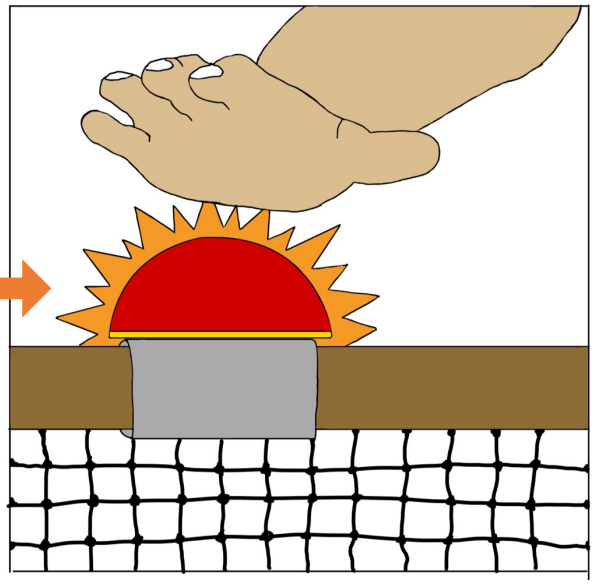


Buttons placed into the corners of the courts (SP1.2)

Inspired by the form and function tennis line markers

Concept Design 1: Quick Touch





1. Buttons are attached across the length of the tennis net.

2. User runs and taps lit up button.

3. User runs and taps next lit up button.

4. Time between flashes decreases to force player's speed to increase.

Light-up and sound emitting buttons: tactile, auditory and visual. (SP1.2)

Small and portable design (SP3.1).

Number of buttons adjustable - dependant on distance desired to run (SP1.2)

Self-explanatory design.

Improves players agile movements across the net – vital for volleying. (SP1.2)

Velcro attachment – easily removable from net. (SP1.1)

Is Velcro ideal to tightly bound product to the net?

Investigate alternative attachment methods

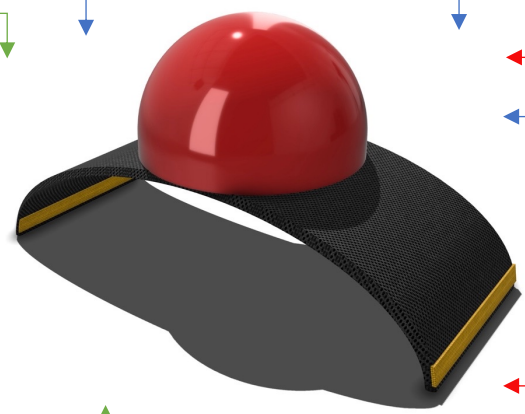
Does not focus on the entirety of the tennis court – can only be used at the net (SP1.2)

Can also be placed and used on a court fence.

Is the product durable enough to withstand tennis ball impact ? (SP6.1)

Material investigation and endurance testing needed.

Not practical for other net sports. (SP2.2)

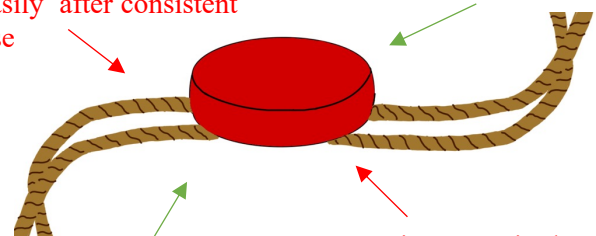


Alternative attachment methods:

1. Rope / String:

Sting material frays easily after consistent use

Allows for ease of adjustability

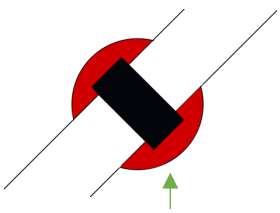


Can be fastened to a extremely tight hold

More time required to set up due to tying rope

2. Magnetic silicon band

Soft and flexible material (SP6.1)



Button can slide on and off strap

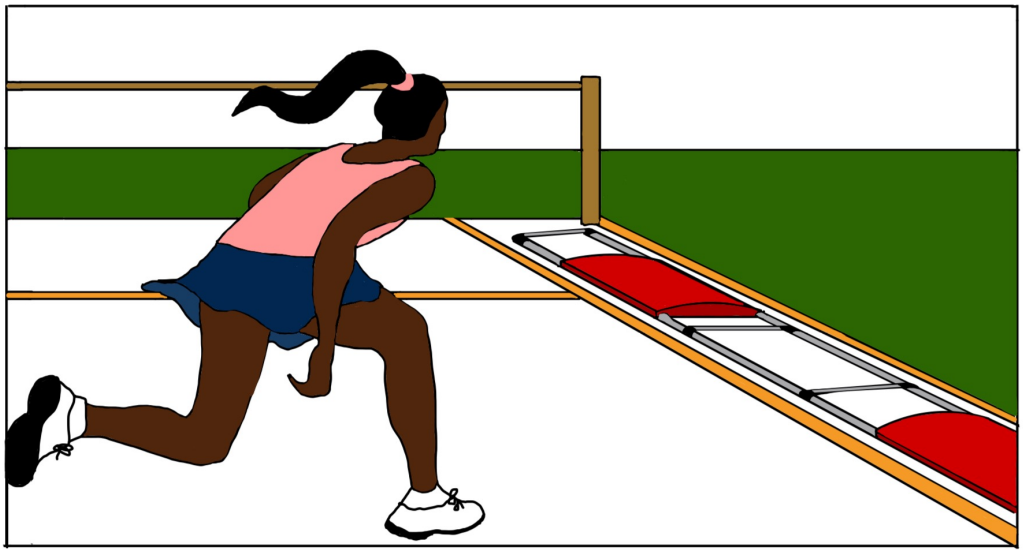
Can conform to any cylindrical shape

Silicon = UV resistant + waterproof (SP6.1)

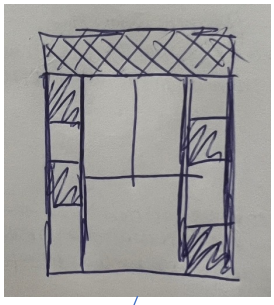
Childish associations - not suited for target market (SP2.1)

Image reference: https://www.pylones.com/en/children-s-watch/10117-slap-watch-funny-time-ladybird.html

Concept Design 2: Speed Step

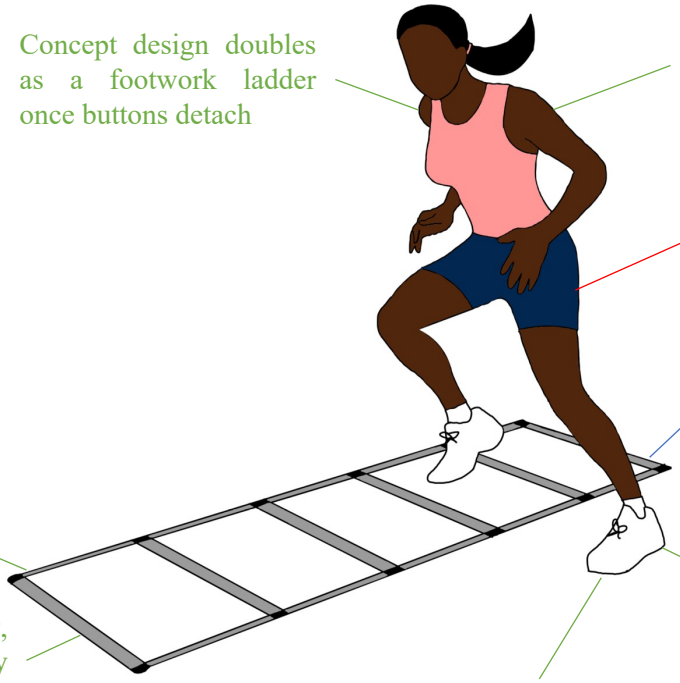


1. User sets up rails in tram-lines of the court
2. Buttons clipped onto tram rails
3. User presses button which lights up next button
4. Forcing user to run between lateral and vertical ends of the court
5. User can detach buttons for alternative training purposes



Design credit: Coach Tom as drawn above

Concept design doubles as a footwork ladder once buttons detach



Metal would provide more structure than commonly used textiles material (SP6.1)

Extra storage space required as button and ladder are separate (SP3.1)

Portability issues – how can ladder deconstruct or reduce in size? (SP3.1)

Higher set up time than other designs

Moves user horizontally, laterally and diagonally across the court (SP1.2)

Multipurpose design (SP2.2)

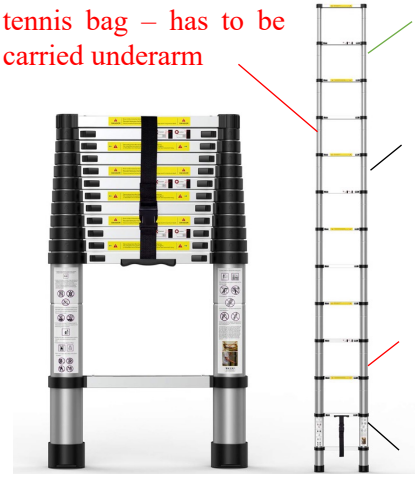
Maximum court distance covered

Alternative methods to compactly store rails/ladder:

1. Telescopic extension ladders:

Unable to store in tennis bag – has to be carried underarm

Ability to extend out and compact down to be portable.



Material opportunity: Aluminium, steel

Blue sky thinking – how would this be produced? (SP5.2)

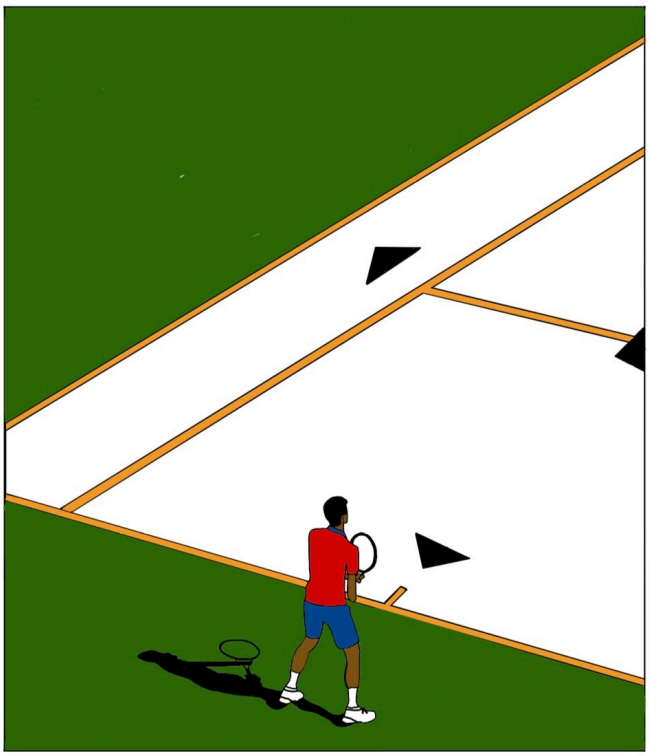
https://amzn.eu/d/0tsF0Ah

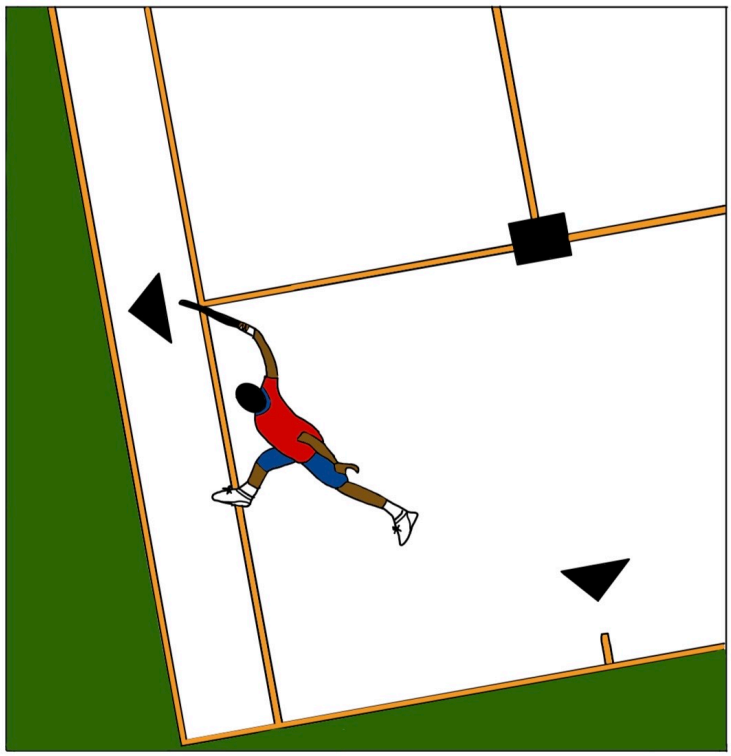
2. Slotting intersection:

Breaks down into many small subsections (SP3.1)

Inconvenient to set up and take apart – time consuming

Concept Design 3: Tessellating Tiles





1. User sets up tiles on the court
2. The tiles will light up in a random sequence
3. Forcing the user to run across the entire court
4. Overtime - the time between light changes will decrease.
5. Forcing user to run faster with more agility on court

Connected via magnets

Joins to make an even square

Psychological reward
Light-up and sound emitting buttons: tactile, auditory and visual.

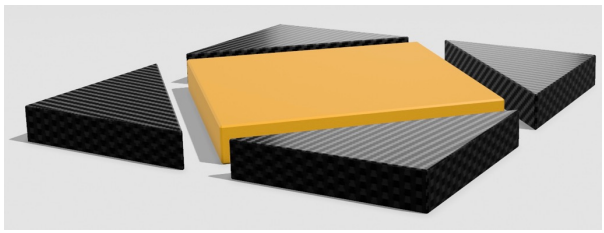
Is this the most ideal shape?

Consists of central 'mother piece' – displays importance in its placement.

/

e.g. Placed in angle bisector of the baseline stresses significance.

Magnets demagnetise overtime – securer alternative joinery mechanism? (SP7.1)



Would a circular shape be more effective ?

Utilises the spacing of the whole court (SP1.2)

Geometric fitting for portability and space efficiency (SP3.1)

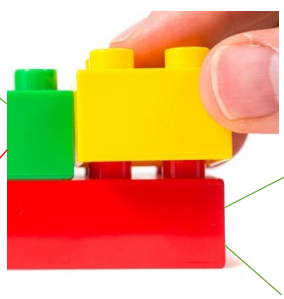
User can personalise the training to distinct areas of the court

Minimal set up time – just placed on the floor (SP2.2)

Alternative joinery methods:

Lego: stud-tube coupling system / biscuit joint

Quick + easy removal



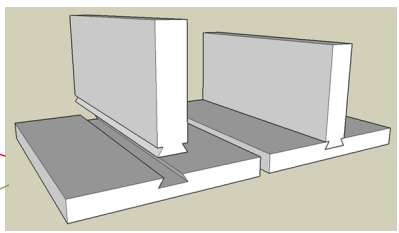
Minimal degradation - will last overtime (SP7.1)

Harder to manufacture

Highly secure -> bottom tubes interlock with another brick's top studs.

Interlocking wood joinery - sliding dovetail joint

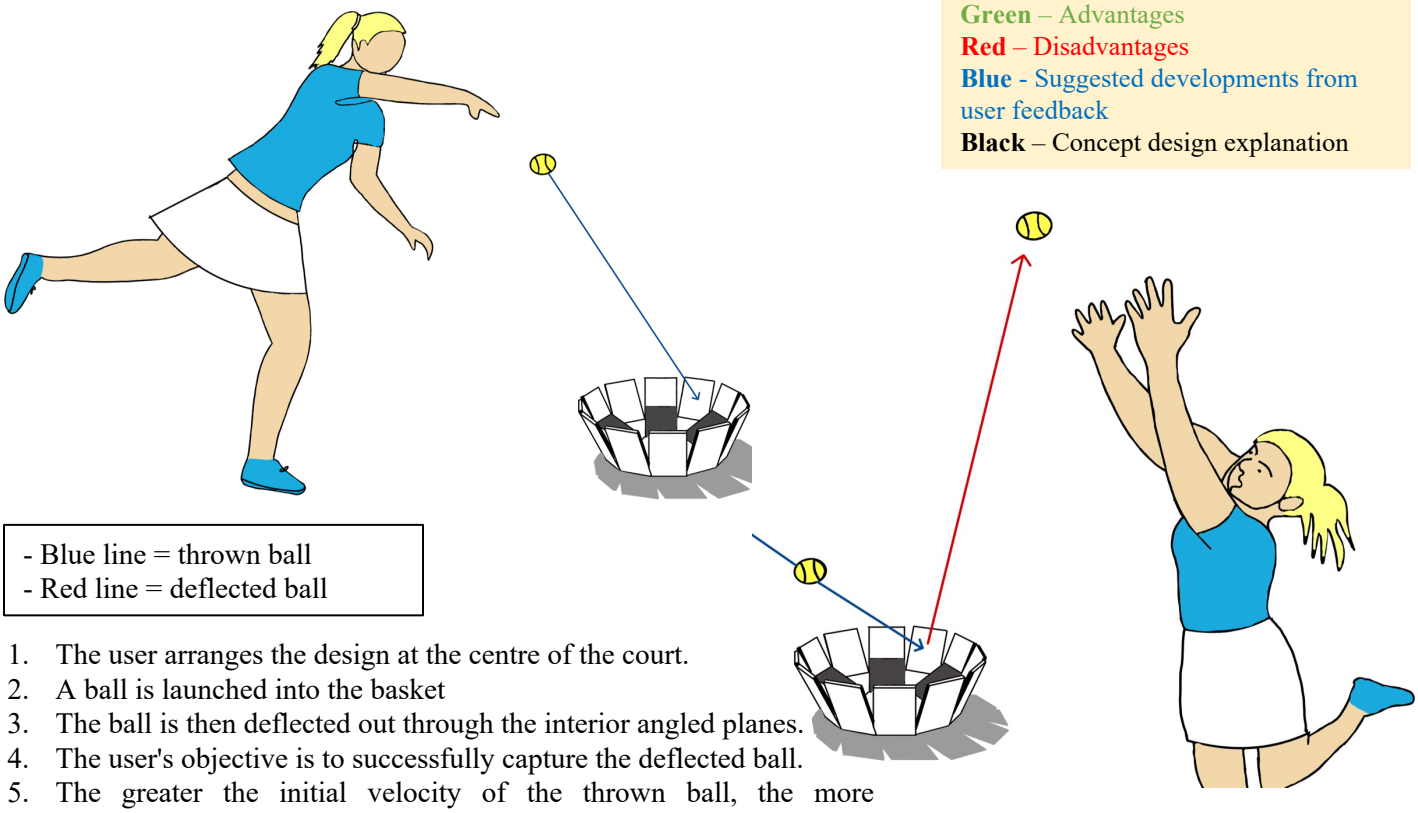
Overtime, friction from sliding could cause erosion to the tiles



Allows tiles to securely attach as-well as easily removed

Concept Design 4: RefractBowl

KEY
Green – Advantages
Red – Disadvantages
Blue - Suggested developments from user feedback
Black – Concept design explanation



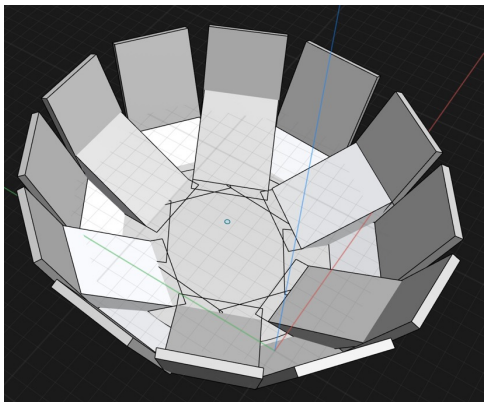
- Blue line = thrown ball
- Red line = deflected ball

1. The user arranges the design at the centre of the court.
2. A ball is launched into the basket
3. The ball is then deflected out through the interior angled planes.
4. The user's objective is to successfully capture the deflected ball.
5. The greater the initial velocity of the thrown ball, the more challenging it becomes to capture the deflected ball.

Relies upon user to throw the ball into basket : inaccurate aim = no deflection (SP1.2)

Random deflections

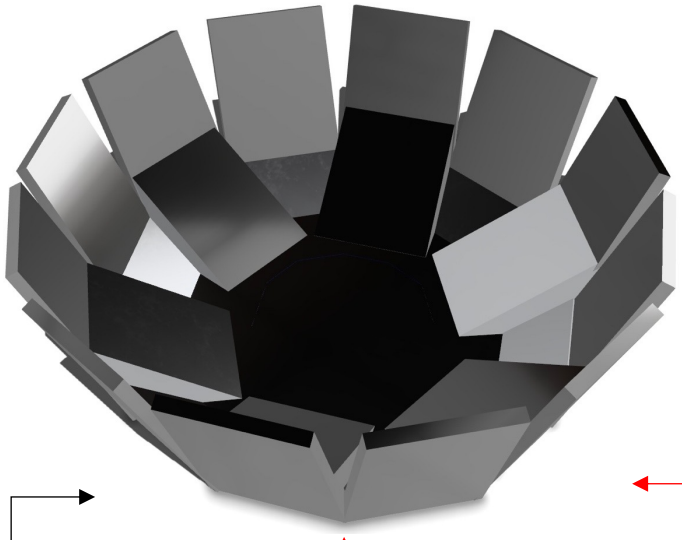
Does not require assistance in set up or play (SP1.1)



Lack of portability (SP3.1)

Expansion: Incorporating leg attachments to allow user to extend height to increase launch of projected ball (SP1.2)

Can be made multiplayer and competitive – first player to not catch deflected ball (SP2.2)



Material: Steel / hard material to allow full deflection (SP6.1)

Form inspired by Caribbean steel drums

Boring/repetitive over time (SP1.2)

Function inspired by Football goalkeeper training equipment

Over time, the user may develop the ability to anticipate the trajectory of the deflected ball. (SP1.1)

Modelling: Concept 1

Attachment testing with user: (Using pre-existing game-show button)

Velcro:

User Feedback:

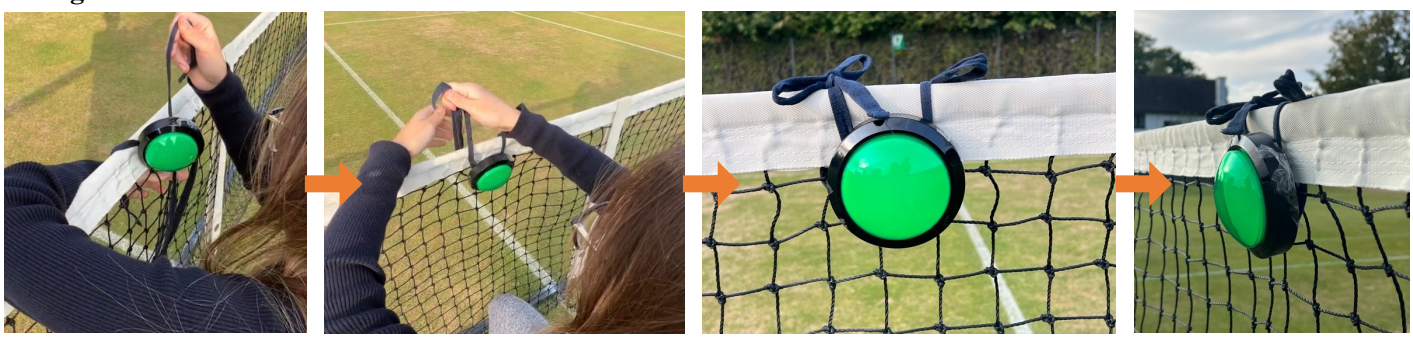
- Attempt 1: straps aligned horizontally resulted in a loose fastening.
- Attempt 2: straps aligned vertically resulted in a tight fastening
- Therefore, instructions would ensure straps maximise holding power.
- Easy use in cold temperatures: fingers to open/close fasteners is not required.
- "Particularly necessary as I wear sports gloves during winter months"
- Overtime, velcro accumulates dirt, dust and debris particularly outdoors (SP7.1)

Zip ties:

User Feedback:

- Permanent: attachment had to be cut off the net.
- Potentially damaging to the net if cut incorrectly.
- Zip ties were not long enough to go on top of net.
- Inconvenient to bring around scissors to remove attachment. (SP2.2)

String:

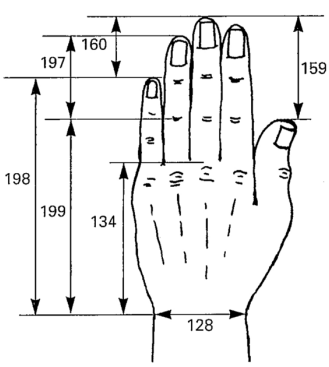


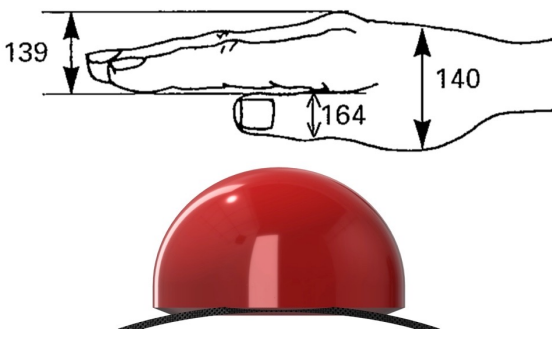
User Feedback:

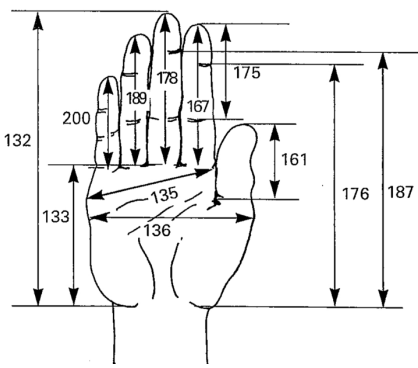
- Fiddly and awkward to loop string through net.
- Longest set up time out of the attachment methods.
- Extremely tight fastening/holding power.
- Understandable to use as tying string is a common practise. (SP1.1)

Anthropometric data:

For this design, understanding the measurements of the hand; particularly that of the fingers which press the button is vital (Source: ADULTDATA – Data for design safety)





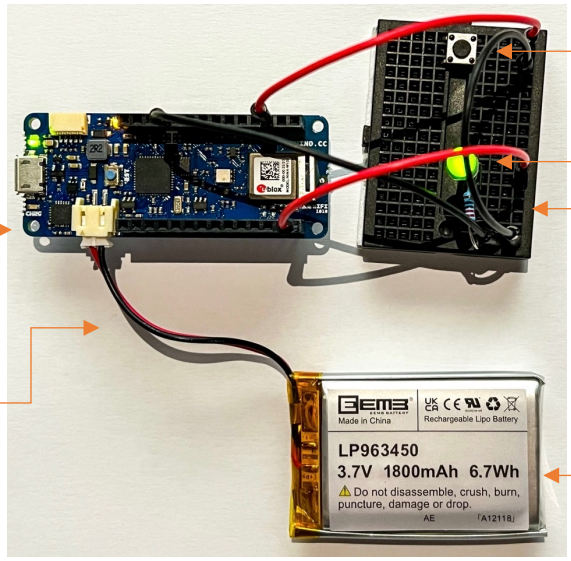


Electronics testing

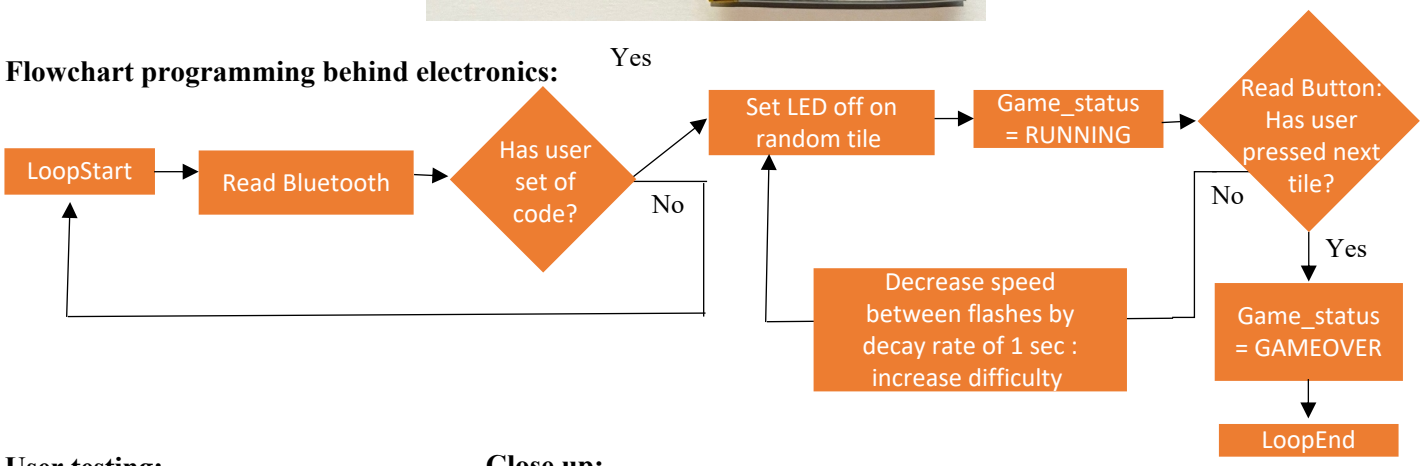
Introduction: All my designs so far revolve round the same flashing light sequence; in which a circuit light will flash, signalling the user to rush and press it. Once activated, one of the other two circuits illuminates, initiating a cycle that speeds up with each button press, intensifying the game. To make this system come to life I have developed and tested the following electronics system.

Electronics layout:

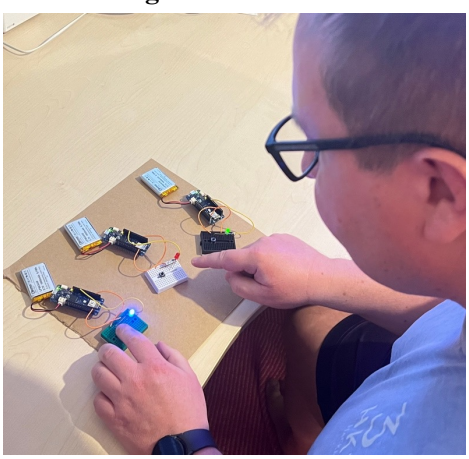
Arduino MKR – essentially a basic computer that is able to communicate protocols wirelessly in a cost-efficient manner (£17)



Flowchart programming behind electronics:

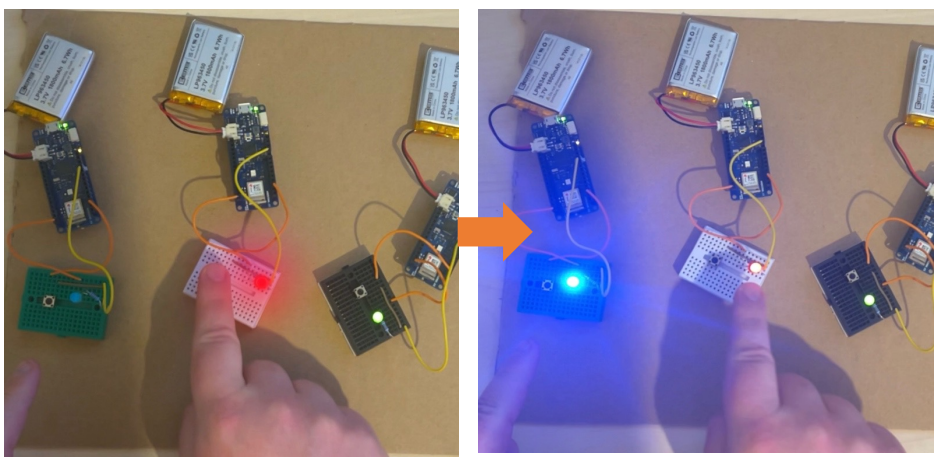


User testing:



User testing the electronic component – scaled down not in a sports setting

Close up:



Red button flashes -> user presses red button -> new light is randomly set off (blue light) -> user moves to press blue button

Simplicity testing

- I presented the electronics to my user but didn't explain the game or how to use them.
- Nonetheless, my user quickly grasped that pressing the button was crucial, and the game sped up after each press.
- Therefore, the layout of the electronics is user-friendly

Enjoyment testing

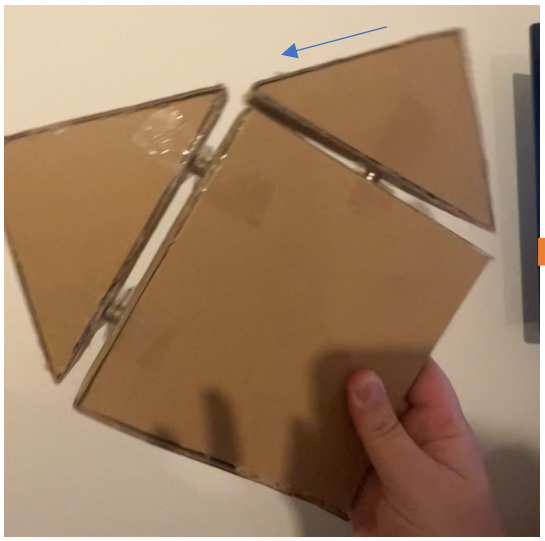
- "The game was thrilling, reminiscent of playing the arcade game Whack-a-mole!"
- " Although this is a scale down form, running across a court to do this would make difficulty and fun factor tenfold. "

Modelling:

KEY
Green – Advantages
Red – Disadvantages
Blue - suggested developments from user feedback
Black – Concept design explanation

Magnet feasibility testing: Determining the strength and optimum location of magnets

- I will tape magnets onto a cardboard model do the tile design, then vigoursly shake the model to determine if the triangular bodies will stay securely attached to the main body.



Strong (nickel) neodymium magnets used

Attachment piece clearly moving from side to side

Testing conclusion

- 1 magnet does not have enough hold power –> 2 magnets minimum required or else product will fall apart in transport or research into more powerful magnets
- Point to consider: Accessibility – stronger magnets may affect individuals with pacemakers (or other medical devices sensitive to magnetic fields)

∴ Separate components may be a design liability as securing to main body requires more components = more cost

Grip testing:

As the product will be placed on the court surface, it must be able to resist the impact of the users force. Thus, I will test a series of products that will improve grip to determine which material is suitable for the base of my prototype.

Material 1: Non- slip Silicone Mat

- Collects dust and dirt from surroundings (SP7.1)
- Due to electrostatic properties, slight static charge builds up debris - unpleasant for user

Material 2: Silicone Gel Pads

– Strong grip due to high coefficient of friction. (SP6.1)
- Does not provide all round grip unless many dots were applied – higher cost + time

Material 3: PVC anti-slip mat

– Provides high levels of traction even in wet conditions due to its textured surface. (SP6.1)
- Non-porous material – resistant to moisture + mould

Testing conclusion: Material 3 is best and will be taken forward

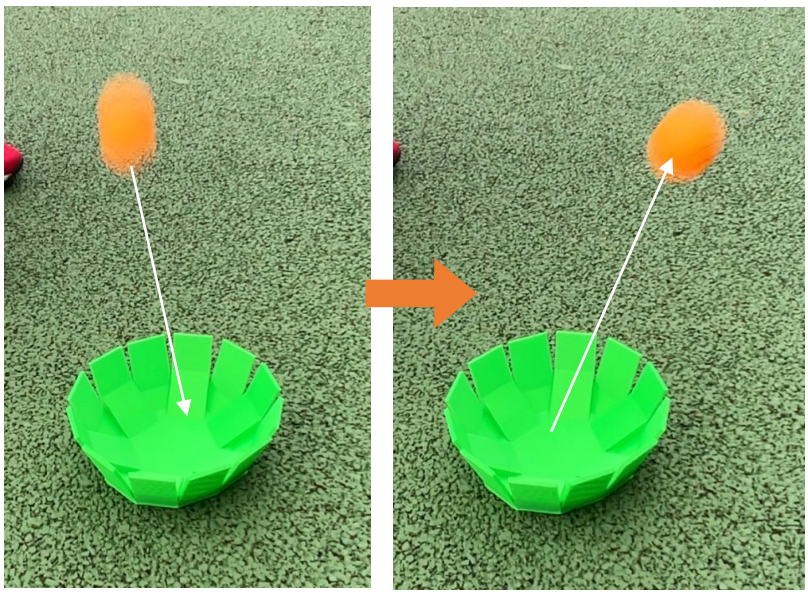
Modelling: Concept 4

Feasibility testing:

To model my concept design, I 3D printed a smaller scale version and employed a ping pong ball to represent a tennis ball. To analyse the deflection properties of the design, I conducted trials by launching the ping pong ball at differing angles and speeds and recorded whether it deflected the ball or bounced the ball back to the user.

Sizing reference:

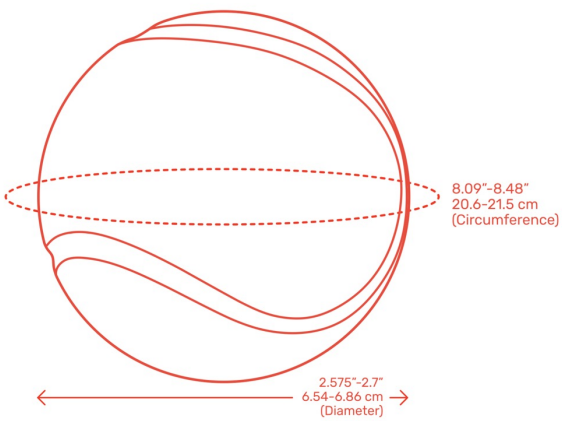
On court testing :



User Feedback

- Gradually disengaging due to insufficient increments in difficulty overtime. (SP1.2)
- Although ball can be thrown faster into the bucket there is a max speed before damage occurs to the bucket
- More appropriate for younger user groups – game feels 'childish' (SP2.1)
- More doubles play oriented – more stimulating when made competitive
- Fragility issues: throwing at speed at a bad angle results in damage – material investigation needed

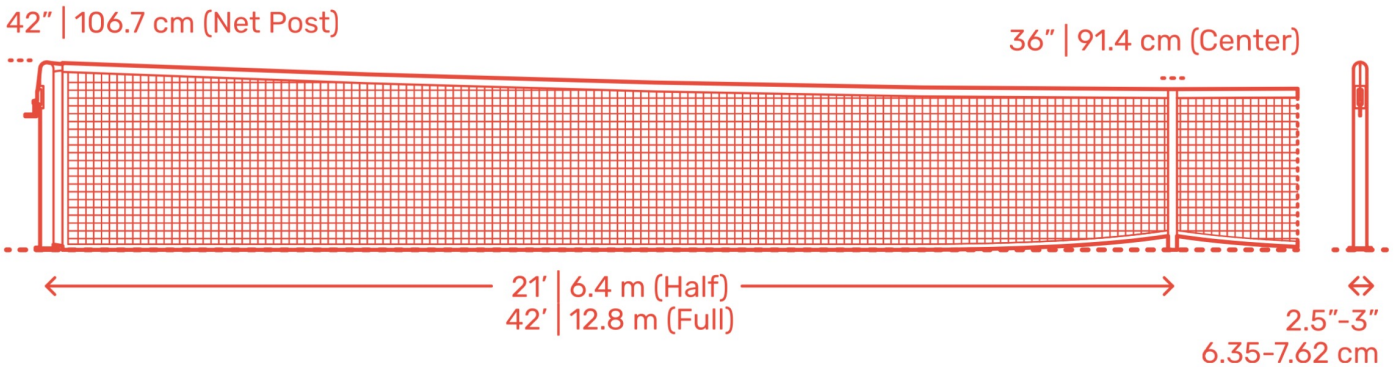
Anthropometric data: (To aid final prototype)



Country	Sex	Mean	sd	5th%ile	95th%ile	Source
UK	m	48.4	4.2	41.5	55.4	PeopleSize 1998
	f	45.3	3.1	40.2	50.4	PeopleSize 1998
Japan	f	41.8	1.8	38.9	44.7	PeopleSize 1998
USA	m	48.6	4.3	41.5	55.6	PeopleSize 1998
	f	45.5	3.4	39.9	51.1	PeopleSize 1998

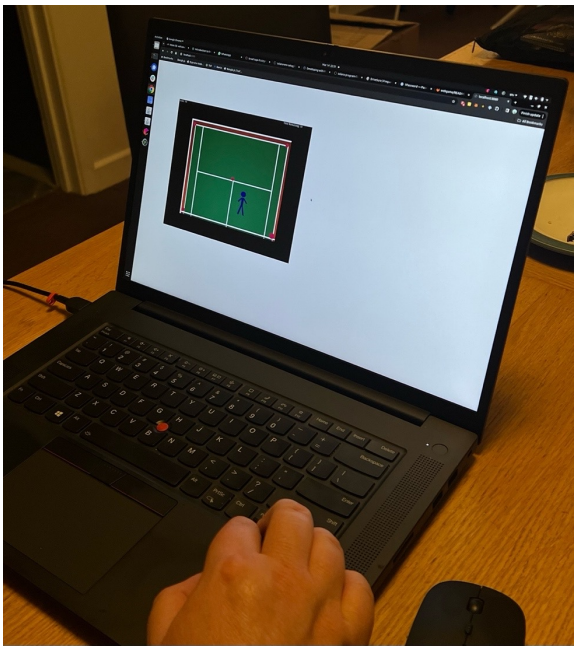
UK – average handspan

- I will utilise the UK's average handspan as the demographic of my users are in England, it makes sense to use England's data rather than the global average or of other nations.



(*Tennis Ball Dimensions & Drawings* | *Available at:* https://www.dimensions.com/element/tennis-ball)

Concept validation testing:



Virtual Usability Lab

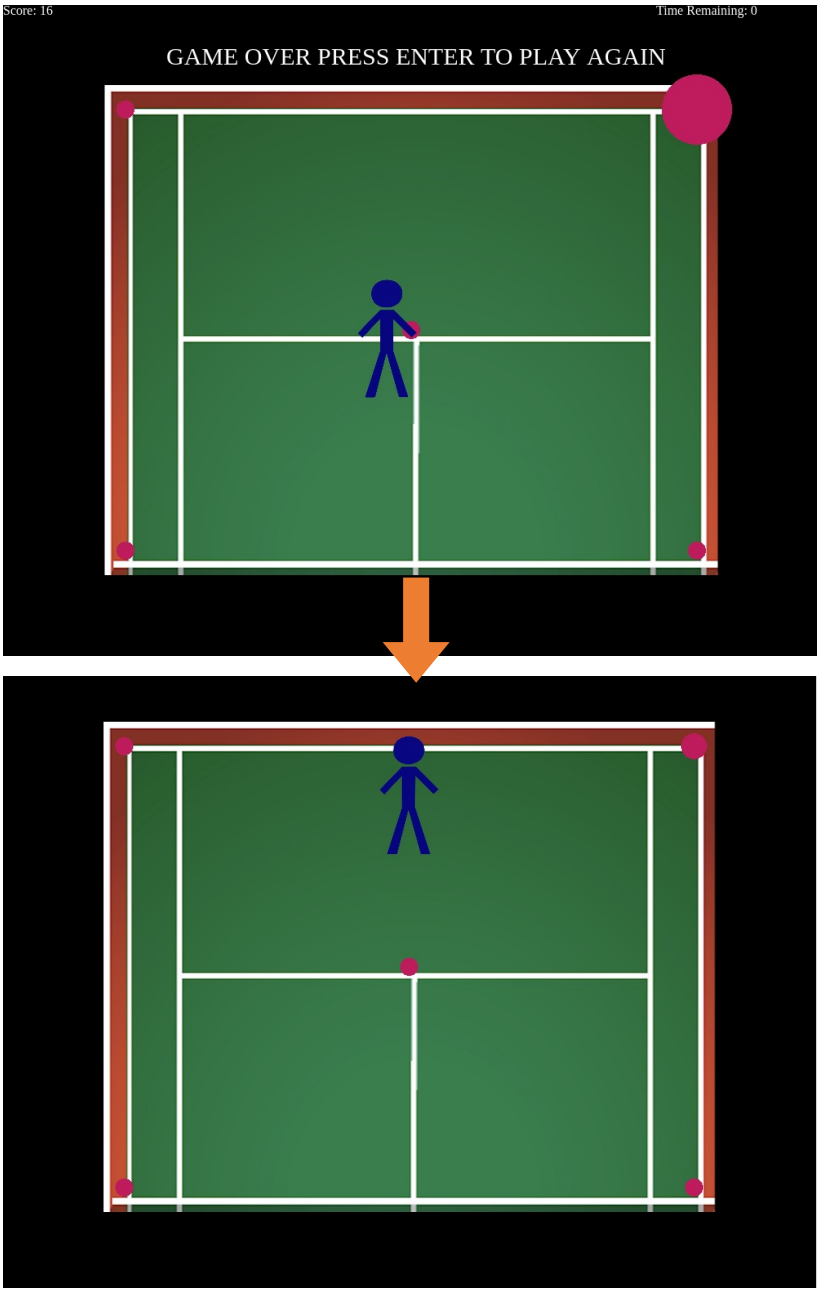
To gauge my primary user's reception to the idea of running towards illuminated points on the tennis court, where pressing one light would trigger another to illuminate, I created a **simulation video game.**

In this game, my user could control their movement by **manipulating a mouse cursor,** navigating towards blinking circles representing the points of interest.

Each time my user reached a flashing light, they earned a point and the time between flashes would get faster. When the user does not make it to the flash in time it is GAME OVER.

Primary user playing concept game

Simulation video game in action:



The aim of the computational model is to represent how the product will be used and I have carried out these steps to show how the user will be forced to run across the court.

I have designed the simulation to make it obvious of this intended goal with ease of commutation.

The blue character represents the user, the layout represents the tennis court and the flashing circle represents the light up design.

Results:

My primary client was highly interested with the use and movement of this design, as the miniaturised digital version highlighted the intense amount of running that will be involved. (SP1.2)

Therefore, through this positive user feedback, I will take forward this design/simulation and turn it into reality.

* Results could be misrepresentative due to highly artificial environment as it is not representiive of sport / agility

Criteria B: Justification of design

B3: Justifies an appropriate idea for detailed development

User evaluation of Design Concepts :

To determine which design to take forward, I will go over each design with my target user and evaluate the design against the specification previously. By rating how each design meets the specification I will be able to pick out specific design features that my user heavily dislikes or likes.

Specification Point	Idea 1	Idea 2	Idea 3	Idea 4	User Feedback
1.1 Must be used without the assistance of a coach/professional. (H)	5/5	2/5	5/5	4/5	- Take forward the PVC grip material on the base
1.2. Must improve user's agility to move across the court. (H)	4/5	3/5	5/5	2/5	- Take forward electronics and programming – reactive lights are unique and engaging. (SP1.1)
2.1 Product catered towards amateur middle-aged persons. (M)	4/5	2/5	4/5	2/5	- More modern elegant look required - Transparent cover to be able to see the electronics; much like the style of the 'Nothing phone'
2.2 Can be used by other stakeholders in other sports that require fast agility. (H)	5/5	2/5	5/5	2/5	- Non of the attachment methods are secure enough – more investigation required, backpack buckle and weeding is a suggested option. (SP6.1)
3.1 Max size: 75 x 23 x 32 cm (H)	5/5	1/5	4/5	3/5	- A box to hold/store could increase organisation and portability. - Reduce the size of product to be hand held comfortably.
3.2 Max weight of product: 4.8kg (H)	5/5	1/5	5/5	4/5	- Keep product compact and parts at a minimum for ease of manufacture (SP5.2)
Total rating:	28/30	11/30	28/30	17/30	

KEY

- Highest scoring designs

- Lowest scoring designs

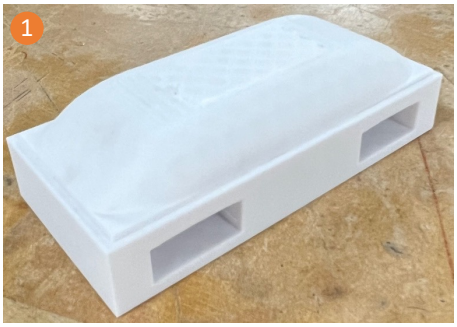
Conclusion:

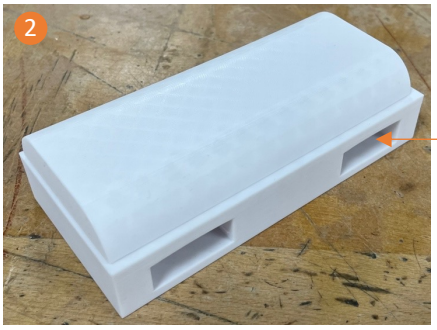
For my final design, I will take forward and combine design 1 and 3 as they responded best with my client. Additionally, as the designer, I believe these designs scored highly due to their complex design elements, particularly in the field of functionality on both the net and court surface.

Additionally, I intend to leverage the insights from the grip testing and simulation testing to aid the form and function of my final prototype.

Development of Final design

Initial forms:





Body cut out to fit the measurements of the buckle

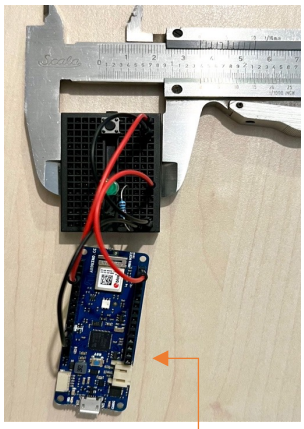
Form inspired by the ergonomics of the iPhone – recognisable shape

User Feedback:

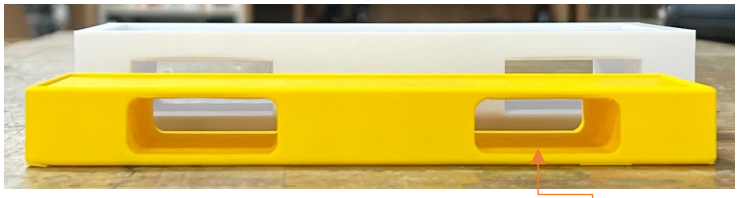
- The size is too 'bulky' – feels uncomfortable in the hand
- The edges are too sharp – potential safety risk
- I prefer the 1st form, curved/slopped lid makes pressing easier.
- The indent is a good choice as it allows the lid to be securely fitted to the body

Second area of development: Base

Size Reduction: (Yellow = prototype 2)



Second prototype: 37% reduction in size



Using a vernier caliper – I measured to ensure no additional space / tolerance.

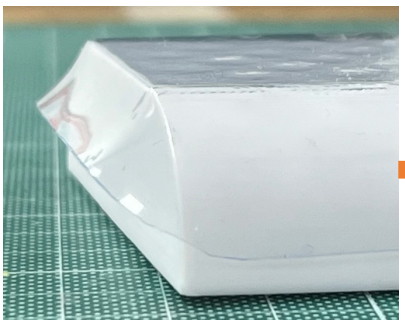
Fillet / rounded corners

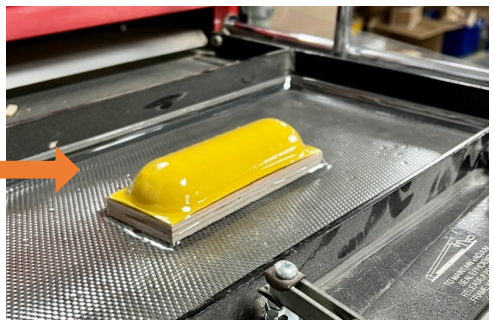
Sacrificing ease of buckle movement, opting to reduce the cut out size.

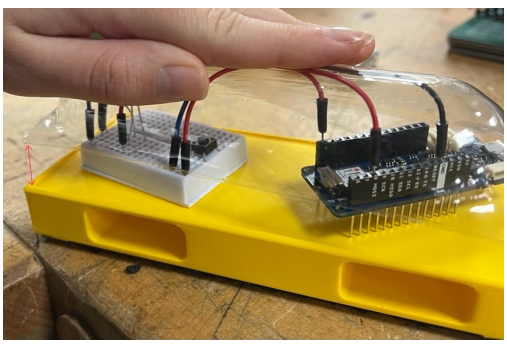
Third area of development: Lid

Vacuum forming plastic lid:

Issue: the plastic edges won't pull to take the full lid form.
Solution: Placing a wooden stand under the lid form and drilling holes will increase suction significantly.

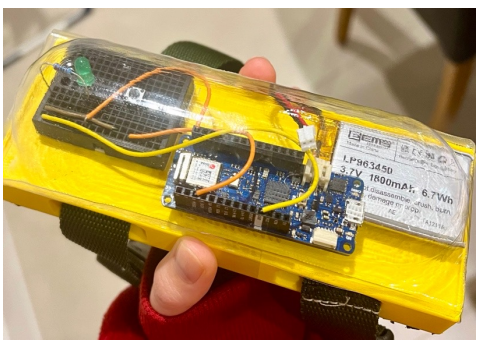






Issue: circuit wires are too large to attach the lid – larger lid would result in a bulky product.

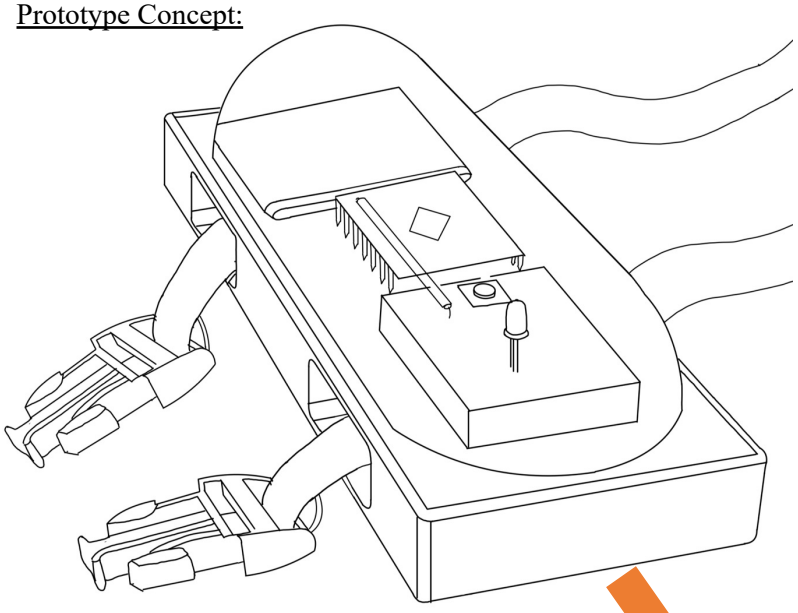
Solution: smaller wires – Soldering wires are significantly smaller than traditional wires.



ANNOTATED FINAL DESIGN

SP = Reference to Specification Point

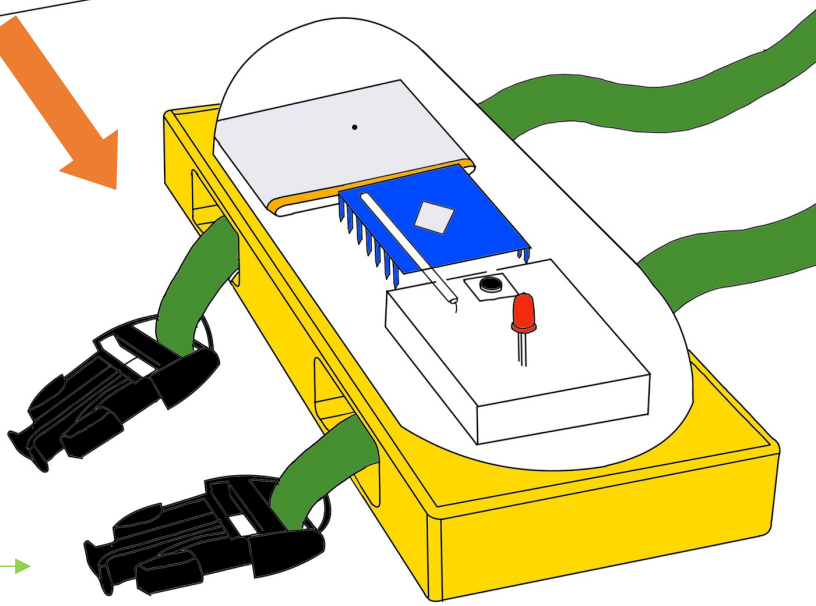
Prototype Concept:



Fitted edges – no damage to electronics in wet terrain (SP6.1)

Plastic lid: waterproof (SP6.1)

Colourised:



Highly portable – secure placement in tennis bag - All three fit comfortably in tennis bag (SP3.1)

Comfortable fit and weight in user's hand (SP3.1)

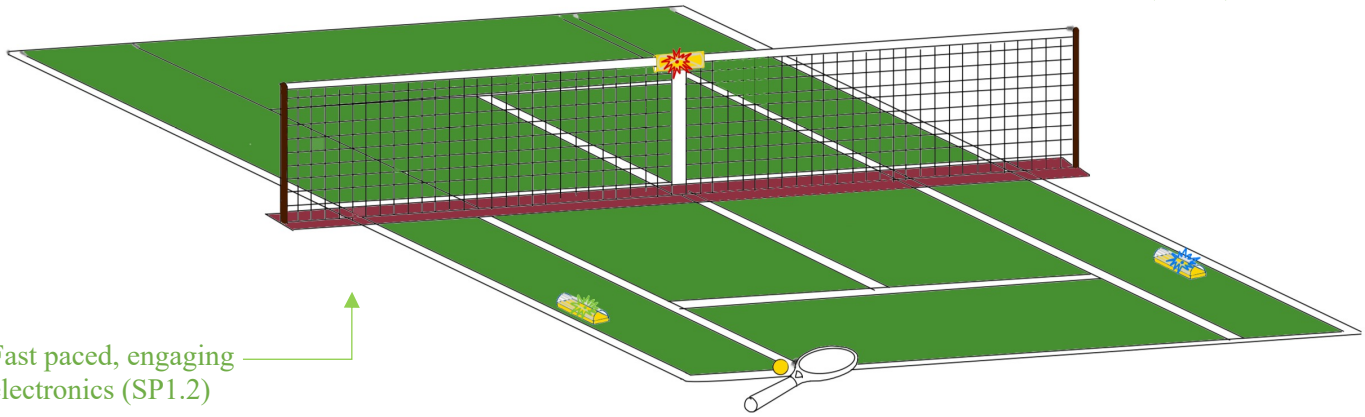
Easy attachment/detachment to the net and fence – intuitive design (SP2.2)

Additional grip on the base – increase in traction on any surface (SP1.1)

Concept of Use:

3 Tiles – 3 minimum to make a random sequence, due to time constraints I do not have time to do 4 tiles (SP5.1)

LED lights are clearly visible from across the court (SP1.1)

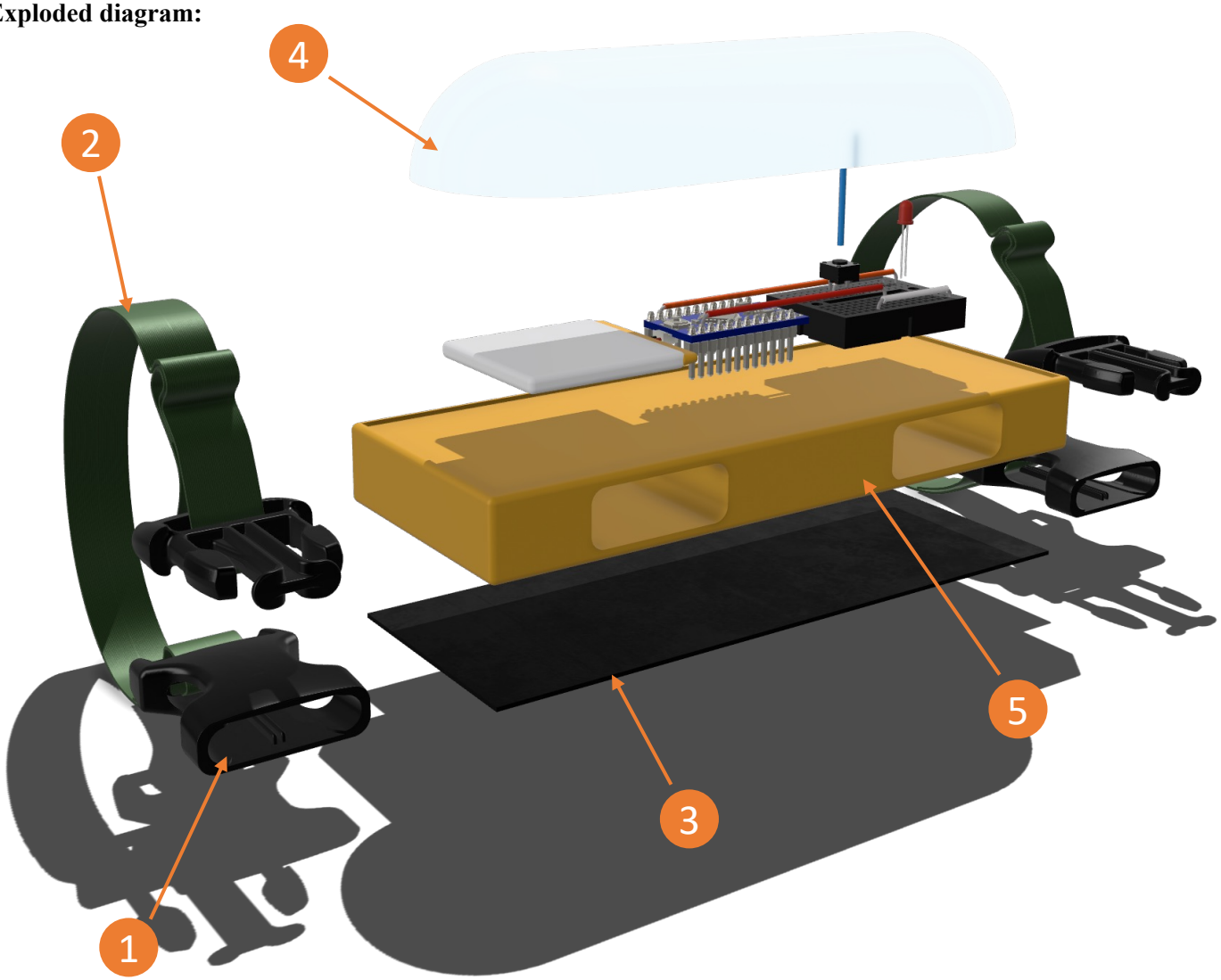


Fast paced, engaging electronics (SP1.2)

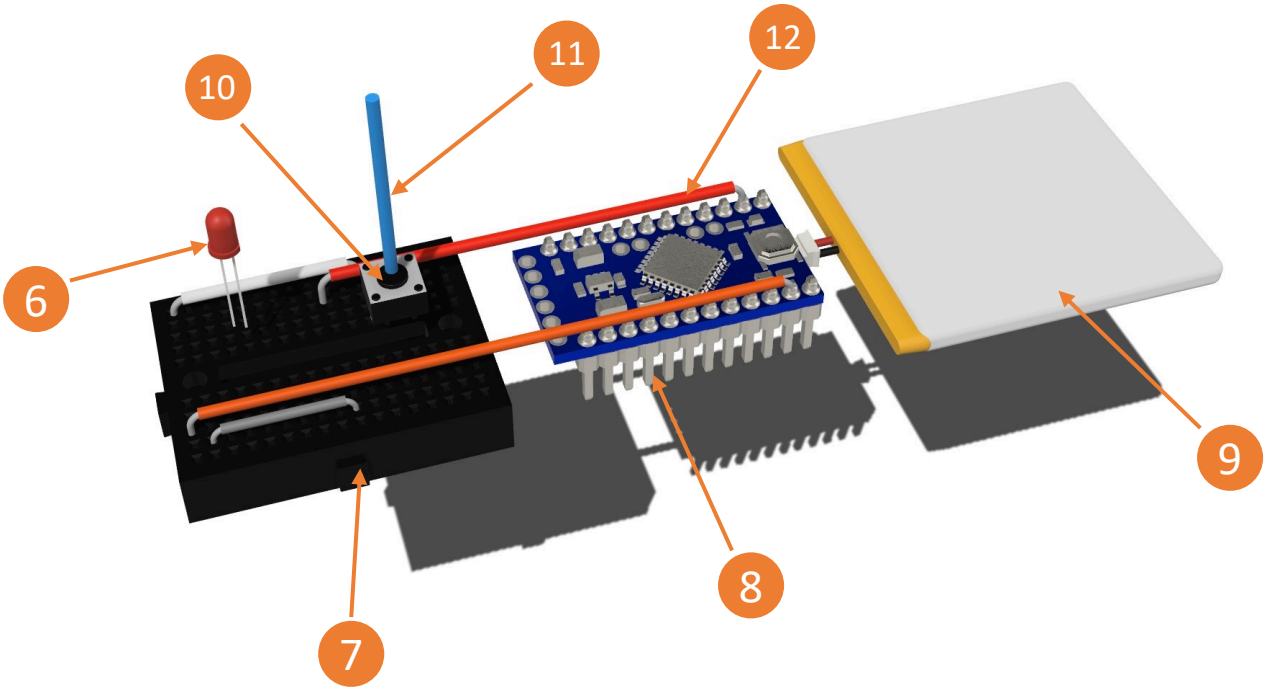
Criteria C: Development of a detailed design

C1: Justifies the choice of appropriate materials, components and manufacturing techniques

Exploded diagram:



Electronic configuration:



Justification of materials: (SP = Spec Point)

Component number + name	Material	Material justification	Size (mm)	General cost:
1. Male and Female buckle	ABS plastic	- Lighter than metal buckles with a density of **1.0-1.05 g/cm^3** [PolymerPlastipedia](SP3.2) - **Corrosion-resistant**; very good **resistance to dilute acids, alkalis** as well as oils and greases. - **UV resistant**: colour will not degrade with time due to its **2 phase polymer blend.** - Cost effective as it is a widely available **standard product.** (SP5.3)	50 x 32 x 15	£0.15 per buckle pair
2. Webbing	Nylon	- **Water resistant** – does not absorb liquids: ideal for outdoor tennis courts. - **High resistance to abrasion:** ideal as strap will experience constant experience when being applied to nets. (SP6.1)	25 x 300 x 3	£3.98 per 6m
3. Non-slip mat	PVC anti-slip mat	- **Good traction:** Textured surface creates **high friction** against surfaces - Does not accumulate dirt like silicon grip mat (SP7.1) - PVC has a relatively **small carbon footprint** (SP6.1) - Due to the reserves of the material being clearly abundant as the main material is salty in which there are over **50 quadrillion tonnes of salt** dissolved in the sea [US Geological Survey Publication]. - Mold and mildrew resistant	56 x 156 x 2	£6.22 per 30cm by 305cm
4. Lid	PVC	- Excellent **transparency** to allow LED light to pass through. - High impact resistance: with **tensile strength of 2.60 N/mm^2** and a notched impact strength of **2.0-45 Kj/m^2.** [PolymerPlastipedia] (SP6.1) - Resistance to weathering and UV radiation due to **heat stabilisers** in the PVC formulations, making it suitable for **outdoor applications**. - Thickness: 0.25 mm - Grade: Flexible form	56 x 156 x 25	£13 per m^2
5. Base	PLA plastic	- Alternative: Polypropylene (PP), as it can also be 3D printed, however the yield strength (the maximum stress a material will tolerate before plastic begins deformations) is greater for PLA. - - High yield strength is vital as my product must be hit without fracturing. - **Yield strength : PLA = 49MPa, PP = 35MPa** [PolymerPlastipedia](SP7.1)	56 x 156 x 15	£15 per kg

Component number + name	Material	Material justification	Size (mm)	General cost:
Lid mould (for injection moulding)	PLA plastic	- Can be quickly and accurately made - Alternative: wood carved lid, however that is extremely time consuming (SP5.1)	57x157x 24	£15 per kg
6. LED light (5V)	5mm LED in Red, Blue and Green	- **Wide angle spread of luminosity** - Can be seen from over 100m away in bright and dark conditions (4.1)	19 x 4 x 4	£0.11 - 1pc
7. Breadboard	ABS plastic panel with a tin plated phosphor bronze contact sheet.	- **Ease of use:** wires can be inserted and removed simply - No soldering required (SP5.1) - Self-adhesive tape on the back - Voltage / Current: **300V / 3-5A**	28 x 38 x 8	£1.05 – 1pc
8. Arduino		- Small, inconspicuous control panel. - **Easily programmable** for non-advanced levels of programming (SP5.2) - Alternative: Rasberry Pi which has more memory and processing power. - However this option is more expensive and not as straightforward to programme (SP5.3)	42 x 34 x 4	£17
9. Battery (3.4V)	Lithium – Polymer	- Rechargeable: can be **charged at a rate of 1 times capacity** (1C), ∴ the current will charge the entire 3.4V battery in 1 hr (SP7.1) - Using **polymer electrolyte instead of liquid electrolyte** to achieve **higher conductivity and increased safety** in thermal properties	41.5 x 37 x 4	£3.99 for one
10. Button		- Allows user to start and stop the button. (SP1.1) - Allows users to press product with **vast force (tactile switch)**	4 x 4 x4	50 for £1.39
11. Rod	Clear Acrylic	- Transparent colour is discrete (SP4.1) - Alternative: wooden rod, however arylic is more durable than wood	15 x 4	£2.99 for 8 pc (25.4cm long)
12. Jumper Wires		- Wires are unobtrusive - Standard component part – can be bought at at extremely low cost (SP5.3) - Bare/metal ends allow for easy insertion into breadboard (SP5.2)	Various: 20mm, 50mm and 17mm length	£4.22 for 560 pc
13. Adhesive	Industrial Superglue:	- Duribond is clear when dried – doesn't affect aesthetics compared to bond glues like Evo-stik (SP4.1)	Glue covering area of 8,736 mm^2	£4.95 for bottle

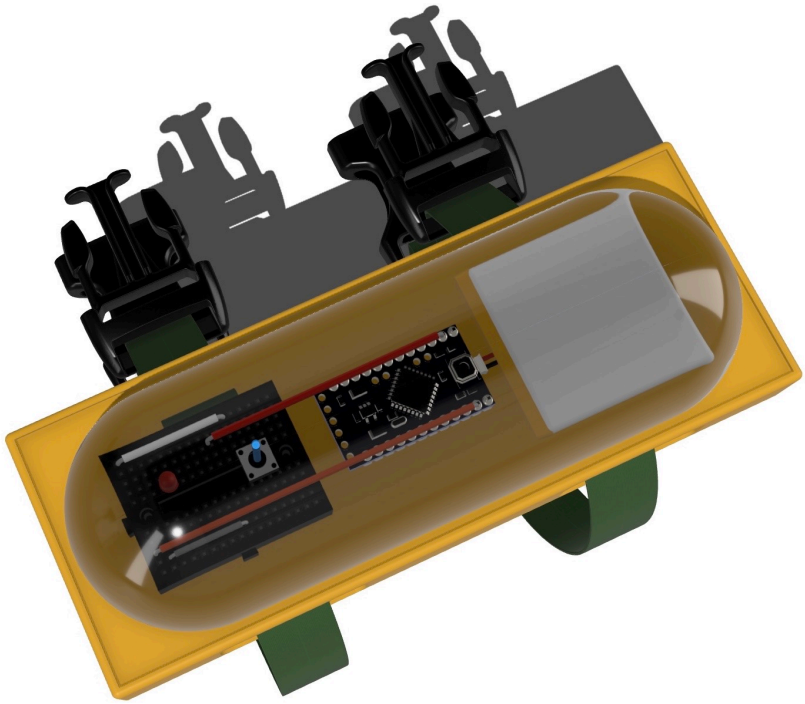
Criteria C: Development of a detailed design

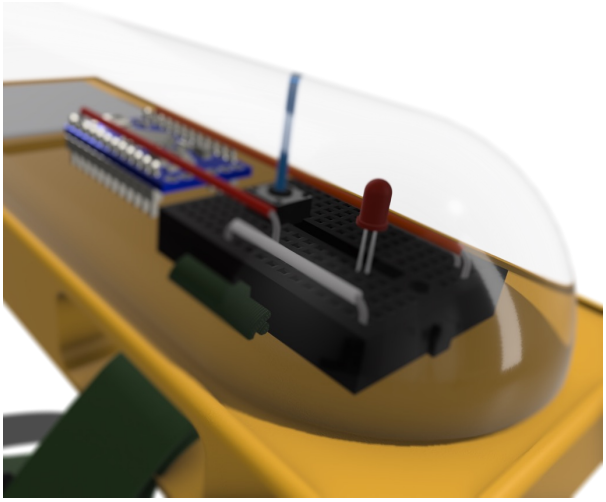
C2: Develop an accurate and detailed design proposal for a third party to manufacture the prototype.

FINAL DESIGN: Isometric drawing (As the working product is three of the exact same product, I will showcase one as they are identical)

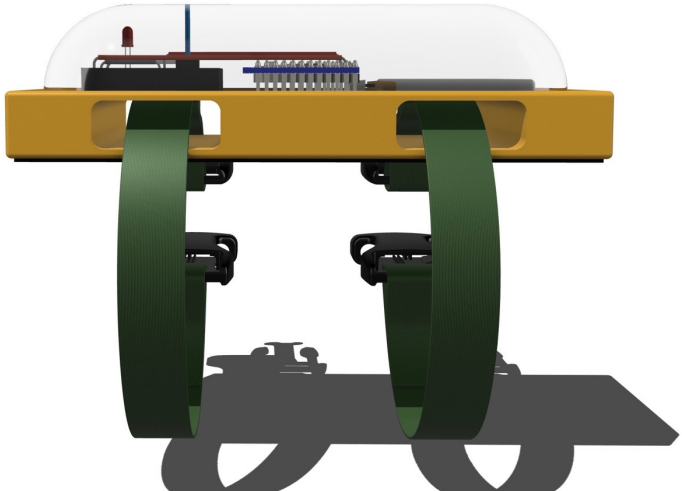
Top View:

(All CAD self made on Shapr3D)

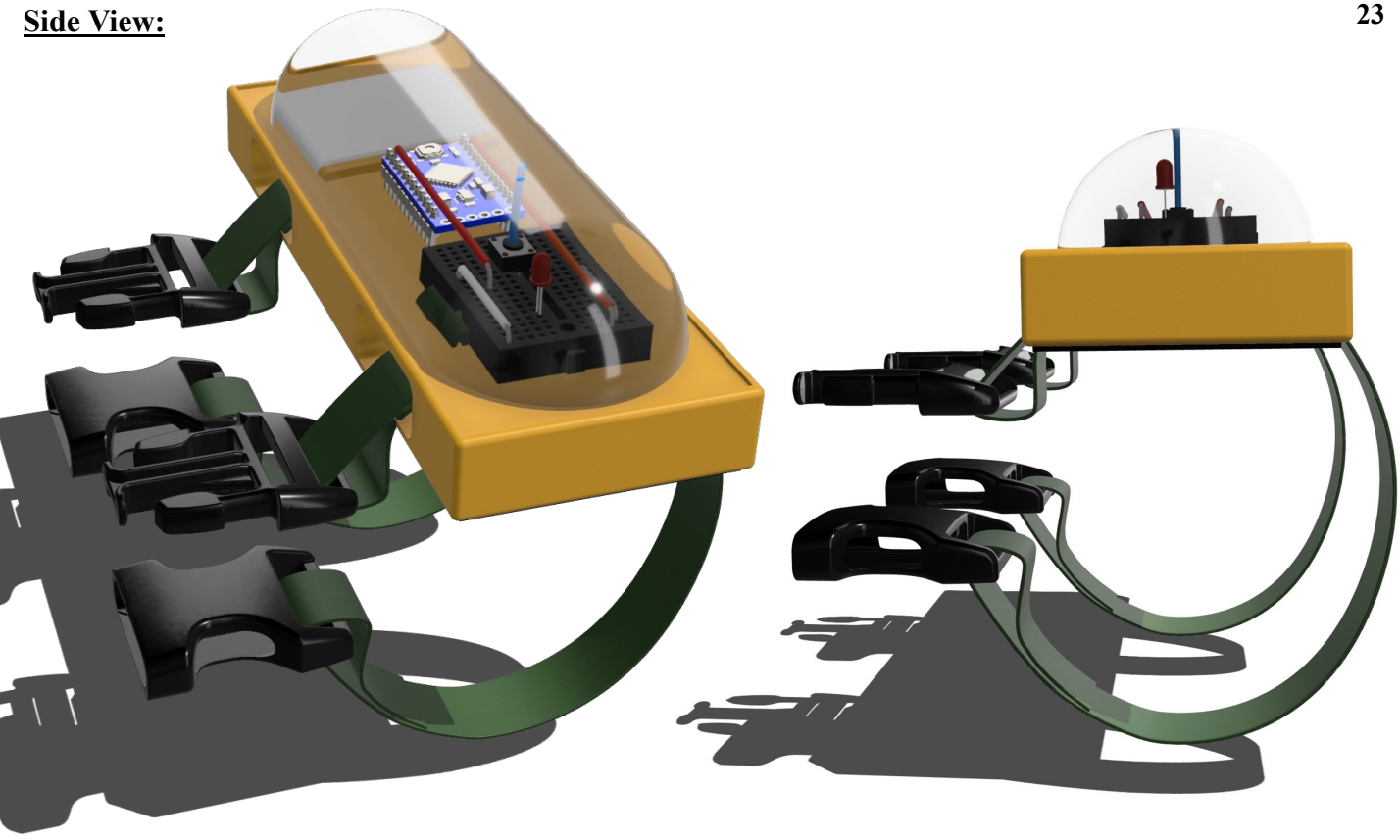




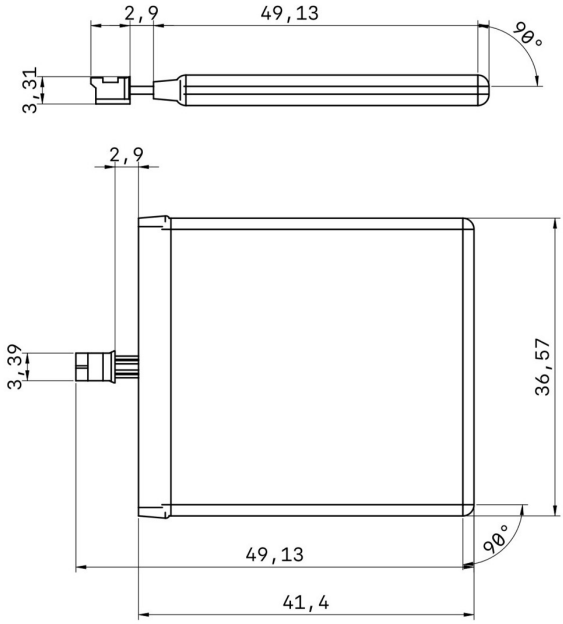
Front View:



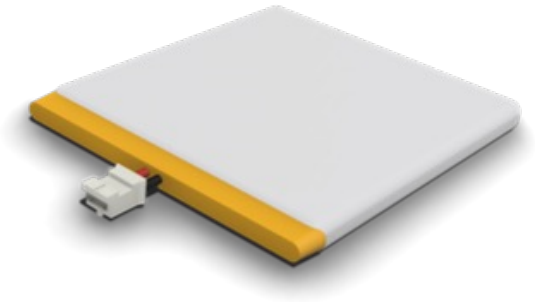
Side View:

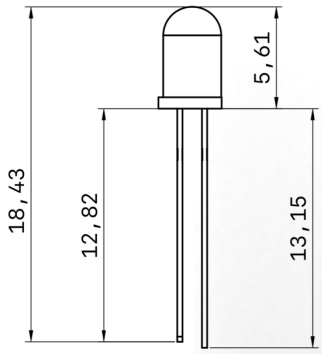


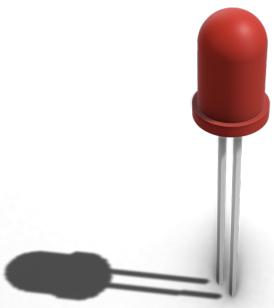
FINAL DESIGN: Orthographic drawing of individual components



TITLE		
LiPo Battery		
UNITS mm	PROJ. ANG.	SIZE A3
SCALE 2:1	LAST UPDATED 01/11/24	SHEET 1/1

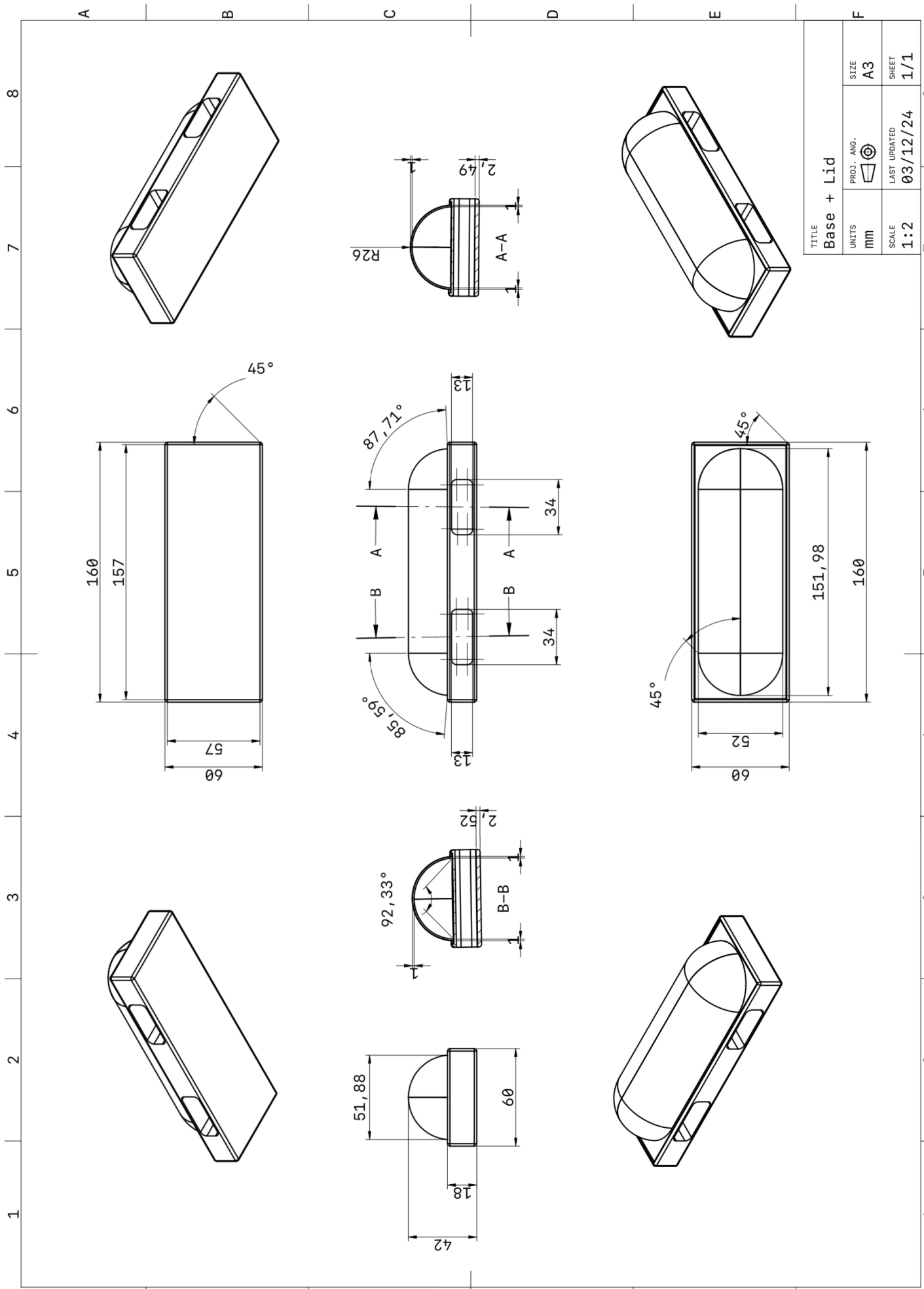


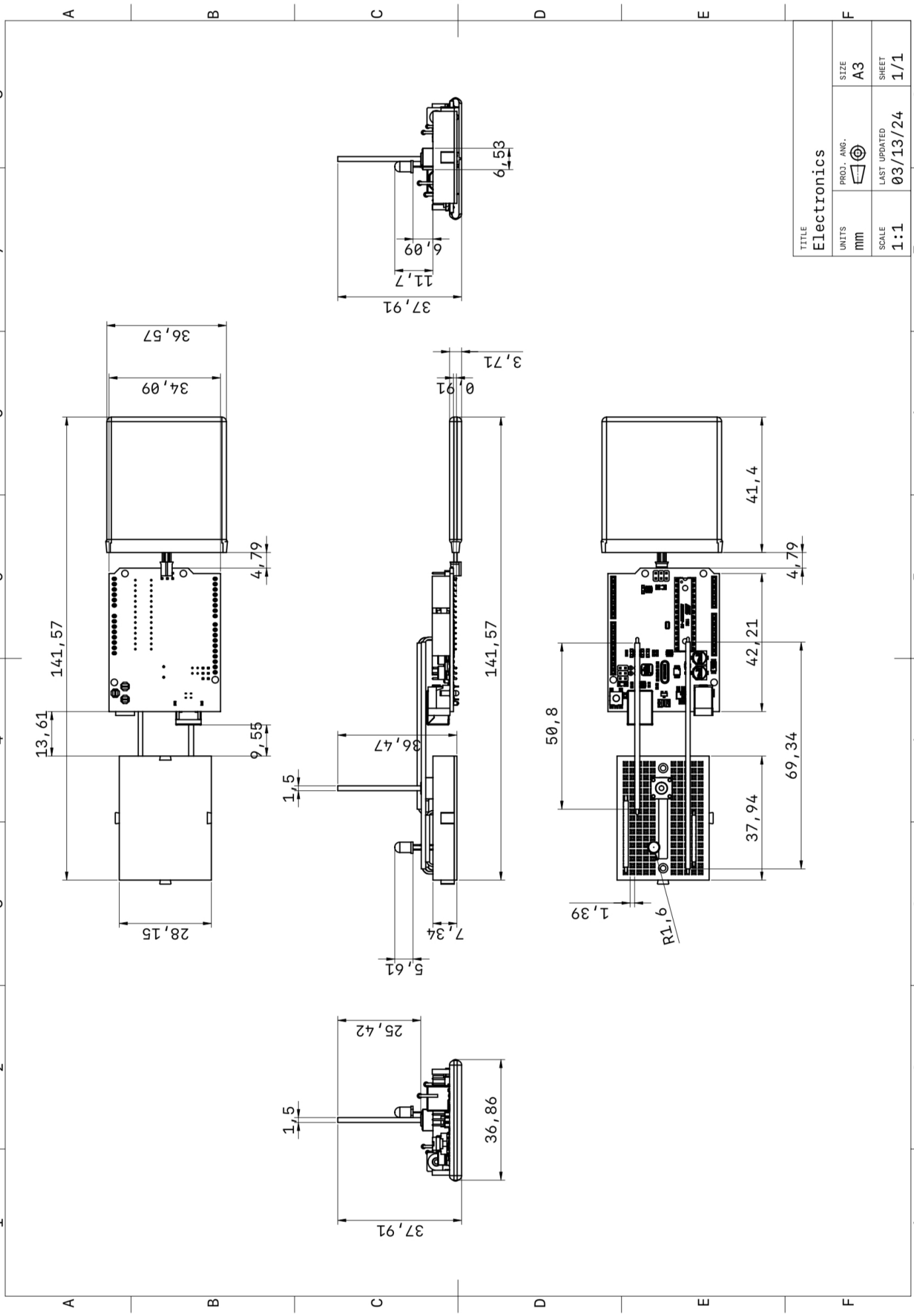




TITLE		
LED		
UNITS mm	PROJ. ANG.	SIZE A3
SCALE 4:1	LAST UPDATED 01/11/24	SHEET 1/1

FINAL DESIGN - Orthographic drawing: Base + Lid




TITLE
Electronics
UNITS
mm
PROJ. ANG.
SIZE
A3
SCALE
1:1
LAST UPDATED
03/13/24
SHEET
1/1
37,91
11,7
6,09
6,53
36,57
34,09
4,79
141,57
13,61
9,55
28,15
3,71
0,91
36,47
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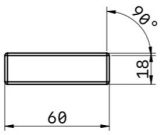
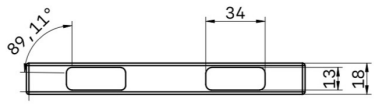
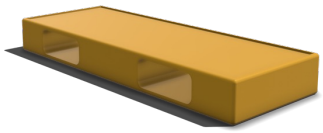
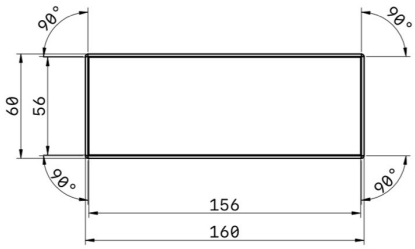
37,94
1,39
R1,9
25,42
36,86



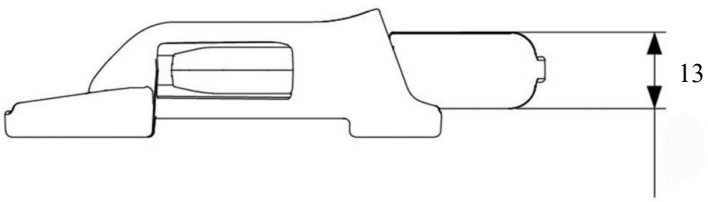


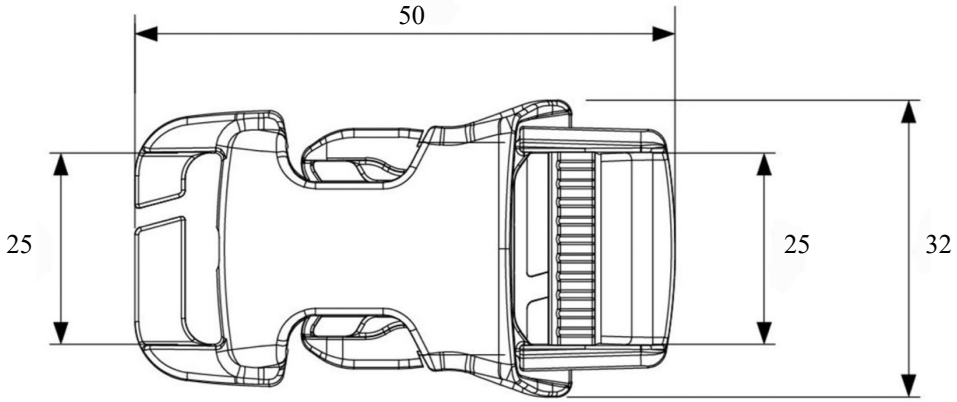


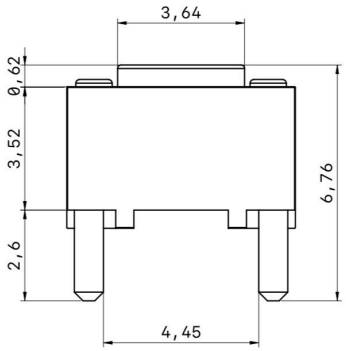


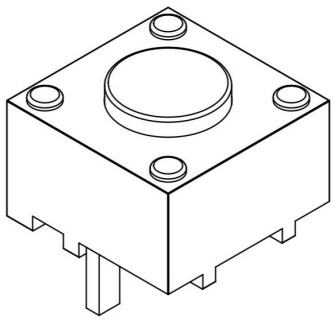
TITLE: Base		
UNITS: mm	PROJ. ANG.	SIZE: A3
SCALE: 1:2	LAST UPDATED: 01/11/24	SHEET: 1/1

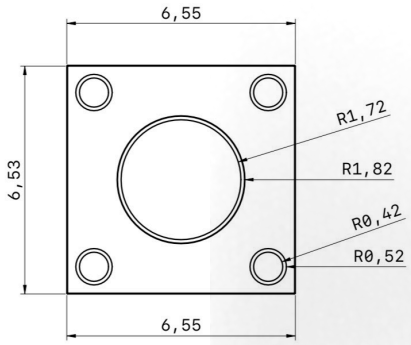
Attachment:

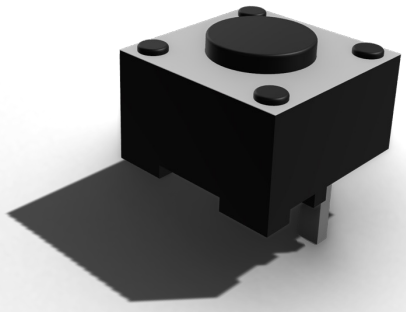




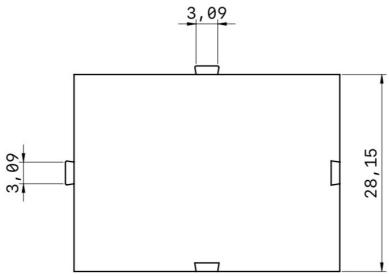


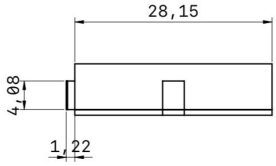


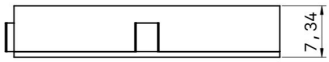


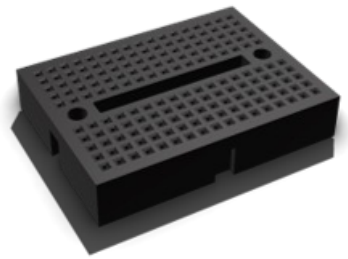


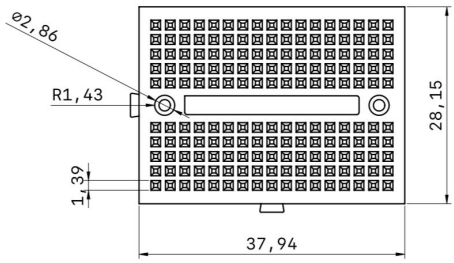
TITLE		
Button		
UNITS	PROJ. ANG.	SIZE
mm		A3
SCALE	LAST UPDATED	SHEET
10:1	01/11/24	1/1







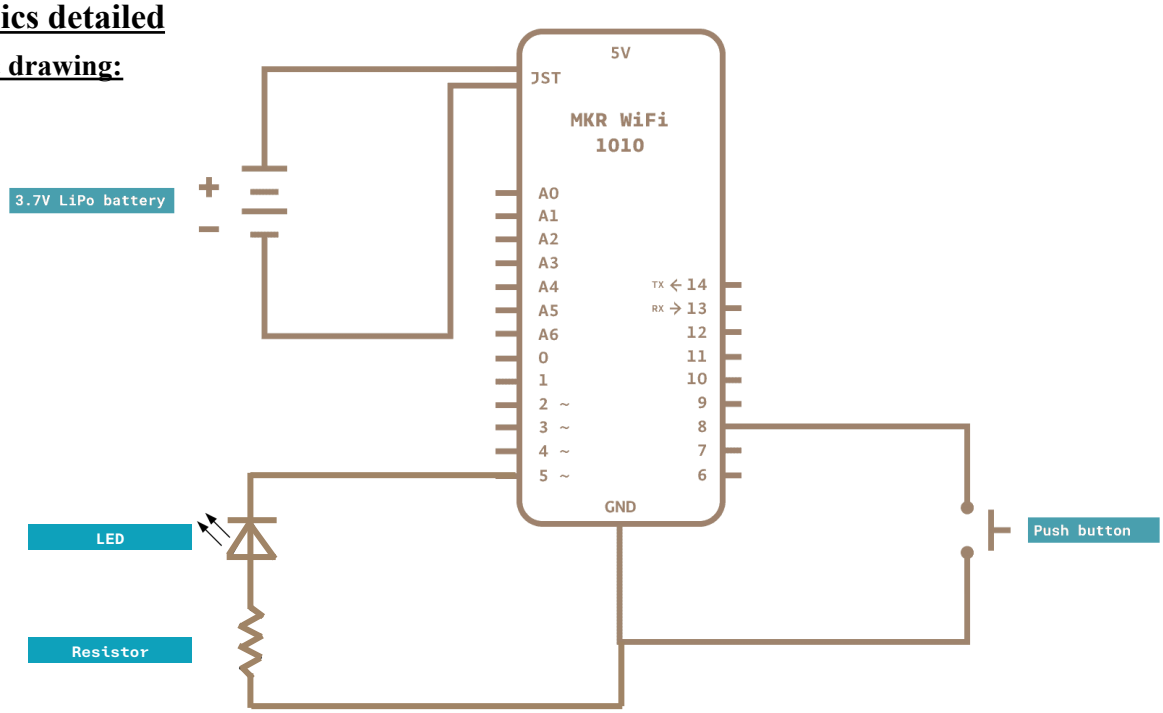




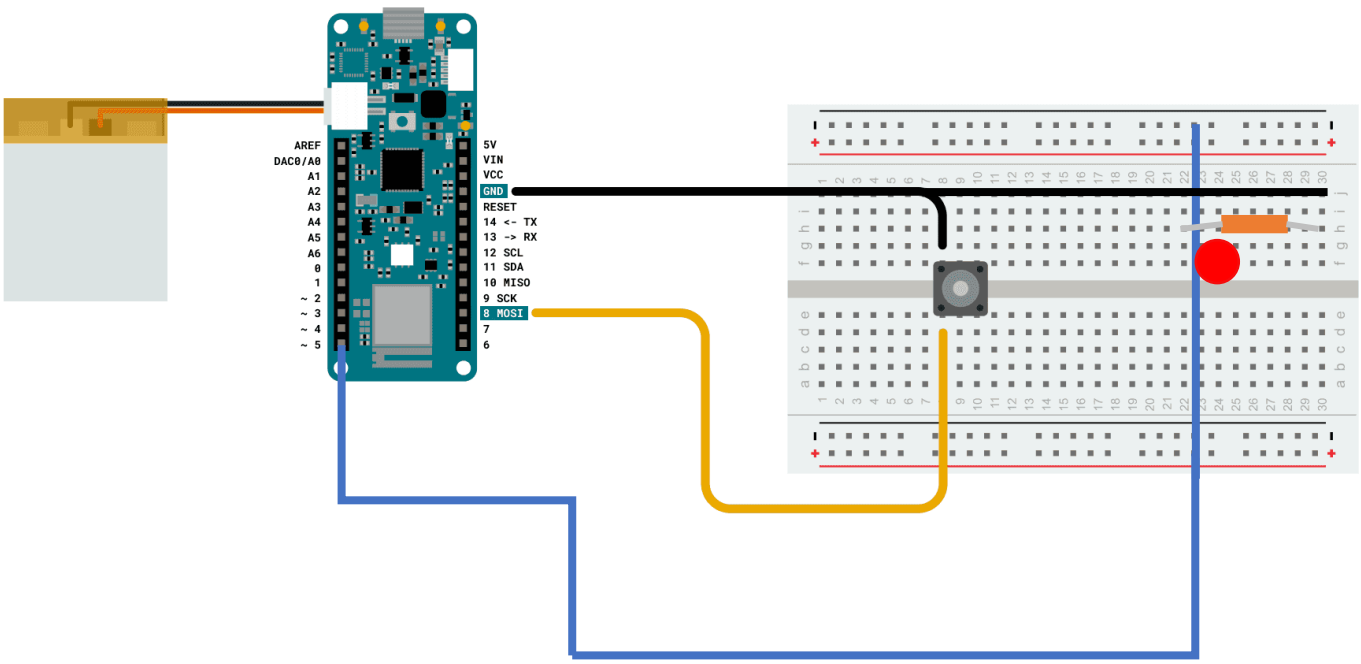
TITLE		
Breadboard		
UNITS	PROJ. ANG.	SIZE
mm		A3
SCALE	LAST UPDATED	SHEET
2:1	01/11/24	1/1

Electronics detailed

Schematic drawing:



Circuit diagram:



Programming extract for arduino: (All programming made by candidate)

```
236  * calculates the next flash state of the LED.
237  * If the LED is ON it switches it OFF and moves the delay to the next flash down
238  * If the LED is OFF it switches it off
239  *
240  */
241  void next_flash_cycle(long now) {
242    Serial.println("Next flash cycle");
243    if (current_flash_state == HIGH) {
244      current_flash_delay = current_flash_delay * decay_rate;
245      Serial.print("delay changed to ");
246      Serial.println(current_flash_delay);
247    }
248    current_flash_state_end_time = now + current_flash_delay;
249    Serial.print("Now=");
250    Serial.print(now);
251    Serial.print(" Next Flash=");
252    Serial.println(current_flash_state_end_time);
253    switch_flash_state();
```

Bill of Materials: For total set up of three tiles (3 tiles needed for random sequence)

Part #	Part name	Dimensions (L x W x H) mm	Quantity	Making/Buying	Unit Cost	Total cost
1	Side release buckles	50 x 32 x 13mm	6 male + 6 female parts = 6 pairs	Buying	10 pairs = £1.09	£0.60
2	Webbing	350 x 25 x 1 mm for one strap	6 individual pieces	Buying	£4.48 for 5m roll	£1.80 for 2.1m
3	Non-slip mat	56 x 156 x 2 mm	3 pieces	Buying	£10.99 for 800 x 1300 mm	£1.38 for 3 cut out pieces
4	Lid mould	56 x 156 x 25 mm (80g)	1	Making	£15 per kg	£1.2
5	Lid	56 x 156 x 25 mm	3	Making	£62.50 for 27m	£0.35
6	Base	56 x 156 x 18 mm (90g)	3	Making	£15 per kg	£1.35
7	LED lights	18.5 x	3 LED: 1 Red, 1 Green, 1 Blue	Buying	£0.25 for one piece	£0.75
8	Breadboard	30 x 40 x 8 mm	3	Buying	£0.75	£2.25
9	Arduino	60 x 25mm	3	Buying	£6.95	£20.85 for three
10	Battery	50 x 37 x 3.8 mm	3	Buying	£4.58	£13.74 for three
11	Rod	15 x 1.5 mm	3	Making	£7.48 for 250mm length rod	(7.48/16)x3 = £1.4

Total Cost for product package : (for three tiles as product will come with three not one)
0.60 + 1.80 + 1.38 + 1.2 + 0.35 + 1.35 + 0.75 + 2.25 + 20.85 + 13.74 + 1.4 = £45.67

Total Cost for 1 Tile:
= £15.22

Criteria C: Development of a detailed design

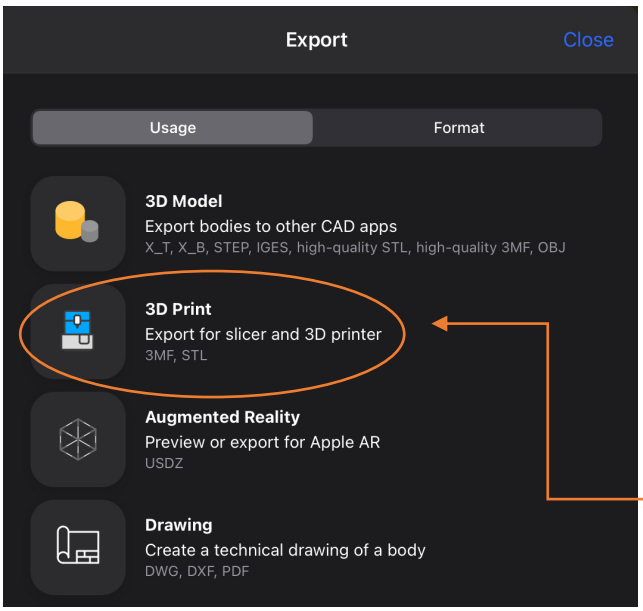
C3: Produce a detailed plan for manufacture of the prototype

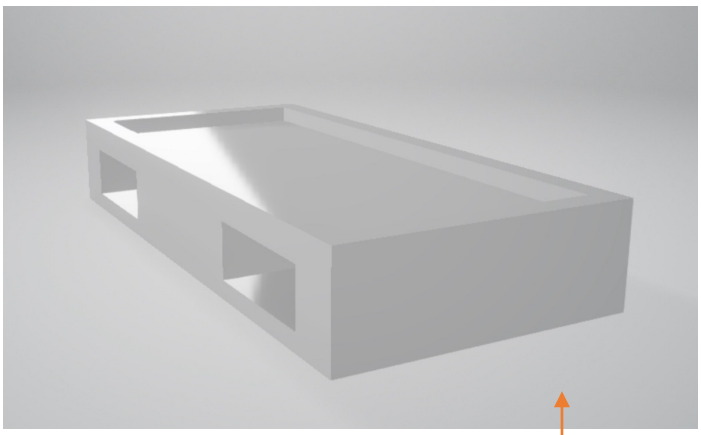
Step	Process	Equipment	Scheduling	Quality Control	Risk Assessment
1	Programme electronics (Iteratively test throughout)	C++ programming language	8hrs	- Manual testing;	- N/A
2	Wiring of electronics: follow wiring set up / circuit diagram	Arduino, Laptop, jumper wires	30min	- Manual testing; is code sequence able to run?	- Electrical shock from direct contact with live wires - Unplug battery before working
3	Create Fusion-360 sketches, save and upload STL file to 3D printer	Computer with CAD software	1hr	- Ensure dimensions and measurements are accurate	- N/A
4	Using slicing software convert the STL file into printable layers by adding supports	Bambu studio software	10 min	- Check settings and connections	- N/A
5	Prepare and load filament into the 3D printer * 3D printing process further detailed in following pages	Bambu studio 3D printer and PLA filament	6 min	- Check quantity and quality of filament before production. - Store in a dry environment using **silica gel packet** to fully remove moisture	- Filament has sharp edges ensure care when loading
6	Initiate and monitor the bodies and lid mould	3D printer	Print time: 2hr 10min	- Check printer settings match requirements - Measure with a vernier calliper to insure accurate sizing	- Mechanical hazards: burn risk from moving parts and high temperatures - Process emits ultra-fine particles and volatile organic compounds (VOCs) - adequate ventilation can mitigate this risk
7	Remove supports from 3D printed parts	Hands / Needle nose pliers	6 min	- Gradually remove the supports slowly to prevent excessive force on the print.	- Use pliers with caution: fingers may get pinched between jaws - Objects may fly off or break posing a risk to eyes
8	Mark out length of webbing	White pencil and ruler	5 min	- Use a metal ruler to measure accurately.	- N/A

Step	Process	Equipment	Scheduling	Quality Control	Risk Assessment
9	Cut 6 pieces of webbing of the same length	Scissors	8 min	- Sharp textiles scissors	- Improper use of sharp blades can cause injury
10	Fire the end of the webbing to seal thread	Lighter	3 min	- Dimensional accuracy – measure after to ensure sizing remains consistent.	- Risk of burn from lighter: handle with caution
11	Thread webbing through male and female-buckle	Hands	3 min	- Checked to determine if threaded correctly	- N/A
12	Sew webbing	Sewing mac hine and thread	10 min	- Visual inspection of finished product: examining seam strength and alignment	- Needle injuries: fingers too close to needle - proper handling needed
13	Cut out and clean a suitable size thermoplastic sheet to ensure there's no dust or debris .	Vacuum former	20 min	- Moniter and maintain heating of the thermoplastic sheets during the heating phase	- PVC material is relatively thick; unsuitable scissors that are not sharp enough will cause harm
14	Insert and clamp sheet into vacuum former frame	- Vacuum former - Plastic sheet	- 1 min	- Plastic must be properly clamped by aligning size correctly.	- Clamping requires heavy force – insure not fingers or objects are not trapped
15	Lower the heated sheet over the mould and activate the vacuum to create suction.	- Vacuum former - Plastic sheet	- 2 min	- Operator training to ensure leaver is pulled and vacuum button pressed at the correct time	Exposure to high temperatures during the heating phase can lead to burns or discomforts
16	Cut out formed plastic from the mould.	Scissors	20 min	- Ensure not to cut into the mould outline - Inspect for jagged edges for user safety.	Using sharp scissors during trimming poses a risk of cuts and injuries – handle with care
17	Glue electronics onto bodies and let dry	Industrial super glue	35 min	- Allow the adhesive to cure under the recommended conditions to ensure optimal bonding	- Super glue can cause chemical burns on sensitive skin – wear appropriate PPE (e.g. latex gloves)
18	Glue lids onto bodies and let dry	Industrial super glue	20 min	Inspect the glued joints for any defects, such as voids or bubbles.	- Inhaling fumes from super glue may cause respiratory irritation

Expanded process of 3D printing:

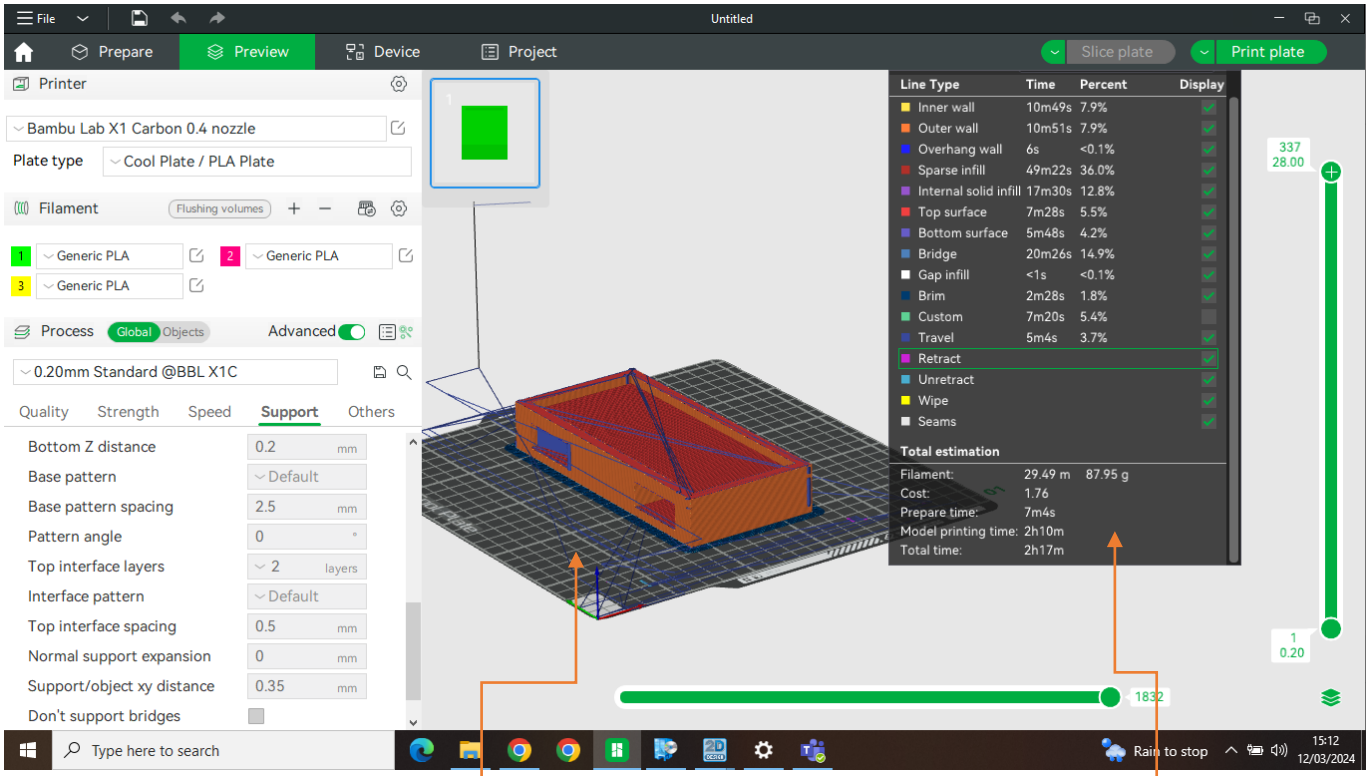
1. Export as a STL file





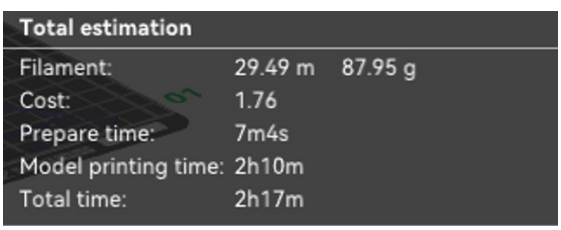
STL – Stereolithography file which represents a 3D model as a collection of interconnected triangles, ignoring: colour, texture and other finer details for simplicity.

2. Bambu studios software set up: (upload STL file into Bambu software)



Sliced model – 3D model file converted into **machine language** (set of instructions to be understood by 3D printer)

The histogram on the RHS displays the information of the printing times and **all parameter involved**



Most important information for manufacture

*3D printing time takes 2hr 10min, whilst printing process takes places, move onto further steps

Criteria D: Testing and Evaluation

D1: Justify a testing strategy to measure the success of the prototype

Testing strategy (In order of priority)	**Specifications tested**	**Method**	**Justification**
Performance testing (Quantitative)	3.1, 3.2, 6.1	- To test performance, I will perform: usability testing by assessing how the user-friendly the product, reliability testing by timing how long it takes for the battery to run out.	- This data is needed to determine how the product performed under user conditions - Determining the product's ability to consistently perform its function without failure.
User trial (Qualitative + Quantitative)	1.1, 1.2	- To test user's experience, I will go to the tennis courts with my primary user and time my user's set up time with a stop watch, allow the user to play the reaction game and ask questions on the experience.	- The quantitate data of the set up time will allow me to evaluate if my product is functional/intuitive enough.
Expert appraisal (Qualitative)	2.1, 2.2, 3.1, 3.2	- I will bring my tiles along to a coaching session and allow him to play around and use my product in its intended environment of the tennis court.	- The opinion of my tennis coach will help optimise the design as he specialises in agility training/coaching - Expert knowledge and advice will be gained
Focus groups: user feedback (Qualitative + Quantitative)	4.1, 4.2, 5.3	- Gather qualitative feedback on aesthetics, features and enjoyment through interviewing tennis players within my target demographic at my tennis club, tennis coaches and regular tennis players.	- I can gauge whether my target audience finds the design visually appealing. - Identify areas of improvement/refinement - Qualitative feedback ensure that the design resonates effectively with target audience
Survey (Qualitative + Quantitative)	2.1, 2.2	- To test demographics, I will send our a survey with CAD models and the prototype of my product to members of my tennis club.	- This data is needed to determine if the product has unique and appealing to target market of middle aged non-beginner tennis players. - Determining competitive edge to attract a broader customers base.
Product comparison (Qualitative)	8.1, 8.2	- A large inspiration for this project was the interactive touch wall (existing product analysis), I will compare and contrast the products.	- A comparison against existing products can demonstrate if the prototype is as good or better than the competition.

Criteria D: Testing and Evaluation

D2: Evaluation against the design specification

Function:

Spec points:

1.1 Product must be used without the assistance of a coach/professional.

1.2 Product must improve user's agility to move across the court.

Testing strategy: User trial (on tennis court with primary user)

Successes: Primary user was able to successively operate and set up the three tiles with ease in **4 minutes 52 seconds**. The user set up the buckles without instruction, thus it was clear how to start the code, as the user had to be simply press execute the code on the laptop.

Areas of development: The button was activated by pressing down on the lid, which had enough flexibility to allow a rod to pass through and make contact with a button on the circuit. However, a problem arose when the rod broke off. Additionally, the user found the lid's lack of downward movement unsatisfactory compared to a traditional button. As a result, I will modify the design to move up and down when pressed by the user.

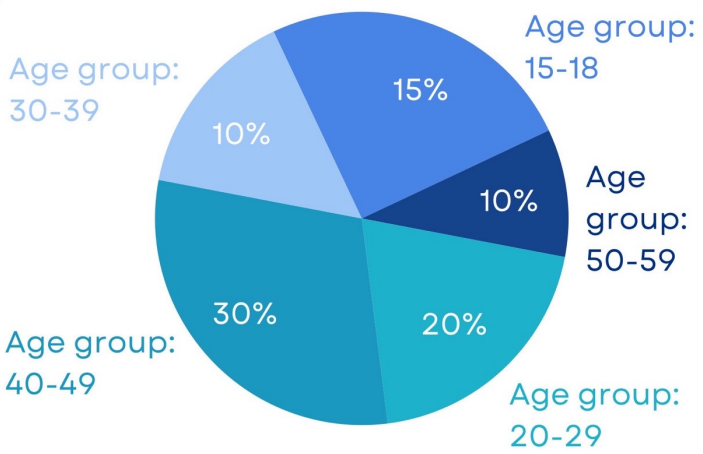
Target Audience:

Spec points:

2.1 Product catered towards amateur middle-aged persons

2.2 Can be used by other stakeholders in other sports that require fast agility

Testing strategy: Survey + expert appraisal



Successes: Coach Tom – "As you get older using cones/markers for training can feel childish – these devices work brilliantly in overcoming this issue by providing a stimulating tech alternative." Moreover, I sent out a survey to my tennis club, of which I received **38 responses**, to determine the demographic of people who would purchase the product from initial impressions. Successfully, the most popular age group was 40-49 and 20-29.

Areas of development: Alternative attachments designed for that have nets with decreased spacing between net holes. Additionally, as commented by a survey member, a magnetic attachment would broaden the product's target market.

Size:

Spec points:
3.1 Max size (compact/folded): 75 x 23 x 33 cm
3.2 Max weight of product: 4.8 kg

Testing strategy: Performance testing + Expert appraisal

Successes:
- All three products easy and successfully fit inside a standard tennis travel bag as required.
- All three products are much below weight requirement (see next pg) – allowing easy portability.

Areas of development:
- **Coach Tom** – "In low light conditions, particularly in the winter month, the product is not extremely visible from a distance, especially when its on the floor, and is completely invisible when the electronics are switched off in the dark."
- Therefore, I will develop the dimensions by extending vertical length and incorporating a fluorescent element to amplify visibility; potentially integrating it within the product's electronics and clear lid to render it entirely visible in the absence of light / low light conditions.

Aesthetics

Spec points:
4.1 Colours must be bold and contrast that of the surface of the court
4.2 Product must not be green or red

Testing strategy: User interview

Areas of development: I will utilise a darker colour scheme. Moreover, to execute the code, the user must press a button the computer. To improve, I could make an app interface instead a basic run code button which aids the user in gathering data on themselves or make the product harder.

Successes: After showing a focus group of 5 people images of the 3 tiles on and around the tennis court, **80%** stated that the products were clearly distinguishable on the court surface, and had a modern and professional look. One participant stated that the yellow colour was too childish, however black and orange will be the intended colour scheme for pre production with school resources. Despite this, the overall sentiment within the focus group was overwhelmingly positive, particularly noting the captivating aspect of observing the embedded electronics.

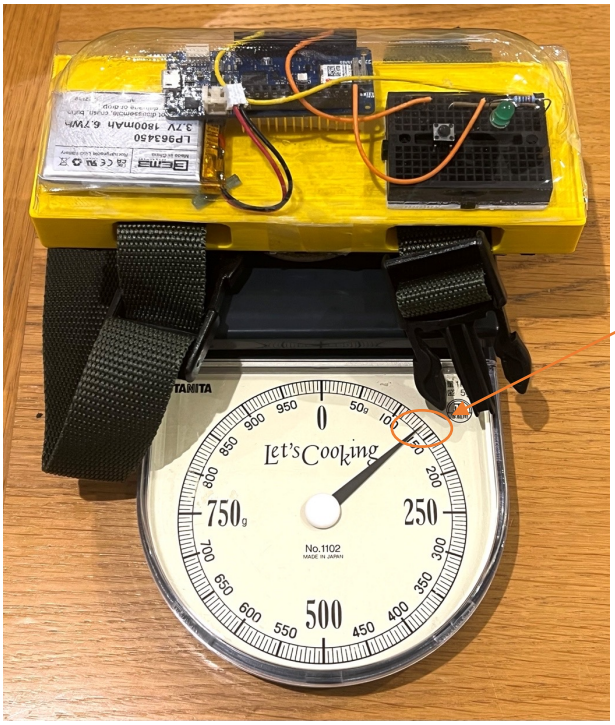
Product constraints

Spec points:
5.1 Must be completed by 15/03/2024
5.2 Must be able to be manufactured in school environment
5.3 Cost no more than £75

Testing strategy: 5.1 + 5.2: self reflection, 5.3: user feedback

Successes: All spec points covered, I am particularly happy with the quick time in which I was able to manufacture this prototype alongside my other IB subjects. This prototype was incredibly fun to make which made the completion process ever faster.

Areas of development: Possibility of price reduction, although product is within the price range, more research can be made into investigating cheaper methods in commercial production.



Spec points:
6.1 Material must be lightweight, strong, weather resistant and sustainable.

Testing strategy: Performance testing + user feedback

Successes: Total weight is extremely light at a total mass of 140 grams (meets spec point 3.2 as it is well below 4.8kg). Additionally, they lid and body are recyclable.

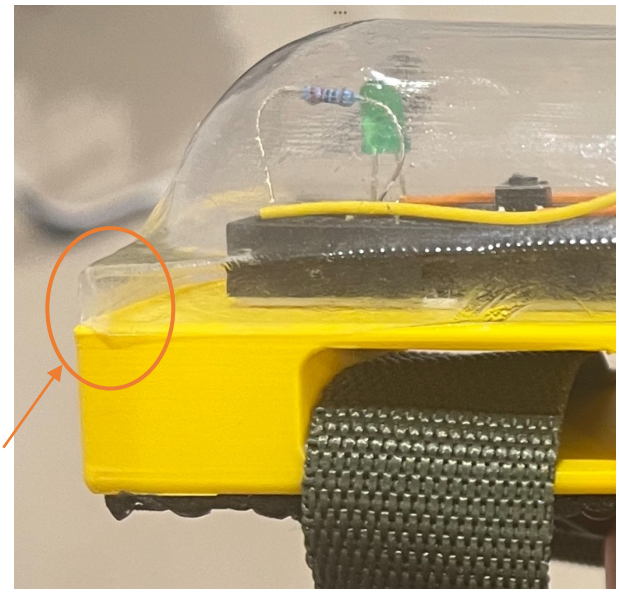
Areas of development: Material is possibly too light, although the wind did not affect the performance of the product, the environment of testing was not in an extremely windy condition. Nevertheless, my user commented how the product felt "unnaturally light as it weighs less than an iPhone". Therefore, I believe I should change the material of the body to a denser yet still strong material such as aluminium or carbon fibre.

Environmental

Spec points:
7.1 Product must be long lasting and not-one-off use
Testing strategy: Performance testing

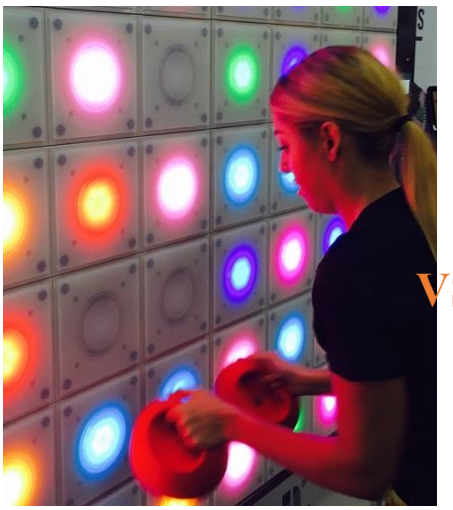
Successes: Battery selected is rechargeable; product has estimate of 20 uses / 30 hrs of battery, before battery dies (product manual), and must be recharged.

Areas of development: Currently the issue preventing the product to be long lasting is the sealing of the lid to the body, small traces of water were able to get in as there was small gaps between the plastic lid and body joined by the glue adhesive as the plastic lid was not cut perfectly enough. Therefore, a rubber sealing around the lid and body could prevent any such damages to the inside electronics.



Quantity

Spec points:
8.1 Ability to be scaled up commercially
8.2 I will make the prototype suitable for batch production
Testing strategy: Product comparison



VS

Successes:
- Meets the excitement of the touch wall with the visual stimulations alongside the challenging sports nature.
- Portability which the wall does not.
- Significantly cheaper; price competition

Areas of development:
- The Twall allows for 2 players to play the reaction game together. Therefore, a multiplayer mode that allows the product to be able to turn into a group game would be beneficial for group coaching sessions or team sports to broaden the potential market.

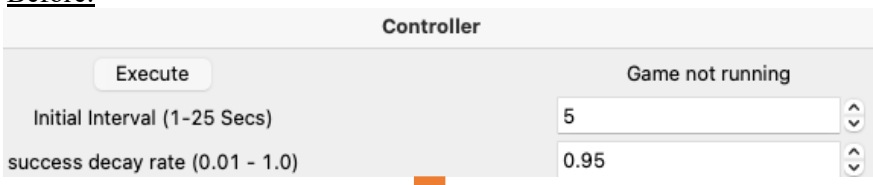
Criteria D: Testing and Evaluation

D3: Demonstrate how the prototype could be improved, considering how individual improvements affect the design as a whole.

Improvement for Running Software (Function & Aesthetic)

The user interface for operating the software on the product fell short of expectations.

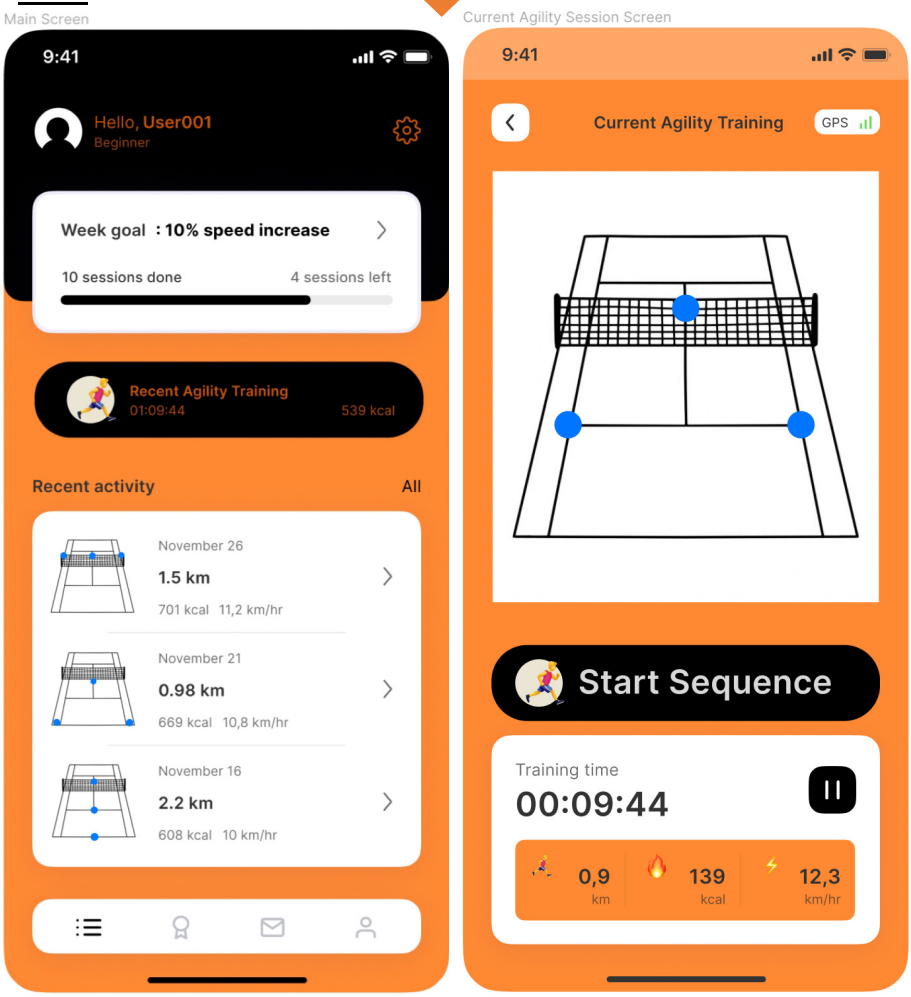
Before:



Functional for only the basics of the product; hindered the user experience of the physical product

Enhancing the user interface to a phone is imperative to elevate the overall product usability and ensure a satisfying interaction for the users.

After:



I have designed an concept app using 'Figma' to showcase this possibility.

User is able to see how much time they spent training through data collection

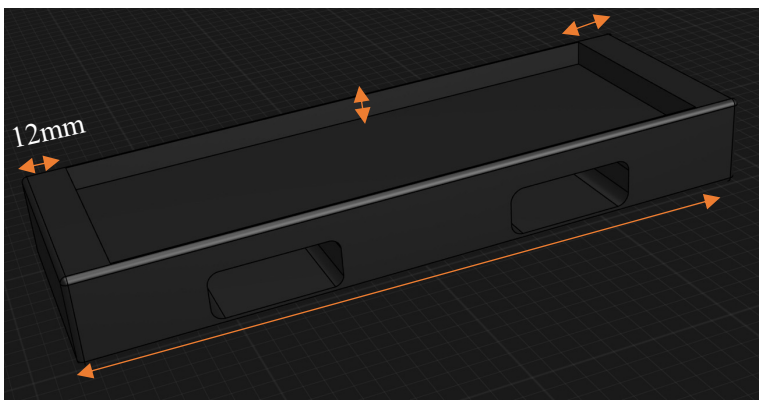
Clearly expresses to the user how to start the light sequence

Colour theme is vibrant and engaging

Additionally data/stats can be determined and provided: max speed, calories burned etc

Improvement for sizing

After:



Vertical length added without increase in lid size – additional 24 mm added (12mm on each end)

Longer in length = more visible from a distance away from the court

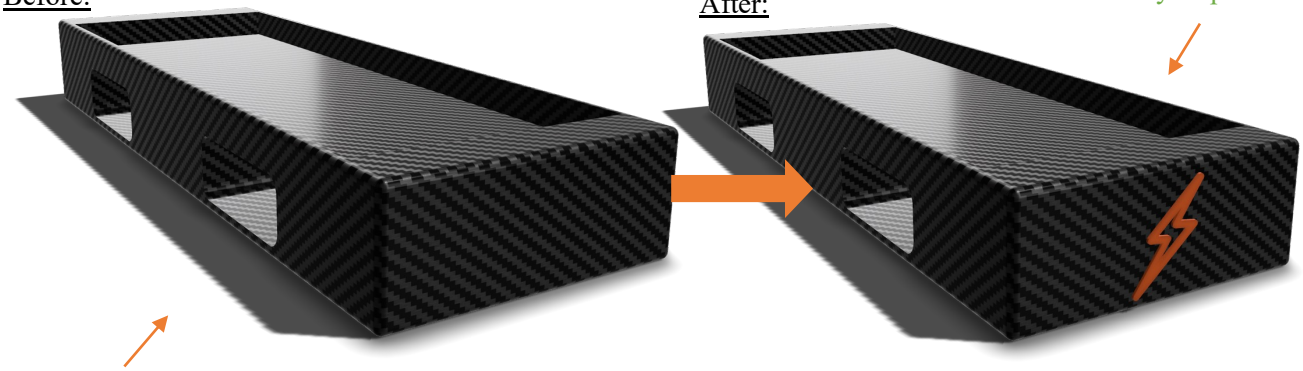
Increase in depth for the lid - more water resistant

Improvement for visibility

Improvement in visibility in the dark – no one will mistakenly step on

1. Before:

After:

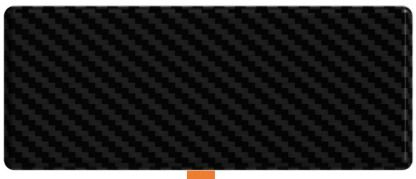


Glow in the dark lightning symbol (company logo) on both sides of the product

2.

Material change – harder ABS plastic, firmer for user when pushing with greater force (SP6.1)

Before:



After:

Before:

Shape change – see spring improvement

Originally fully transparent - clear can allow the product to appear washed out from a distance

After:

Translucent – tinted lid for a more vibrant appearance, electronics still visible

Improvement for lid attachment: Springs

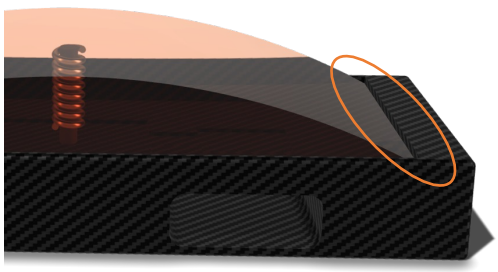
Replace flexible lid material and adhesive attachment method with a firm lid and springs

Before:

Increasing material and manufacturing complexity, however provides a better user experience

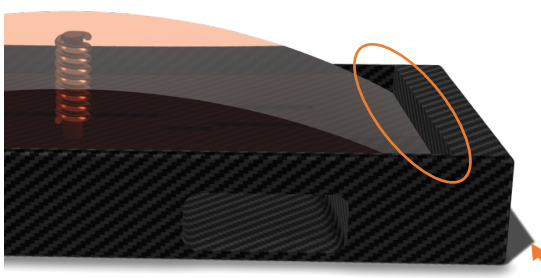
Pressure is placed on the button, resulting in the depression of the internal spring.

After:



(Released button)

This forces the lid to move down and have a satisfying retraction.



(Pressed button)

Button is now able to move up and down

Criteria E: Detailed development of a commercial product

E1: Develops the design, addressing the required modification for a commercially viable production process.

Dematerialisation / Disassembly:

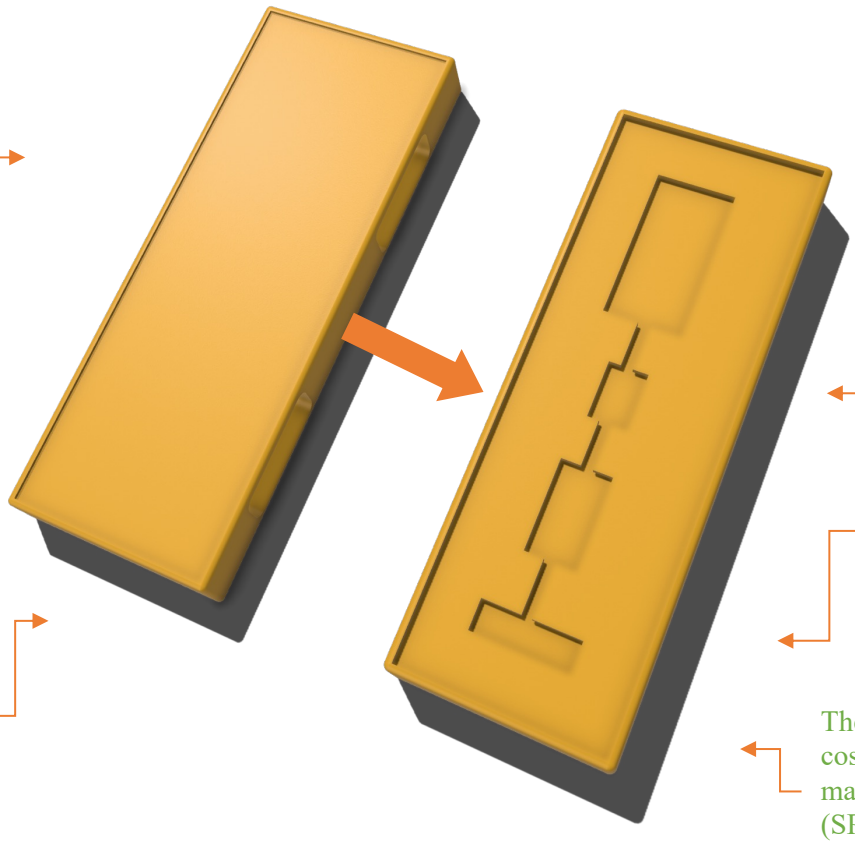
Aim: Reducing the overall material used in the product

Making the product easy to disassemble by finding alternative to glues, and hard to disassemble parts

The electronics can be fixed with form-fitting indents.

Fitted to the exact measurements of the electronics.

Indents would allow for easy assembly/disassembly as parts can be popped in/out



Compact fit – prevents separation

Joinery effect – Inspired by battery fittings

Indents would eliminate any need for adhesive/glue

Therefore, reducing the cost of production and making production faster. (SP8.2)

Component / Cost reduction:

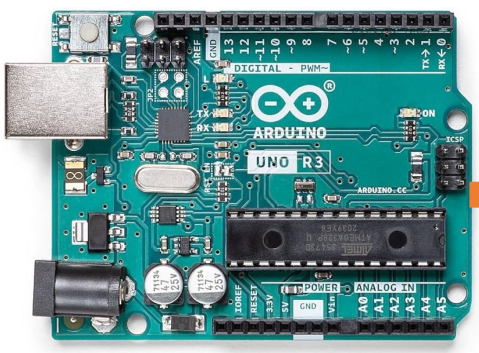
Aim: Reducing the use/number/cost of components

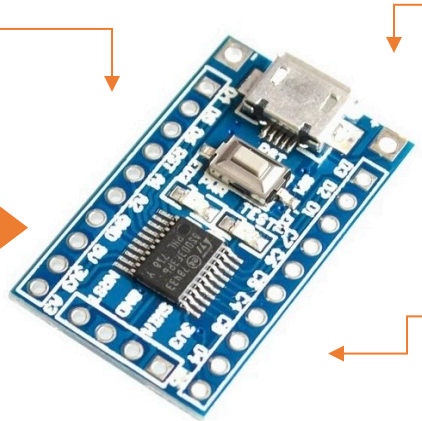
Arduino is easy to programme and test code and functions.

Third–party manufacture would burn software onto chip -> no need to transfer software

Less powerful – however additional power is not needed for my product

Once code is made, code can be transferred to a production board





Cheaper in bulk and has the same software capacity

Arduino is necessary as the building block of the prototype not for commercial production

Arduino UNO: £6.95 per unit

STM8S003F3P6: £0.75 per unit

Soldering process required for this component change

Significantly reduces production cost – higher profit margin / more competitive pricing choice

Disassembly and recycling:

Aim: Making it clear what materials are to aid recycling (recycle marks)
Making clear how the product meets recycling regulations

WEEE: Waste Electrical and Electronics Equipment regulation

As my product consists of electronic pasts, it must be follow legal guidelines on its recycling. The primary UK guideline being WEEE compliance.

"WEEE compliance refers to the obligations on producers and retailers of electrical and electronic goods. Under the WEEE Regulations they must ensure processes and collection systems are in place so that old electrical and electronic appliances get reuse and recycled, rather than being thrown away." - [recycleyourelectronics, 2023]

Development for WEEE compliance:

As the battery used is made of lithium ion, the product can't be simply disposed of.

There needs to be an **incentive** for the user to give back the electronics.

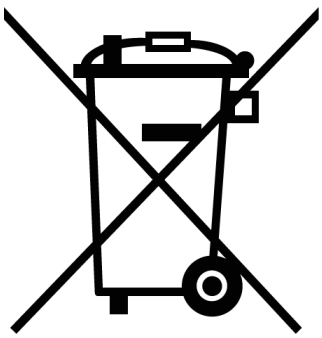
I believe the trade in scheme which Apple popularised would work beneficially for my product's life cycle

Users can mail back old products for a discount off new products.

Follows WEEE regulation – electronics would get disposed of correctly

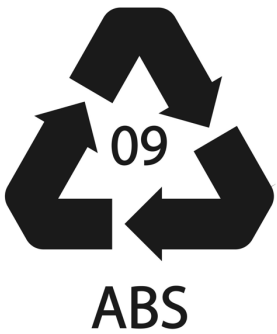
Also encourages money to be spend back into the company

Recycling marks to add to packaging:



- WEEE logo: serves as a clear indicator that electronic components require special disposal
- Ensuring users understand it cannot de discarded conventionally.

- Lid of the product is made of HDPE, logo indicates that when separated it can be recycled



- Base of the product is made of ABS, therefore is fully recyclable when detached from rest of product.

Importance of recycling electronics:

- Resource conservation: valuable and limited resources; recycling reduces mining demand.

- Recycling ensures proper handling of heavy metals and toxic chemicals within.

- E-Waste reduction is a global environmental concern / movement – part of the solution not the problem.

- Improper disposal in landfills can lead to contamination of soil and water

Achieved: Product is easy to completely disassemble as no glue is now used
All recycling regulations are met and clearly marked on packaging / product

Manufacturing:

Aim: Research manufacturing methods more suitable for commercial production

Research: 3D printing vs Injection moulding (IM) for commercial production:

Production speed:

- IM = high-speed process and highly efficient for mass production
- IM is capable of producing **large quantities of identical parts** in a short time.
- 3D printing for commerical production may be challenging due to **layer-by-layer additive nature**.

Cost-Effectiveness:

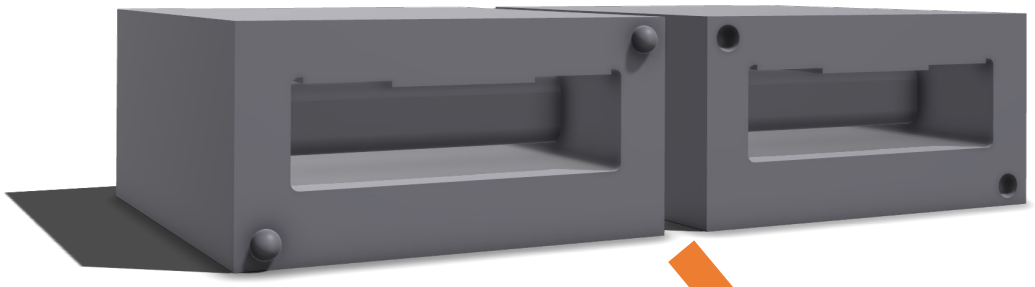
- IM is more cost-effective for large production runs.
- IM requires initial tooling costs for creating moulds
- **Economical for large-scale manufacturing:** the per-unit cost decreases significantly with higher quantities using IM.

Surface Finish and Detail:

- IM produces parts with **smoother surfaces and higher detail** than 3D printing processes.
- Crucial for my product where a **polished, professional appearance** is essential.

Therefore, through these benefits, I will take forward injection moulding for commercial production.

CAD Injection mould

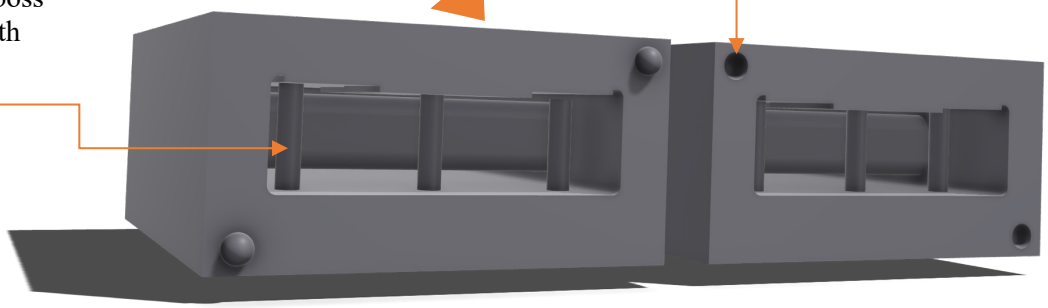


Dot joint to line up the mould precisely

One mould with pertruding sphere and one mould with inverted sphere

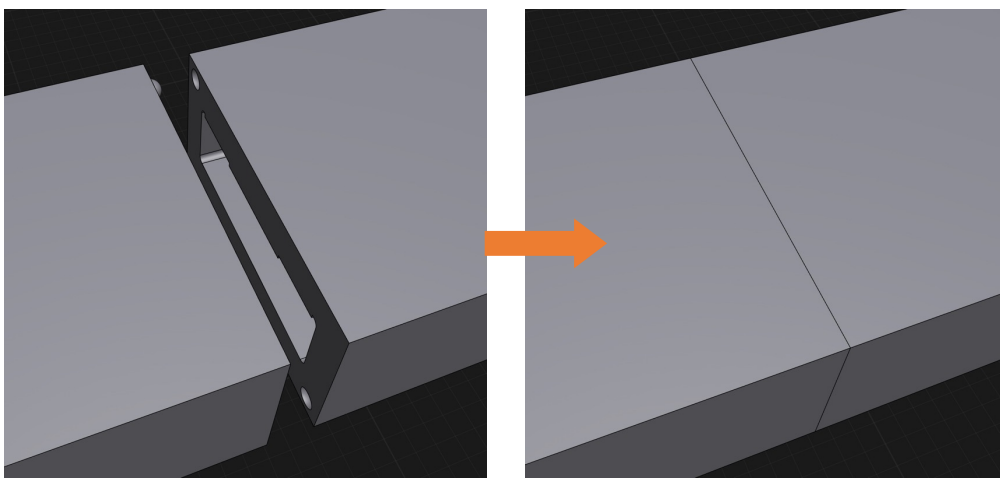
Mould improvement

Support boss added after more process investigation - boss designed to improve strength



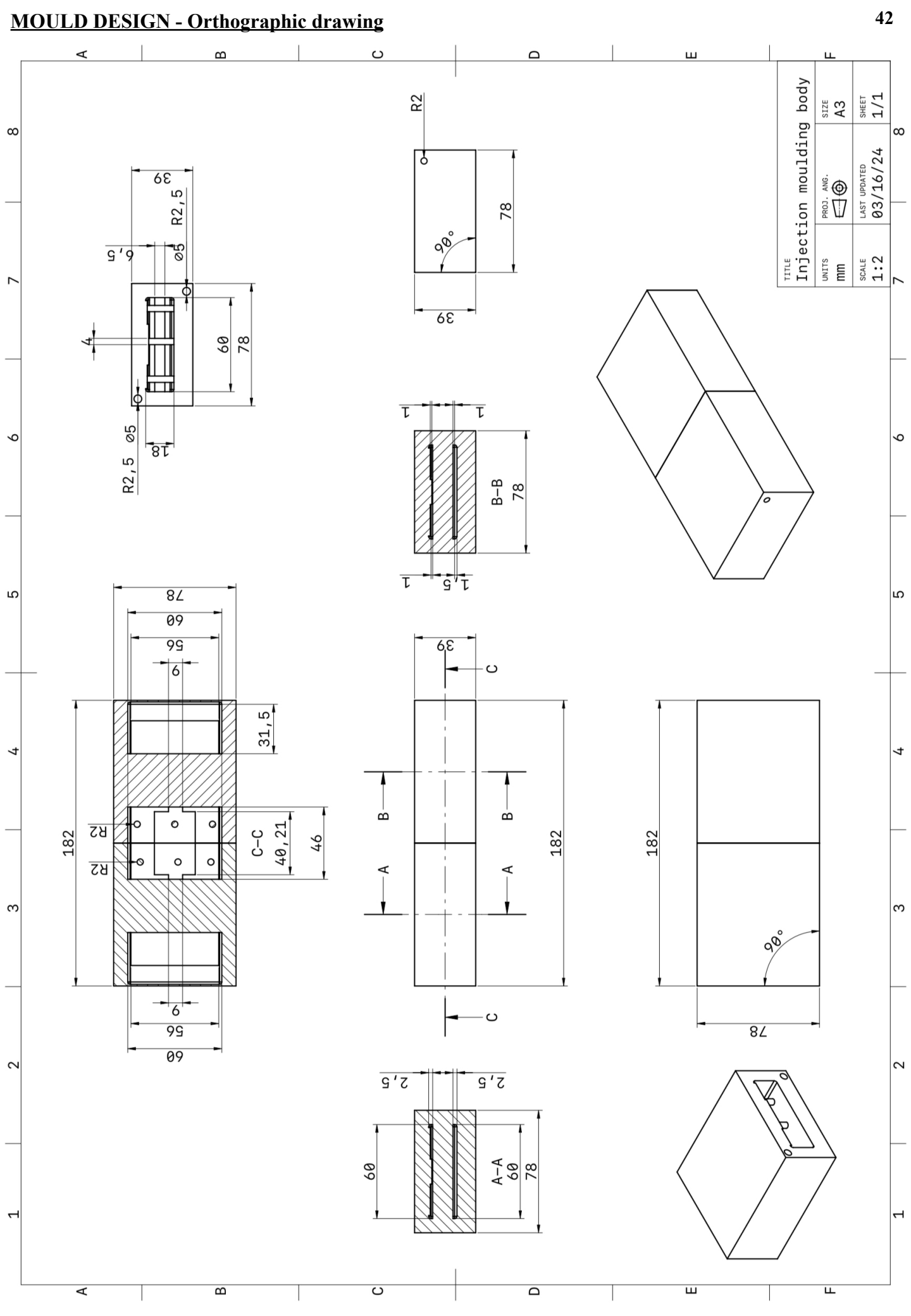
(Breaking apart a remote controller to investigate screw boss placement)

Parting line – allowing product to be removed easily from mould once set



Material poured through pour spout when mould is joined.

Visualisation of how the mould disconnects


TITLE
Injection moulding body
UNITS
mm
PROJ. ANG.
SIZE
A3
SCALE
1:2
LAST UPDATED
03/16/24
SHEET
1/1
R2
78
90°
39
39
R2,5
ø5
6,5
4
60
78
18
ø5
R2,5
1
1
B–B
78
1
1,5
78
60
56
9
31,5
182
R2
R2
C–C
40,21
46
9
56
60
39
C
B
A
B
A
182
C
182
90°
78
2,5
2,5
60
A–A
60
78

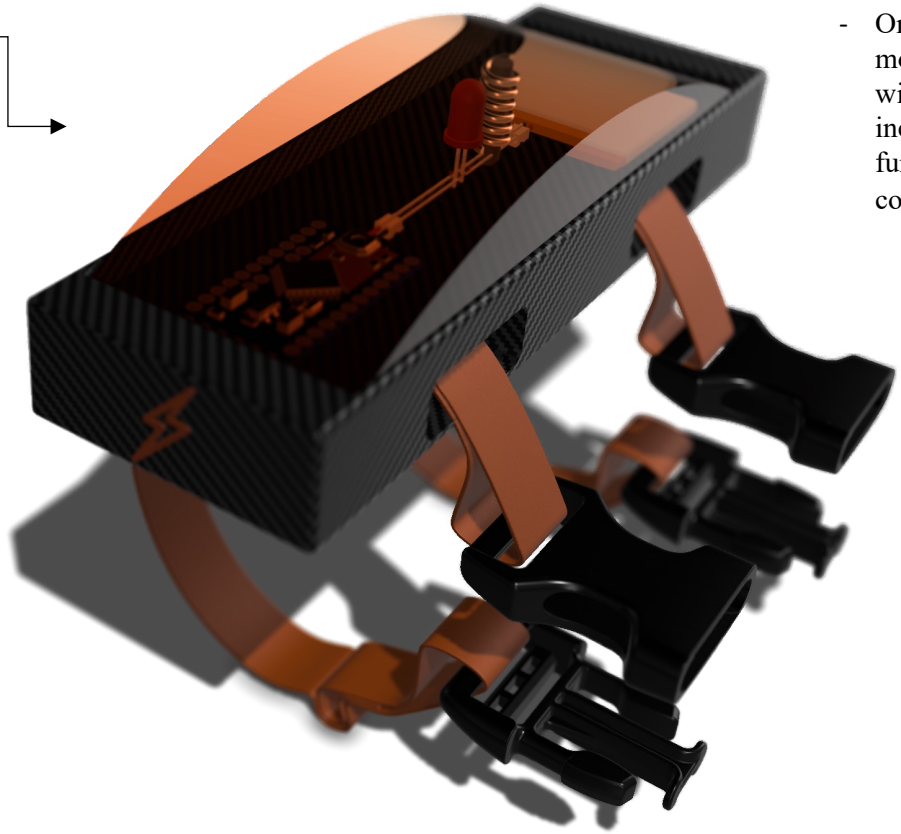
/0

Criteria E: Detailed development of a commercial product

E2: Presents the developed commercial product comprehensively

Overview of modifications:

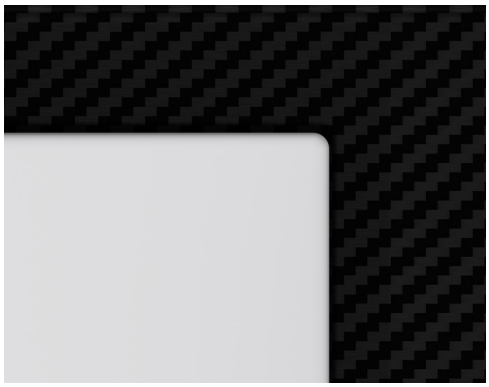
- Base material change to carbon fibre composite
- Lid material change to acrylic
- Opaque lid tint colour
- Refined and simplified circuit board
- Logo / lighting emblem addition
- Orange and black complementary colour combination.

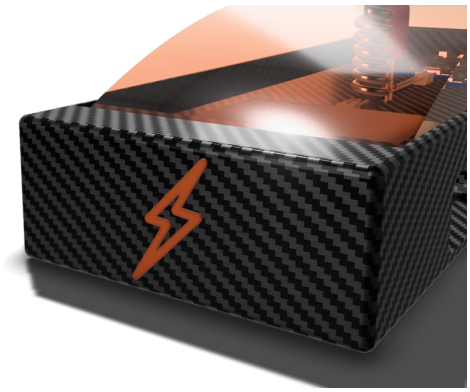


- Once profit is made, more colour ways will be added to increase appeal to a further range of consumers (SP8.2)

Close up (Important new features):

Logo on the product allows for distinctive brand identification (SP8.1)





Precise indents allows electronics to be fitted without adhesives.

Tarnishes on clear transparent material are clearly visible – tinted opaque allows for stain coverage (SP7.1)

Light Speed

Agility Revolutionised

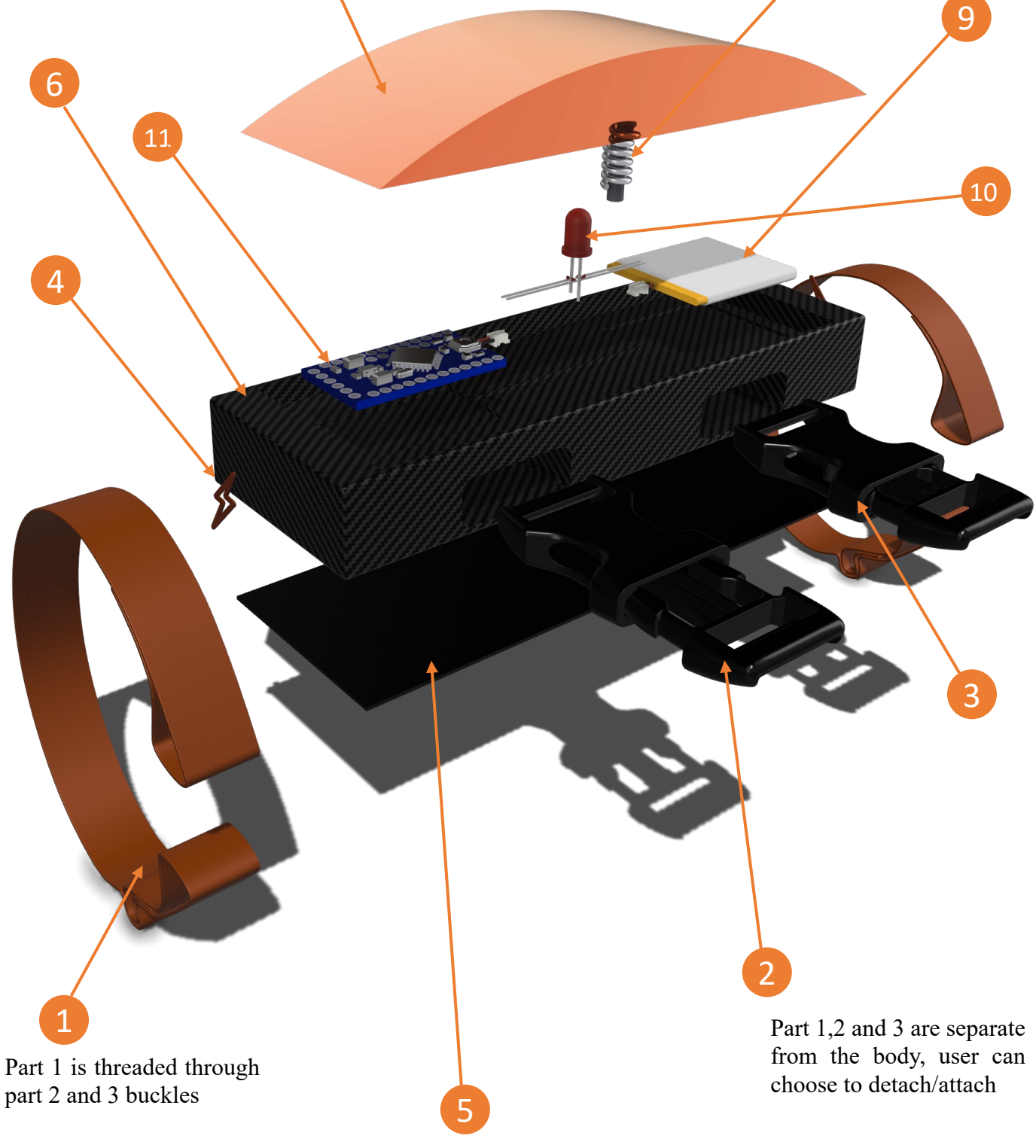
Logo:

- Name + logo has connotations to fast speed
- Suggesting to the viewer their speed and reaction can be 'light speed' (SP2.1)
- Tag line eludes to a unique product that doesn't give the whole project away.

Criteria E: Detailed development of a commercial product

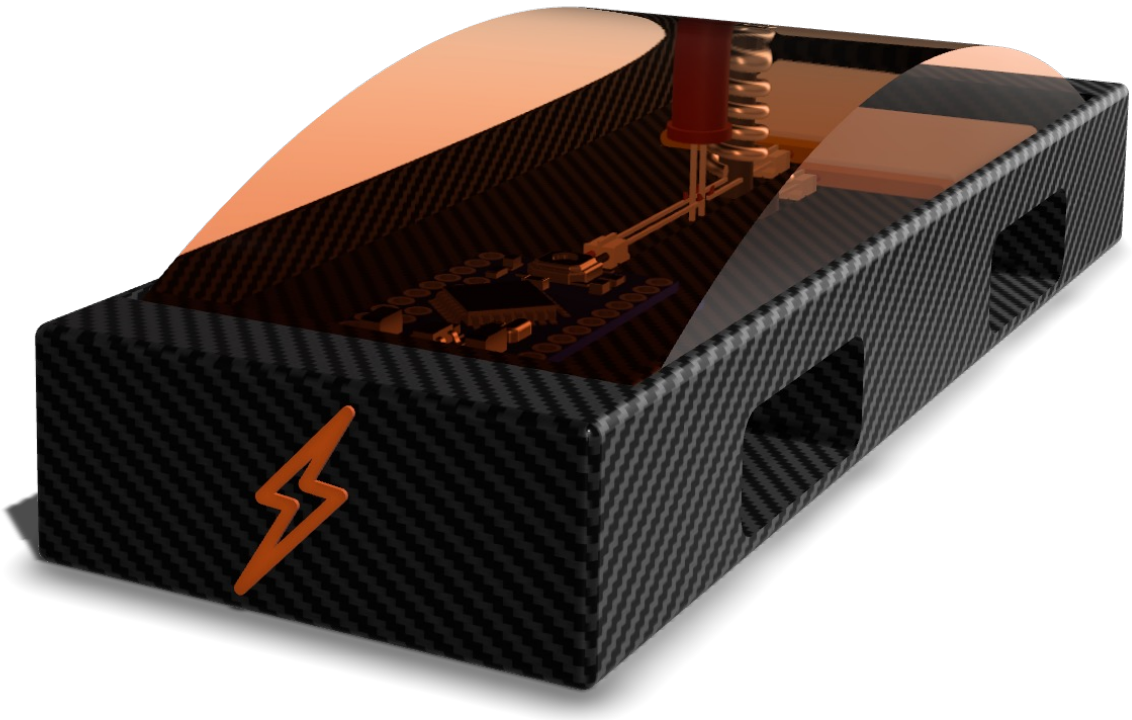
E3: Commercial Design Proposal

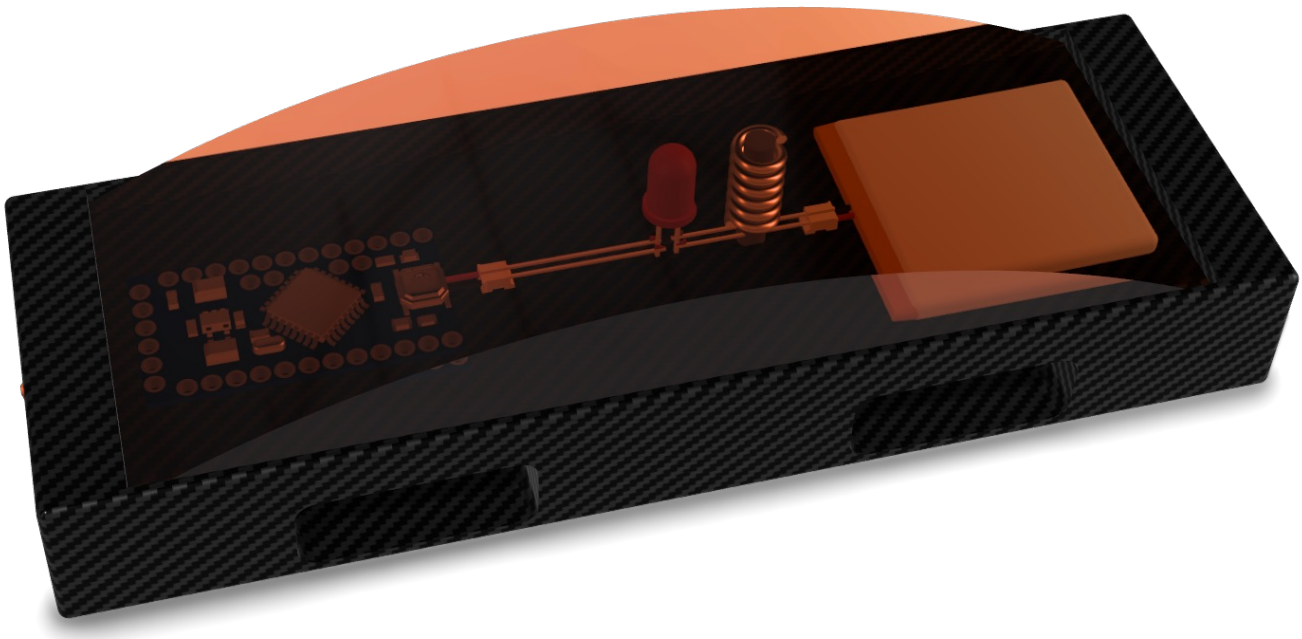
Assembly drawing

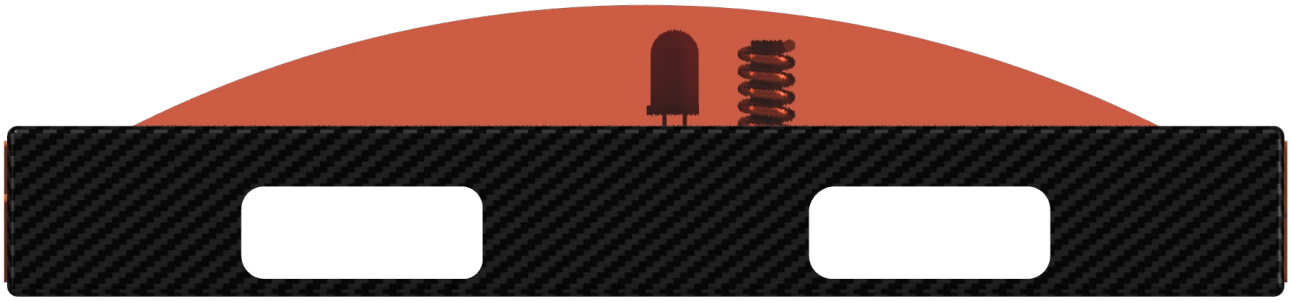


Isometric drawing (without buckle and strap):

(All CAD self made on Shapr3D)

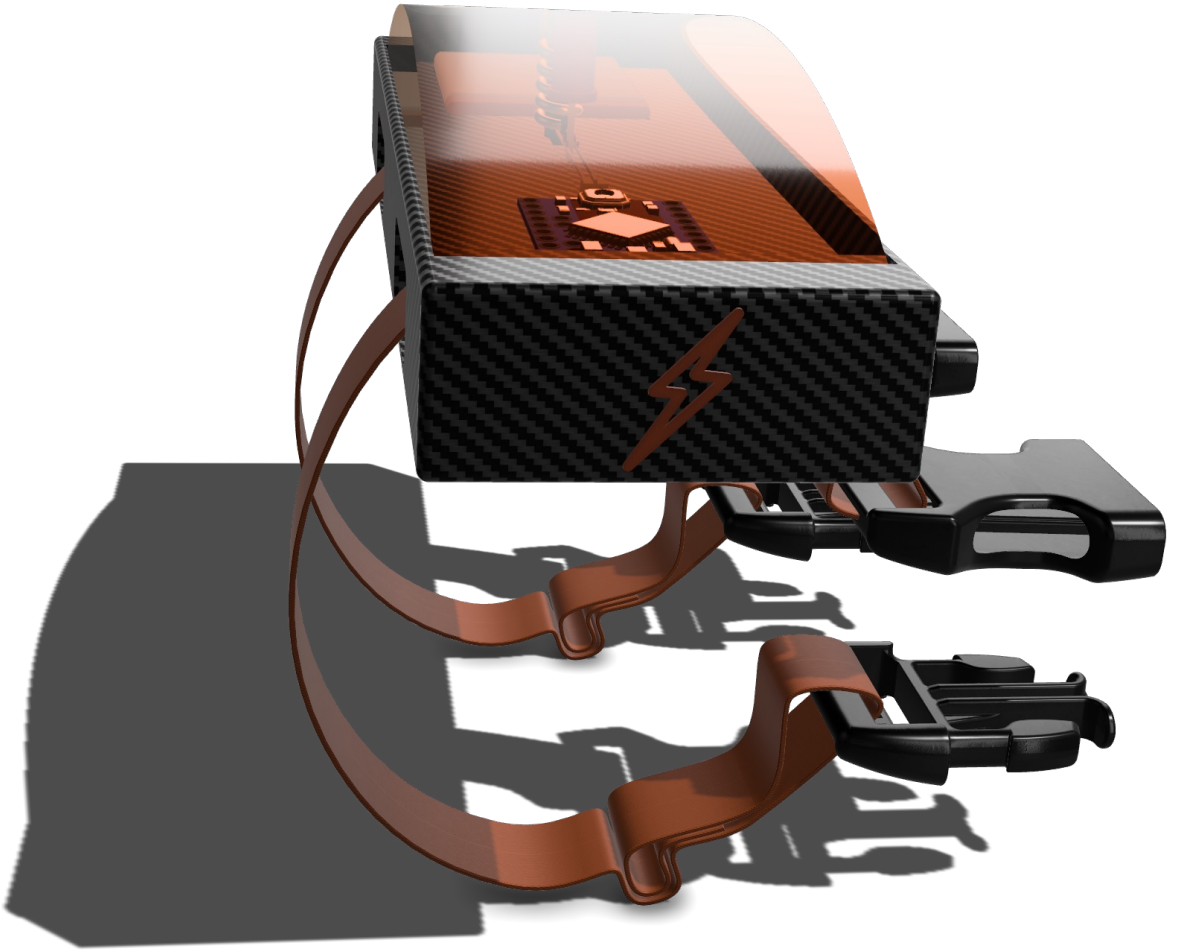


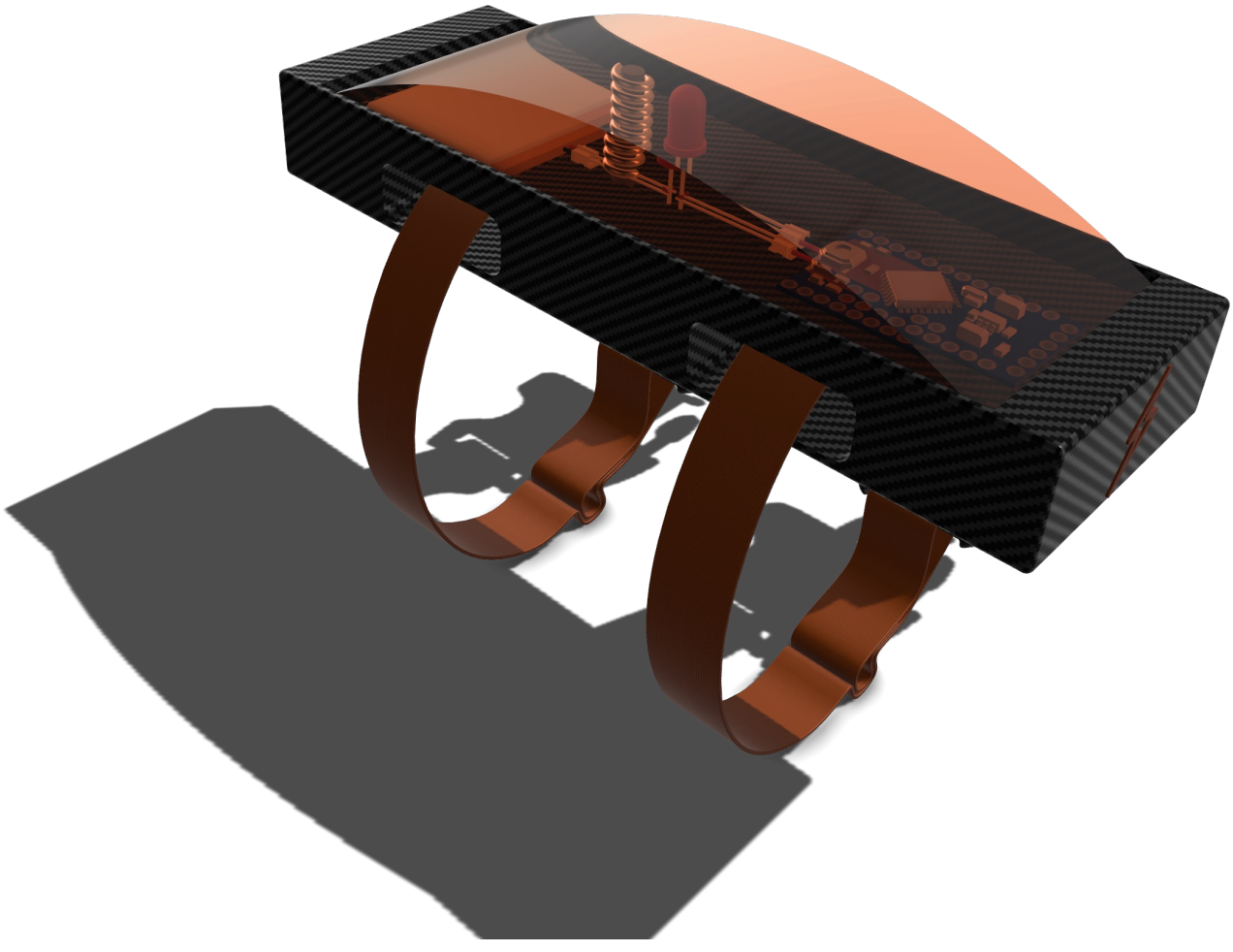




Isometric drawing (with buckle and strap):

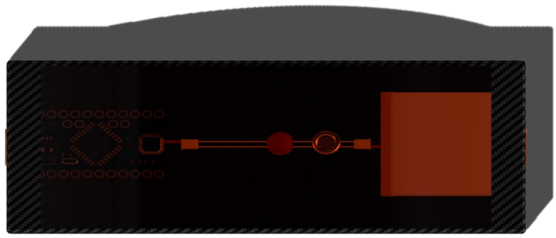
(All CAD self made on Shapr3D)



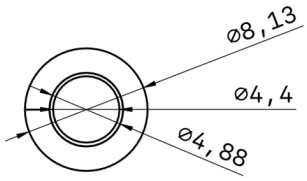


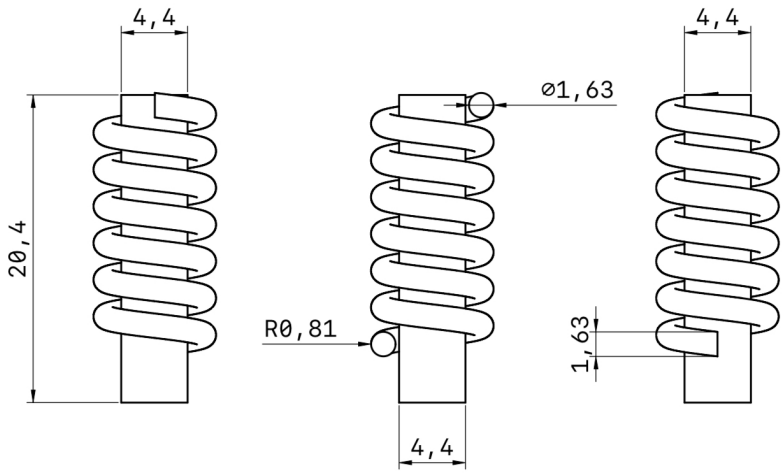
Isometric drawing:

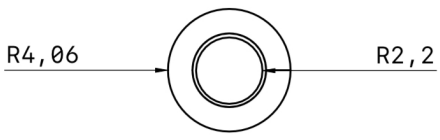
(All CAD self made on Shapr3D)



Orthographic drawing: new components



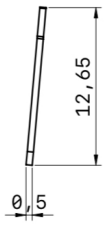


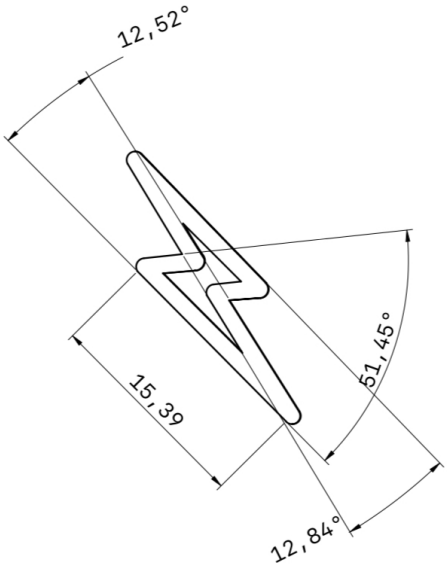


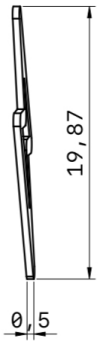
TITLE		
Spring – Button		
UNITS: mm	PROJ. ANG.	SIZE: A3
SCALE: 3:1	LAST UPDATED: 02/13/24	SHEET: 1/1

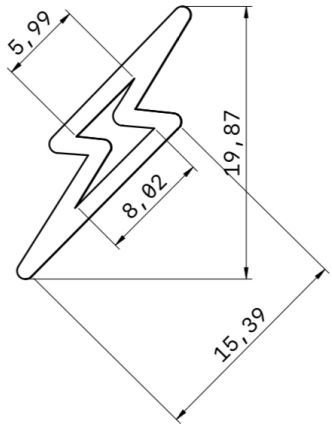
Orthographic drawing: new components

TITLE		
Florescent Lightning Lo.		
UNITS: mm	PROJ. ANG.	SIZE: A3
SCALE: 3:1	LAST UPDATED: 02/08/24	SHEET: 1/1

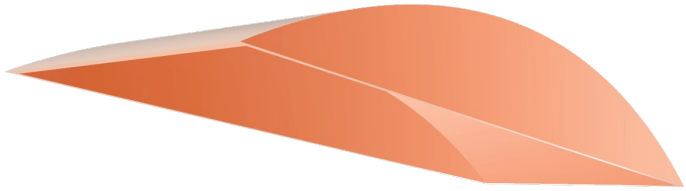


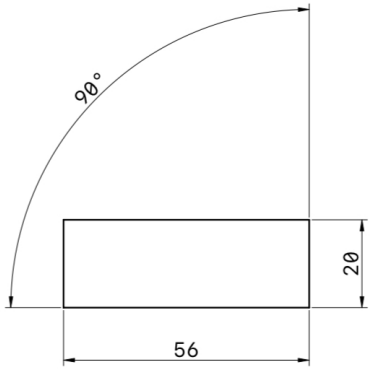


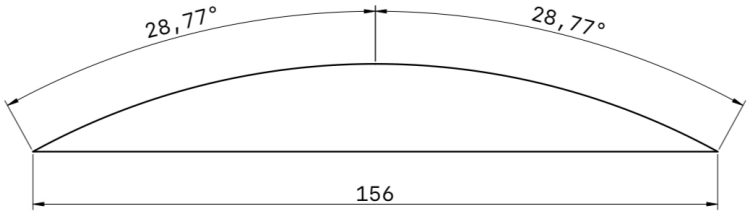


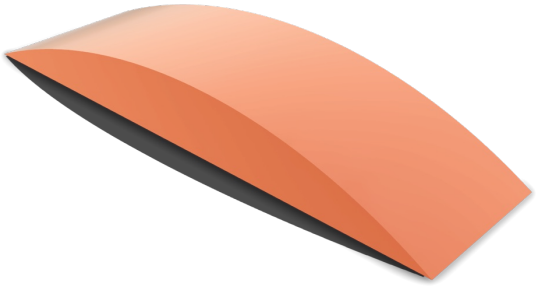


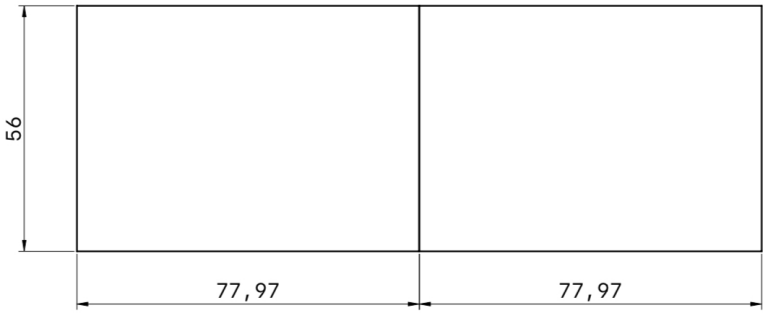
TITLE		
New Lid		
UNITS: mm	PROJ. ANG.	SIZE: A3
SCALE: 1:1	LAST UPDATED: 02/10/24	SHEET: 1/1

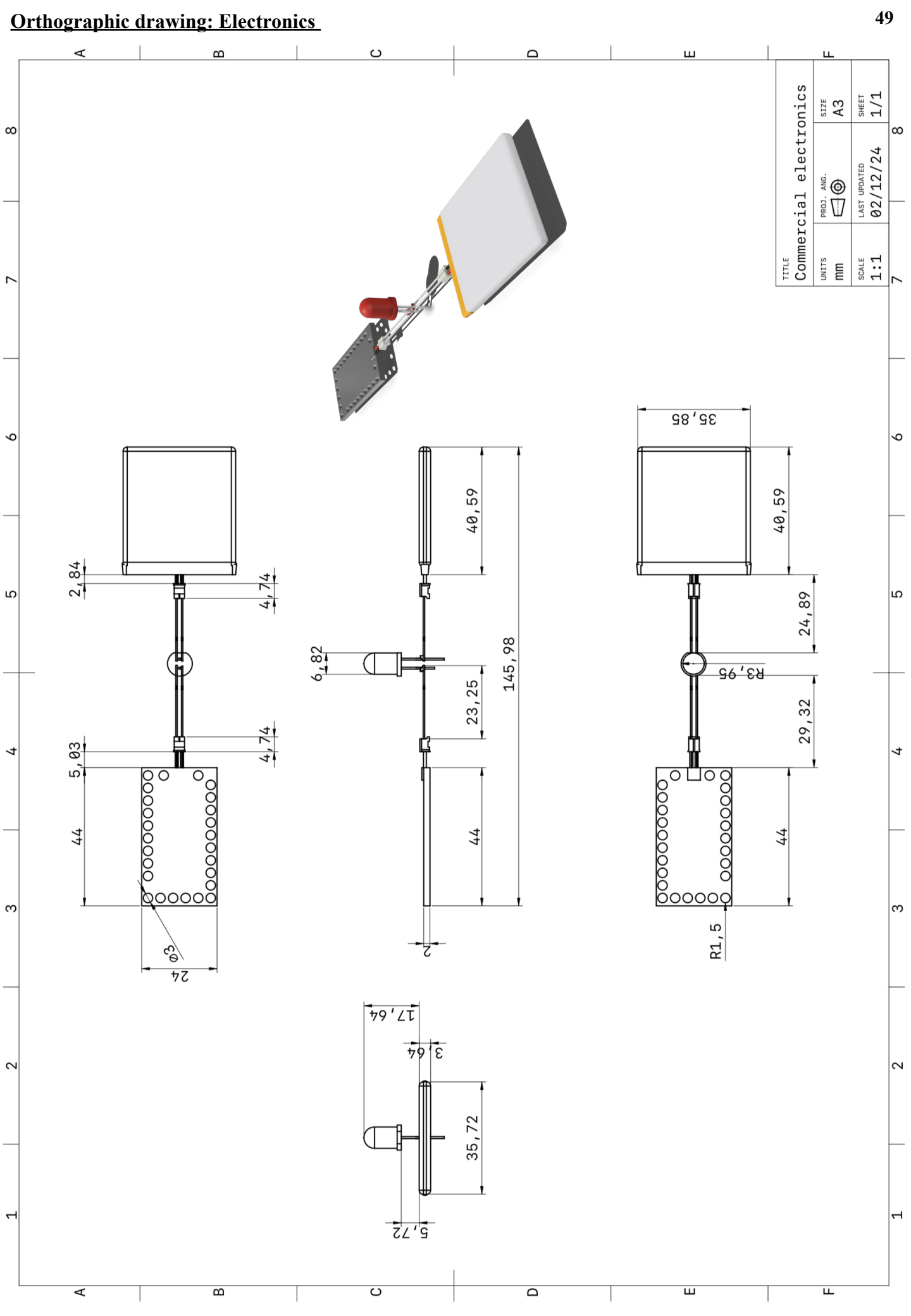








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Commercial electronics
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PROJ. ANG.
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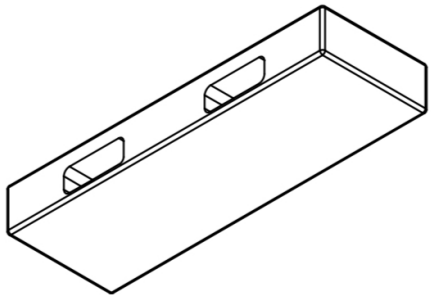

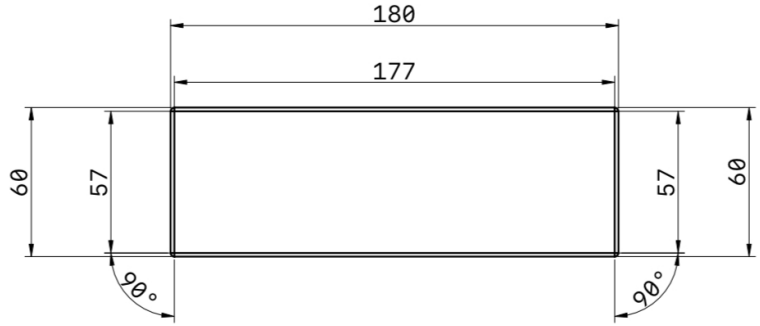

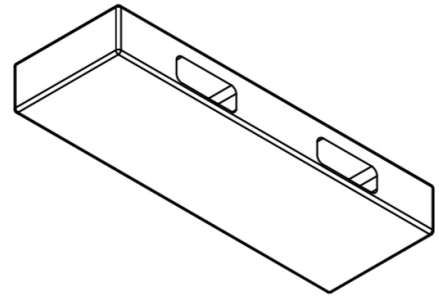

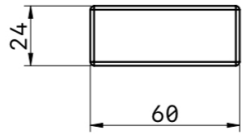

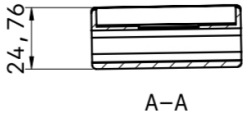

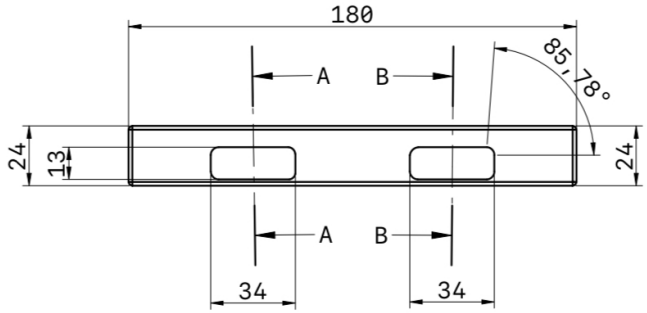

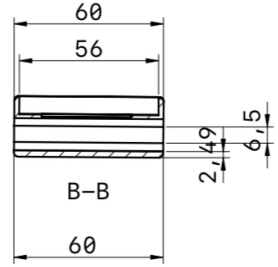

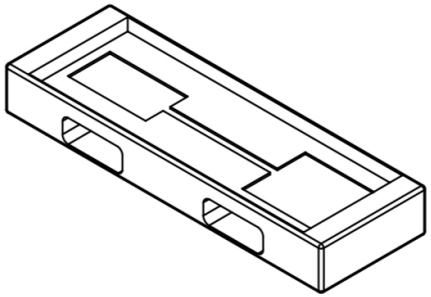

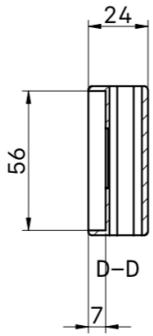

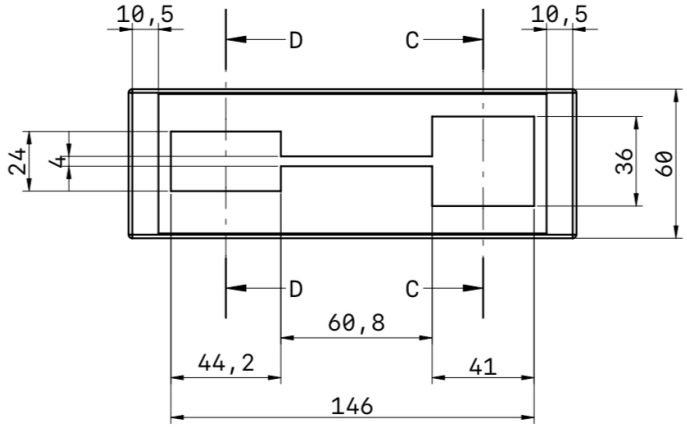

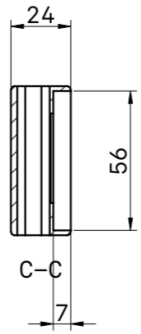

TITLE: Body with indents		
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SCALE: 1:2	LAST UPDATED: 03/13/24	SHEET: 1/1

/350

Criteria F: Making choices for commercial production

F1: Justifies the choice of materials and components appropriate for commercial production

Component number + name	Material	Material justification
Part 6: Base/Body	Carbon Fibre *(composition reinforced with thermoset resin and polypropylene for injection moulding)*	- Carbon fibre alone cannot be used for injection moulding, as carbon fibre is a **woven fabric with long continuous fibres**, - A composite material mixed the fibres into plastic. - Alternative: **carbon fibre with nylon composite offers high strength and stiffness,** however the properties of PP composite outweigh that of nylon. - Composite materials are more durable and have longer lifespans due to the **dual-phase structure** allows favourable properties of each constituent material while minimising their individual weaknesses. - Compared to traditional CF, composite CF has an **increased interfacial shear strength at the micro-scale of 300% and a tensile performance at the macro scale of 70%.** - These improvements can be attributed to **chemical bonding** as a result of **esterification of hydroxyl groups** on the CF surface [Burn. D, University of Nottingham, (2015)] - Pellet form of this material is suitable for injection moulding, allowing mass manufacture of the body (5000+)
Part 8: Spring	High carbon steel spring	- High tensile strength – able to withstand repetitive heavy force from user running and pressing. - Fatigue resistance makes this material reliable for long-term use in the demanding sports environment. - Other options: Chrome silicone, Chrome vanadium - However, high carbon steel springs are much more widely available, making it easier to source in comparison to the alternatives metals.
Part 4: Lighting symbol	Glow in the dark Phosphorescent / Photoluminescent Acrylic – Orange	- High resistance and durabiltiy against weathering. - Non toxic -> glow created from non radioactive properties. - 'Recharged' by the exposure of UV light, ∴ glow has a large span as sunlight is accessible and available. - Alternative: Lighting logo could be painted on with **photoluminescent paint** - However, the **tactile element** of acrylic enhances the user experience through aesthetics and appealing to the sense of touch
Part 11: 8-bit micro controller - STM8S003F3P6	Pre-made component (made from semiconductor materials, primarily silicon)	- Low power consumption: will not drain the battery, allows for longer life of the battery. - Primary material = silicons due to its abundance, stability and controllable electrical properties - Cheapest microcontroller on the market: **price advantage** – contains all necessary processing and control functions for my product.
Part 7: Lid	ABS (Acrylonitrile Butadiene Styrene)	- Durable – high impact resistance; **24.0-138 MPa Ultimate tensile strength** [MatWeb, Material property data] - Which makes it more suitable when subjected to high force from my users - Easily coloured during the manufacturing process : able to release more colour options for future releases

(For components not mentioned see Section C1 – not mentioned for repetition)

/350 **Criteria F: Making choices for commercial production**

F2: Justifies the choice of manufacturing techniques appropriate for commercial production

Component number + name	**Process**	**Process justification**
Part 6: Base/Body	Injection moulding (IM)	- Minimal post-processing (e.g. trimming or surface finishing) - product can be cooled and quickly moved forward to assembly. - Allows for design flexibility – if I were to change the geometry when expanding the range of my product IM would easily allow for that. - High efficency: **15 to 30 seconds interval between cycle times** [moldchina, N/A]. - High consistency and precision ensuring uniform quality across all products in a production run
Part 4: Lighting symbol	Laser cutting (LC)	- Minimal material waste due to **narrow kerf width** and precise cuts. - This efficiency can lead to environmental benefits and cost saving when scaled up. - CNC milling is another viable option, however LC produces more precise edges with a focus of **25 microns and an accuracy of +/-0.1 mm** [Velling. A, 2020], - High levels of precision is necessary due to the small size and curves of the lighting shape.
Joining parts 4 & 5 to part 6	Automated adhesive dispensing system 	- Offers precise control over the dispensing process -> ensuring uniform application and minimising waste of adhesive material - Optimising material usage -> consistent and accurate as it eliminates variations caused by human error - Improved worker safety – eliminating large adhesive exposure in factory settings; will **decrease exposure to toxic fumes** - Environmental consideration: designed to **optimise energy consumption**; energy saving features (standby modes). - Integrating automated adhesive dispensing systems into production lines can streamline processes and reduce cycle times, leading to improved overall process efficiency - This efficiency gains translate into cost savings by reducing labour hours, equipment idle time, and **overhead costs associated with inefficient workflows.**
Electronic components:	Quality control: Automated Optical Inspection (AOI)	- **High resolution cameras** and image processing algorithms will be employed to scrutinise the surface-mounted components on the electronic components. - AOI systems detect defects such as misaligned components, soldering defects, and foreign objects, utilising principles of **image analysis and pattern recognition.** - Alternative: manual inspection, produces inconsistent results; **human inspectors miss 20-30% of defects whilst AI-powered vision lowers false positives by as much as 95%.** [Sandia National Laboratories, NA]
Electronic components:	Functional testing: Automated test equipment (ATE)	- **Test patterns and stimuli** are applied to input and output interfaces, sensors, actuators, and communication protocols, while measuring electrical signals, response times, and error rates. Statistical analysis methods, including **signal processing algorithms** and hypothesis testing, are utilised to evaluate test results and ensure compliance with performance specifications.

Criteria F: Making choices for commercial production

F3: Justifies an appropriate scale and volume of production, based on appropriate research and suitability for the product

Market Size:

Scale and Volume of production: Who is the market for my product?

Market	Amount
Market Segment 1: Tennis clubs in the UK	5,273 clubs/registered venues – (LTA Business report, 2020)
Market Segment 2: Tennis coaches	6,400 LTA accredited coaches
Market Segment 3: Sports centres UK	4,997 sports club facilities
Total:	16,670 opportunities

Time required for full volume manufacture:

Production cycle time formula:

T= Ti + Tp + Te + Ts + Tl + To

∴T(estimate) = 15 minutes per tile

Ti: Total Injection Time / Filling Time
Tp: Total: Pressurised Cooling Time
Te: Total electronics attachment time (Automated)
Ts: Total spring attachment time
Tl: Total lid attachment time
To: Total buckle attachment time

Marketing mix:

Promotion:

- Above the line (ATL) advertising: Getting famous tennis players/athletes to be a part of an advertisement/campaign would be most effective to target market (Negative = high initial cost -> Positive = high reward of mass awareness)
- Word of mouth by coaching/tennis clubs speaking highly of the product
- Search Engine Marketing (SEM): Increasing web traffic through paid advertisement in search engine (e.g. Google, Yahoo) visibility.

Place:

- Offer in store testing: **technophobes and techno-cautious users will need conviction** through testing before purchase.

Flow diagram (production and assembly) :