Final Report
Circular Cricket Batting Pads: Prototype Development

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August 2023

Funding for Circular Cricket Gear project was provided by UKRI CE-Hub Flexible Fund

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1. Introduction

The Circular Cricket Gear (CCG)[1] project was conducted by University for the Creative Arts (UCA) in collaboration with the University of Cambridge (UOC) and other partners between September 2022 to August 2023. The aim of this final report is to offer insights into the findings from the development of four circular innovations for cricket batting pads that were produced as part of the CCG project. The prototype development consolidates the learnings and recommendations from previous research undertaken during the CCG project. While other cricket gear considered within the CCG project (e.g. cricket batting gloves), prototype development focused solely on cricket batting pads due to feasibility, time and budget constraints.

The below outlines the research tasks completed under the CCG project that contributed to defining the circular design innovations presented in this report:

i) A design innovation workshop
ii) A player/user online survey and expert interviews
iii) Disassembly exercise
iv) A Lifecycle Assessment (LCA) on cricket batting pads
v) Report on sustainable materials for cricket gear

The following section summarises the findings from the research undertaken within CCG, highlighting its relevance for the development of a prototype for a circular batting pad that demonstrates the implementation of four innovations. Innovation one and two are described in section 4.1 and integrate the use of a Piñatex Light (plant-based vegan leather (PBVL)) as innovation #1 and the re-use of the end-of-life internal padding as innovation #2. Innovation #3 (section 4.2) shows the successful replacement of the Velcro and learnings for repair - as a product circularity strategy - while innovation #4 (section 4.3) focuses on the development of the internal kneecaps 3D printed with polylactic acid (PLA) filament and a 2nd life nylon made from fishing nets (Fishy Filaments) to replace existing polystyrene kneecaps.

2. Identifying and Defining the Relevant Circular Innovations

An online design innovation workshop was organised in December 2022 to introduce product circularity (PC) concepts to CCG partners. Using an adapted entry-level PC checklist developed by UCA as part of the ongoing European Commission funded ORIENTING project[2], participants[3] were requested to generate ideas related to PC for cricket gloves, pads, and balls. Ideas were subsequently recorded on a predefined Miro board which was then discussed individually to contextualise the proposed concepts.[4] The workshop highlighted that the reduction of production waste, maximisation of the ease of maintenance, increased access to spare parts and the use of renewable materials were potential PC strategies for further exploration. The learnings from the innovation workshop also highlighted issues related to health and safety related to the repair and reuse of selected cricket gear classed as

[1] See https://cfsd.org.uk/projects/ccg/research/

[2] As this is an ongoing research project, details related to the entry-level PC checklist are not publicly available. However, further information on ORIENTING is available at: https://orienting.eu

[3] The workshop included participants from CCG's academic partners (UCA & UoC), a cricket gear manufacturer product manager, BASIS and a PhD student linked to CfSD at UCA.

[4] See https://cfsd.org.uk/projects/ccg/research/

Personal Protective Equipment (PPE). This requires further research. Technical and player testing were not completed within the CCG project due to economic and time constraints. The innovation workshop also helped to scope and define questions for a series of expert interviews and an online survey conducted with recreational cricket players. The findings from this survey - which received a total of 42 responses - indicated that most players consider the main environmental impacts of cricket gear to be a) issues related to the disposal of cricket gear and b) the high embedded carbon footprint associated with overseas manufacture.[5] Furthermore, the survey highlighted that while awareness of repair and reuse initiatives was low, willingness to trial such services was high, as highlighted by 86% of respondents. Furthermore, participants were asked to provide the main reasons for purchasing new cricket gear. The top three reasons highlighted were the following:

i) Wear and tear
ii) Seeking improved performance or technology
iii) Changes to sponsorship.

Respondents were also asked to indicate the main product failures identified for both cricket batting gloves and batting pads. For various reason prototype development focused on batting pads[6]. When considering the key product failures associated with batting pads, the following issues were identified:

i) Damage to the straps (e.g. straps breaking or becoming lose and the Velcro no longer attaching properly).
ii) Wear and tear of the external material (e.g., Polyurethane leather (PU) ripping).
iii) Issues with the internal padding (e.g., signs of mould such as discoloration).

A disassembly exercise was undertaken to assess the internal components and materials used in cricket batting pads to identify opportunities for circular cricket gear. Findings from the disassembly exercise conducted on a cricket batting pad revealed that the size and shape of the internal components such as the high-density polyurethane foam (HDF-PU foam) padding and the external (PU) leather and polyester (PE) lining appear to be cut based on experience (e.g. no layout plans have been used for cutting the materials). Therefore, as standardisation appears to be non-existent it can be assumed that there is substantial pre-consumer waste from the cutting and assembly process. This reinforces the finding from the innovation workshop that highlighted potential opportunities to reduce waste in production/assembly. The disassembly exercise also revealed an excess of material within the batting pad that is not required for the product's performance, thus leading to potential overuse of materials that could be addressed by streamlining the product. However, further research and testing is required to effectively assess the trade-offs related to the implementation of light weighting, as it emerged that this could potentially affect product durability and protection. Lastly, this exercise concluded that protective properties of the internal components i.e. the internal cane, HDF padding and the kneecap are unlikely to be impacted in the product's *use*

[5] See Sanchez-Moreno, L., & Charter, M., (2023). Findings from Online Survey: Cricket Gear Users/Players. Available at: https://cfsd.org.uk/wp-content/uploads/2023/09/Survey-of-Cricket-Gear-Users_Players_August-2023.pdf

[6] Due to pragmatic reasons including feasibility for prototype development, time and budget constraints, prototype development focused solely on batting pads.

phase; unless a batter dives and damages batting pads. In summary, it was concluded that when the product reaches its end-of-life and disposed, the internal components could potentially be given a second life.

A streamlined LCA on a pair of batting pads was also conducted as part of the CCG project.[7] The results from the LCA offered an initial overview of the main areas of environmental concern related to the product's lifecycle. The LCA indicated that highest impact is related to the manufacturing stage, as most of the materials used to produce the batting pads are produced from virgin non-renewable sources, particularly fossil-fuel derived polymers. The LCA also indicated that the use of PE for the lining and mesh are the highest contributors to the product's overall carbon footprint, despite only representing 220g (13%) of the total weight of the batting pads (1.728 Kg). Furthermore, the study indicated that the use of HDF-PU foam represents the highest environmental impact within the category of human health due to HDF's carcinogenic properties. Aligned to these findings, the UoC conducted research into materials used to produce cricket gear and sustainable alternatives. The research showed that for cricket batting pads, the high-impact resistant, rigid moulded components such as the kneecap can be substituted with semi-synthetic biopolymers (e.g. Polylactic Acid (PLA), sugar-based plastics, starch-based thermoplastics and seed-oil based plastics (cashew-nut, soybean oil, etc). As for the internal padding, materials identified as a substitute to HDF PU foam and wadding made from cotton and polyester blends were non-isocyanate PUs, bio-PUs, PLA-based foams and waste fibres from agriculture or fruit harvest (date palm leaf, pineapple/banana leaf).[8]

A design brief for a series of circular design innovations was developed based on findings from the research outputs and the innovation workshop summarised above. The brief focused on batting pads and addressed the following areas:

i) The replacement of fossil-fuel derived materials with renewable alternatives. Therefore, one of the selected innovations sought to replace at least one fossil-fuel derived component with a sustainable alternative identified within the materials research conducted by UoC.
ii) Tackling the high volume of waste as a result of cricket gear being landfilled.[9] This was completed by seeking to extend the life of the product by enabling repair to replace damaged parts/components and by exploring avenues for harvesting parts and components from old cricket pads (specifically padding and kneecap).
iii) The player survey identified the damage to the straps and wear and tear to the external material as the main areas for product failures for batting pads.

[7] See Sanchez-Moreno, L., & Charter, M., (2023). Streamlined Life Cycle Assessment: Pair of Cricket Batting Pads. Available at: https://cfsd.org.uk/wp-content/uploads/2023/05/Final-Streamlined-LCA_batting-pads.pdf

[8] For access to the full report see: Shah, D.U., (2023). Materials in Cricket Ball, Gloves and Pads, and their Sustainable Alternatives. Available at: https://cfsd.org.uk/wp-content/uploads/2023/06/Materials-in-cricket-balls-gloves-and-pads-and-their-sustainable-alternatives-June-2023.pdf

[9] For an annualised summary of waste items and weights based on 2022 data, see: https://cfsd.org.uk/wp-content/uploads/2023/06/Sustainability_Cricket-Gear-Final-July-2022-Updated-June-2023-1.pdf

3. The Brief

A brief containing was written for five visuals describing the circular design innovations based on the insights summarised above. The next part of the process was to identify a 'maker' with the appropriate skills and equipment for prototyping. It was anticipated that finding a 'maker' with the relevant skills would be relatively straight-forward through UCA's connections to UK repair café network and the textile/fashion design community. However, early on, it became apparent that there is a gap in the UK to make cricket gear. Research did not identify any appropriate makers and only through an ad hoc conversation with an enquirer to the project was a relevant person highlighted who is a multi-skilled prop designer working at a major national theatre.

The brief outlined the required skills for the incorporation of each innovation. The primary skills identified for producing the prototype were de-stitching, cutting, and operating an industrial sewing machine to a high standard. Previous experience with leather work was deemed useful but not essential. Table 1 shows a matrix of the design innovations and the related PC strategy,[10] the skills and materials required and how viable it was to complete the prototype within time and budget constraints. Based on this, four out of the five innovations displayed below were completed. The fifth innovation was excluded due to time and technical constraints for designing and manufacturing the 'clip-on' solution.

To facilitate the identification of a 'maker' with the capabilities required to undertake the production of a prototype, a visual for each design innovation was created (see Annex 1). Each visual contained specifications related to the targeted product part/component, a list of materials and the process for completing the prototype. The visuals where then sent as a PowerPoint presentation to a network of social enterprises[11], maker spaces[12], charities[13], repair cafes and UCA colleagues within the Business and Fashion departments. As mentioned earlier, it was thought that the required skills could easily be identified within these sectors. However, relevant cricket gear making skills were not identified within this network. Further research will be undertaken by UCA to address this, and a random connection identified the 'maker' with the relevant skills.

[10] See Sanchez-Moreno, L., & Charter, M., (2023). Assessing Product Circularity in Practice: Insights from Industry. In Niinimäki, K., & Cura, K., (ed), Proceedings 5th PLATE Conference, Espoo, Finland-31 May-2 June 2023. Available at: https://kth.diva-portal.org/smash/get/diva2:1795825/FULLTEXT01.pdf

[11] See for example: https://poplarworks.co.uk/programmes/

[12] See: https://www.fashion-enter.com/index.php/factory-london/

[13] https://www.rvs.org.uk/

Table 1: Design Innovation Matrix

No.	Component	PC Strategy	Description: Design Innovation	Skills Required	Feasibility	Materials Required
1	Velcro on straps	Repair	For used batting pads, the Velcro can be easily replaced by unpicking existing Velcro and sewing new Velcro on. Velcro can easily be sourced online and is inexpensive.	‘unpicking’ stitches. Cutting Operating a sewing machine	**HIGH**	Velcro Thread Sewing machine
2	Straps	Design for disassembly	Identify existing ‘clip’ on straps to enable the replacement of straps by users. The aim is for new straps to be offered directly by the cricket gear manufacturer.	‘unpicking’ stitches. Cutting Operating a sewing machine	**MEDIUM**	A suitable clip-on solution has not been identified. Potential to design a prototype for a ‘clip-on’ solution that can be 3D printed. CAD blueprints/3D printer Velcro Straps Sewing machine
3	Exterior material	Material substitution	Replace the use of PU leather with one of the identified PBVL. E.g., Piñatex performance.	Pattern cutting, Operating an industrial sewing machine with minimal seam allowance.	**HIGH**	Sustainable alternative to PU leather (e.g., Piñatex Light)
4	Internal padding/structure	Material substitution	Replace the use of HDF with a sustainable alternative. For example, flax composites, Non-isocyanate PUs, bio-PU’s, PLA based foams.	‘unpicking’ stitches. Cutting Operating an industrial sewing machine	**MEDIUM**	What are the compressive strength requirements? Identify the most feasible substitution. Impact testing on alternative foams would be required.
5	Kneecap	Reuse	Reuse/replace existing knee protector from end-of-life gear for the development of new batting pads. Reduce waste and extend the life of the kneecap.	‘unpicking’ stitches. Cutting Operating a sewing machine	**HIGH**	End of life batting pads. Thread Sewing machine 3D printing PLA filament

4. Prototype Development

This section aims to offer an overview of the prototype development for each of the cricket batting pad innovations.

- Section 4.1 highlights the findings from developing a left cricket batting pad that integrates two innovations: the use of a PBVL (Piñatex Light) for the batting pad's exterior case (innovation #1) and the reuse of end-of-life internal padding (innovation #2).
- Section 4.2 highlights the findings and learnings from successfully replacing worn-out Velcro with that aimed to explore the implementation of repair as a service and/or enable self-repair (innovation #3).
- Section 4.3 focuses on the development of the internal kneecaps using PLA and Fishy Filaments to replace existing polystyrene kneecaps (innovation #4).

4.1 Batting Pad Using Piñatex Light and Reused Internal Components

Research completed by UOC[14] identified that bovine leather is no longer used for producing cricket batting pads, but the player survey indicated interest in the use of plant-based vegan leathers (PBVL) for other cricket gear. UoC conducted an extensive study of PBVLs for the potential application to cricket gear and performed mechanical testing of 5 samples of PBVLs. This included Piñatex original (produced by Ananas Anam) which was deemed unsuitable as a replacement for bovine leather as were the other samples.[15] At the time that the research on PBVLs was being completed[16], Ananas Anam was conducting R&D into Piñatex Light, which was later recommended as a potential replacement of other materials used in cricket gear e.g. PU leather. As a result, it was decided to explore the use of a PBVL in the exterior of batting pads. This innovation was developed in collaboration with Ananas Anam who provided materials expertise and samples of Piñatex Light.[17] It was assembled using a Highlead[18] industrial sewing machine with a leather walker, a diamond shaped needle and linen[19] threads recommended by the manufacturer (Ananas Anam).

The Piñatex Light used to replace the PU leather used in batting pads is 61% polymer-based (8% bio-based PU and 53% PU) and 39% Piñayarn[20]; but it is anticipated that the overall sustainability impact of the prototype will have significantly improved. Compared to the original Piñatex material, which is a non-woven product, this new development uses pineapple leaf fibre in a knit backing to achieve more flexibility, which is crucial for structuring and assembling cricket batting pads. The material has a reduced thickness of 1.1 mm, also facilitating the stitching process.

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[14] See Taylor, B., & Shah, D., (2023). Leather Alternatives for Cricket Gear. Available at: https://cfsd.org.uk/wp-content/uploads/2023/04/Final-Vegan-leather-alternatives-22-4-23.pdf

[15] Ibid

[16] For further information on leather alternatives for cricket gear, see: https://cfsd.org.uk/projects/vlcg/research/

[17] https://store.ananas-anam.com/collections/light-collection

[18] https://www.highlead.co.uk/

[19] Linen fibres are derived from a renewable source e.g. flax and are strong and absorbent https://idyllo.eu/blogs/news/linen-properties-and-care

[20] Piñayarn is an innovative and low impact yarn, made from waste pineapple leaves. See: https://www.ananas-anam.com/pinayarn/

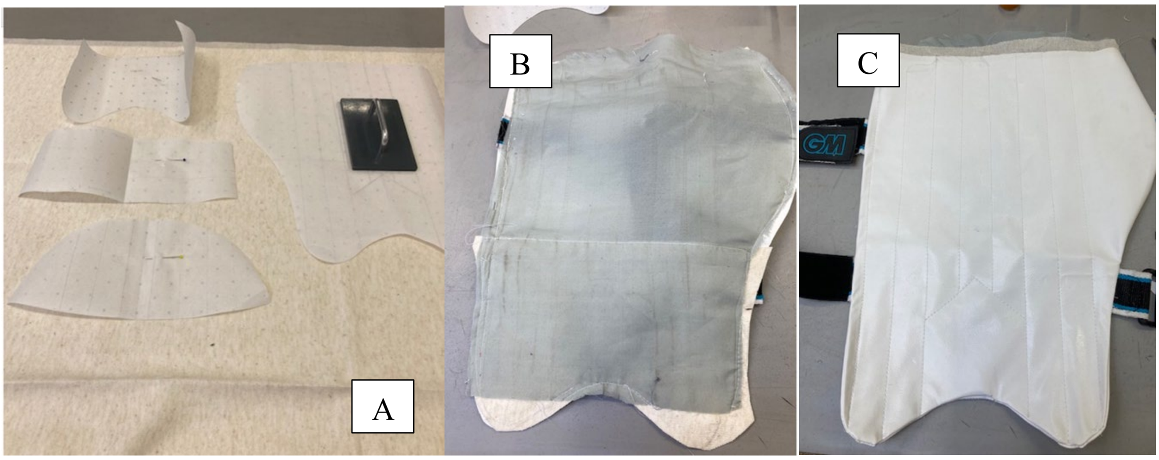
Below is a time breakdown to produce 1 batting pad (from a pair), which took 12 hours in total:

- Unpicking existing pad and sorting parts – 3 hours
- Creating pattern using existing parts – 1.5 hours
- Cutting pattern in new fabric – 15 mins
- Constructing pad – 6 hours
- Documenting and administration - 1 hour

The process for making the prototype is described in the following section, based on the 'maker's' experience which was recorded and sent to UCA.

A first step was to disassemble an end-of-life batting pad (left)[21] to study the various components, harvest the internal padding and structural canes, as well as to use the existing exterior case to create the pattern. The pattern was marked as shown in **Image A**, leaving 1cm for the seam allowance. Once the patterns were created, cutting the material-Piñatex Light-was relatively straightforward and time efficient. The batting pad outer case was then reconstructed in two parts: starting with the bottom section and proceeding to assembling the top section that includes the kneecap protector. Starting with the bottom section, the PBVL and the lining were stitched together using the 'bagging out'[22] technique shown in the **Image B**. Whilst stitching the bottom section of the pad, the straps were included, and a gap was left at the base to insert the padding (see **Image B & C**).

Prototype: Pattern development and stitching

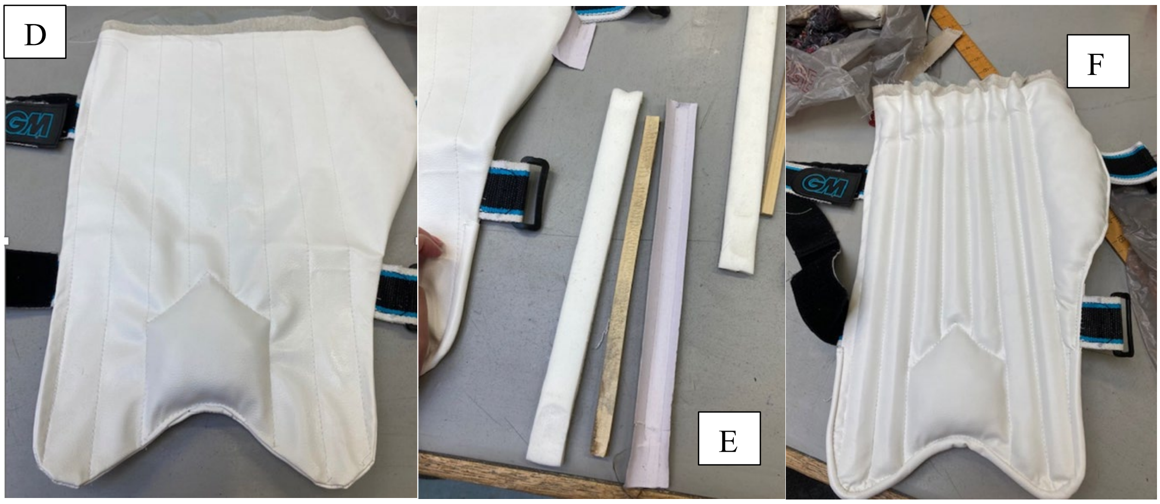


The top section of the batting pad was then turned inside out and the insert lines for the protective and structural canes and padding (see **Image E**) were marked on the pattern and stitched bottom to top (see **Image D**). The canes were then inserted, followed by inserting

[21] Batting pad was provided by a recreational cricket player who also acted as an external consultant helping to coordinate the prototype development.
[22] 'Bagging" refers to stitching pieces sides together inside out, so that when the item is turned the right way, the seam allowance is hidden between the 2 pieces on the inside.

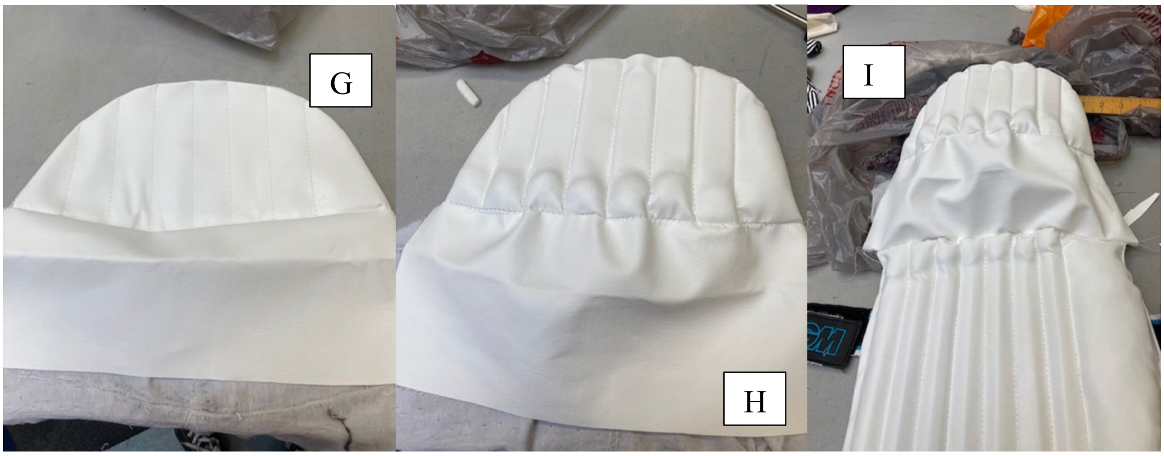
the padding and wadding, and then stitching the top to close and bind the edge of pad (see **Image F**).

Prototype: Assembly process of the internal padding



After completing bottom part of the batting pad, the 'maker' proceeded to develop the top section of the pad. **Image G** shows "bagging out" of the top outer section with the PE lining and the attachment of the middle outer section for the kneecap. **Image H** shows the insertion of the wadding, while **Image I** shows how the top section was then attached to the bottom section. The 'maker' highlighted that this step was 'tricky' due to the thickness of the padding and recognised that if a second prototype was produced, there we opportunities for improvement to the assembly process e.g. altering the order in which the padding is inserted to a later stage of the assembly process.

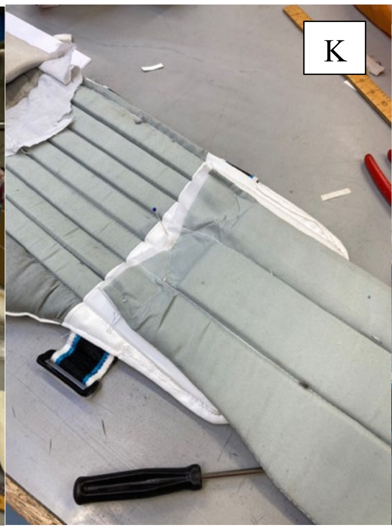
Prototype: Assembly process top section



Once the top and bottom section were stitched together, further wadding was inserted in the middle section. As shown in **Image J**, it was not possible to obtain a smooth surface compared to the original batting pad. As such, it is recommended that the process for inserting the padding to meet manufacturing standards is explored further.

Following the completion of the exterior case, the existing knee protector and knee straps were inserted and top stitched into the sides of the middle section (see **Image K**). The internal padding was then attached through the "V" of the padding at the base of pad. It was completed upside down and then flipped back into position as shown in **Image K**. Finally, the internal padding was attached to the knee protector (see **Image L**) with the completed prototype shown **in Image M.**

Prototype: Stitching the kneecap padding



Final prototype: PBVL case with reused internal padding

4.2 Repairing a Pair of Cricket Batting Pad Straps

Innovation # 3 consisted of replacing the damaged Velcro straps on the batting pad to explore options for repairing the cricket batting pad and identify potential design innovations required to enable repair. The repair process was completed in 25 minutes: 10 minutes for unstitching the previous Velcro and 15 minutes for sewing on the new Velcro. The Velcro used was purchased online and is widely available in exact the dimensions required for the batting pads straps. Overall, the result of this repair meets industry standards[23] and is a highly effective solution for prolonging the pads use phase (See **Image N** for results). While the repair was undertaken by an experienced 'maker', feedback from the 'maker' suggests that this repair can be undertaken by a user/player with zero to basic sewing skills. To facilitate this, cricket gear manufacturers could potentially offer spare Velcro along with online instructions on how to repair.

Final prototype-replacement of Velcro straps

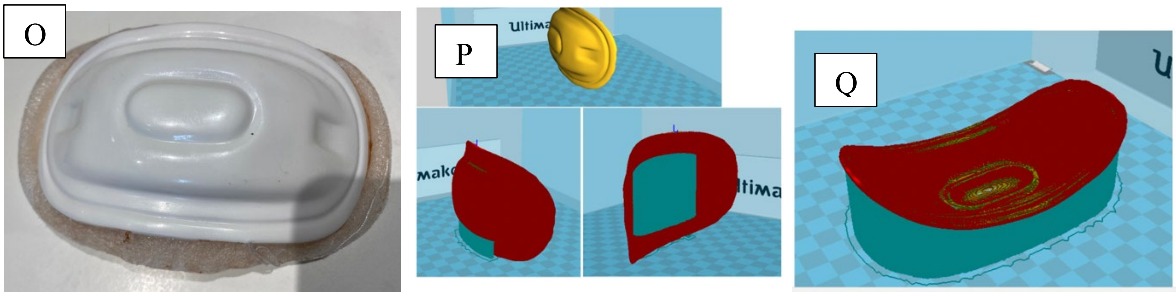
4.3 3D Printed Kneecaps Using a Sustainable Material Alternative

The final circular innovation (innovation # 4) aimed to identify a sustainable material alternative to replace the existing PP kneecap. While the internal kneecap is intended to add increased protection, extra protection is also added by embedding the kneecap within 2 layers of HDF PU foam and wadding. Therefore, the compression strength required was not considered a challenge to the production of the kneecaps. In this sense, for the purpose of

[23] As per the BS6183-3:2000, 'restraint systems for cricket gear shall be designed to remain in place during normal play and during impacts. Restraint shall be achieved using integral straps with buckles, touch and close fasteners, a harness, or by other items of protective equipment or clothing.' Source : https://www.en-standard.eu/bs-6183-1-2000-protective-equipment-for-cricketers-general-requirements/

producing a prototype, 3D printing appeared to be the most viable solution rather than using other processes such as injection moulding which would benefit the production of a higher quantity of pieces. For 3D printing this component, a CAD file of the piece was required. This was generated by the UoC using a 3D scanner. The original kneecap (see **Image O**) was painted grey to reduce reflection and facilitate scanning. Once the CAD files were generated, two challenges emerged: a) the piece did not have a single flat surface; and b) the 3D printing software had to generate support scaffolding to hold the part in place whilst being printed; this scaffolding then had to be removed with a sharp knife (see **Image P** and **Q**)[24]. It is pertinent to mention that while the scaffolding generated to support the piece in place is generally discarded, it can be recycled to reproduce 3D printing filament, thus further reducing production waste.

Final prototype: CAD file for kneecap showing structural support for 3D printing



The filaments recommended for this prototype were polylactic acid (PLA) and Fishy Filaments[25], a 100% recycled nylon originating from end-of-life fishing gear.[26]

Printing time for the PLA kneecap (see **Image R)** was approximately 5 hours and was completed by the engineering team at Farnham Repair Café (FRC) [27]. While **Image S** shows the printed kneecap using Fishy Filaments, with its corresponding scaffolding/structural support printed by 3D Printing Cornwall[28]. Both sets of kneecaps were tested in-house to assess their structural integrity by applying pressure to the top section, with initial conclusions suggesting that they are both viable options for replacing existing fossil fuel-based kneecaps. However, a caveat to the use of Fishy Filament is that due to nylon 6 filament being hygroscopic[29], a nylon 3D printing expert with prior knowledge of working with Fishy Filaments was required to complete the prototype within the project timeline.[30]

[24] Files created by Dr Darshil U. Shah, University of Cambridge
[25] https://fishyfilaments.com/filaments/
[26] For other potential applications for 3D printing from fishing nets, see: http://www.circularocean.eu/wp-content/uploads/2016/11/Potential-Applications-of-3D-Printing-in-the-Recycling-of-Fishing-Nets-Ropes-FNRs.pdf
[27] https://frc.cfsd.org.uk
[28] https://www.3dpc.org/
[29] For further information see: https://www.makerbot.com/stories/design/nylon-3d-printing/
[30] Due to Nylon 6 being hygroscopic, prior to using this filament, the materials need to be dried by heating to at least 80C then placing it in a vacuum chamber for approximately 30 or by maintaining that temperature for 12+ hours. These techniques have been automated in the industrial environment; however, they can equally be achieved for small scale production with 'home-cooked' versions For further information related to the use of Nylon 6 (Fishy Filament) see: https://fishyfilaments.com/dry-filament-is-good-filament/.

Final prototype: standard PLA kneecap (Image R)

Final Prototype: Fishy Filaments kneecap (Image S)

5. Conclusions

The prototype is aligned to TRL 3 (experimental proof of concept)[31]. Within the constraints of time, budget, materials, and skills availability, the development of this circular batting pad is a useful starting point to develop further innovations, improvements in making and experimentation with new materials. Technical and user (player) testing will enhance the practicality of the development and compliance with industry standards such as the British Standard 6183-3:2000 on "Protective equipment for cricketers", which provides requirements and test methods for leg protectors for batsmen, wicket keepers and fielders, and for forearm protectors, forearm and elbow protectors, thigh protectors, and chest protectors for batsmen.[32] Whilst there are visible aesthetic faults in the circular batting pad prototype e.g. not as smooth in appearance compared to existing batting pads, the structural integrity and protective elements of the product appear to have been achieved. However, as the internal padding and other components have been re-used from an existing end-of-1st-

[31] See: https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels

[32] See: https://www.en-standard.eu/bs-6183-1-2000-protective-equipment-for-cricketers-general-requirements/

life batting pad, user (player) and technical testing is required to confirm that the protective properties of such padding have not been compromised. Aligned to this, testing is also required to measure the impact resistance for the 3D printed kneecaps. As for testing methods, batting pads would be required to undergo 'impact testing using a steel striker mounted on a guided falling mass, combined to make (2.5 +- 0.1) Kg. The striker shall be hemispherical and (72+-2) mm in diameter. The drop height above the top surface of the protector shall be adjusted to provide an impact energy conforming to the standards stated in the BS6183-3:2000 with an accuracy of +- 5%.'[33] Specific personal protective equipment (PPE) lab testing is required for this.

Regarding production times, as mentioned by the 'maker', unstitching the batting pad was significantly time-consuming (3 hours), therefore further exploration of unstitching methods that are more time efficient are required. Likewise, further research is required to explore alternative manufacturing processes for developing the kneecaps with a sustainable material alternative. As 3D printing the kneecaps is currently not commercially viable as it is too time consuming, taking approximately 5 hours. Conversely, repairing the worn-out Velcro on cricket batting pads proved to be a relatively simple solution for extending the life of a product as this can be done by a user/player with zero to basic sewing skills and should be explored further in the context of services offered by the manufacturer.

The 'maker' also highlighted that the most challenging part of the production process was reinserting the padding and filling, as "it was hard to get smooth and full". The 'maker' anticipated that this could be due to re-using 2nd life inserts which were less rigid. Lessons could be learnt from videos on the making process in India, that shows that whilst this step remains labour intensive it has been solved by using a metal cane.[34] Nonetheless, the use of a Piñatex Light performed well under manufacturing/assembly conditions e.g. the material did not show signs of tearing and was overall easy to stitch using a standard industrial sewing machine. However, further player testing is required to assess the material's durability and performance under game conditions. In this context, CfSD is planning to conduct player testing within future projects. Furthermore, the prototype development indicated that the process for making a batting pad with reused components needs to be refined if it is to be replicated as a local production system that supports the use of internal components, biomaterials and/or recycled materials.

6. Findings and Recommendations

Findings from the development of prototypes indicate that:

i) Cricket batting pads appear to be kept for over 3 seasons with some up to 8 seasons basing on findings from a recreational player survey conducted by UCA[35], and parts and components that remain in good condition such as the internal HDF foam and kneecaps present an opportunity for reuse.

[33] Ibid.

[34] See "how batting pads are made in the factory". Available at: https://www.youtube.com/watch?v=ZtfOYXeOFO8

[35] See Sanchez-Moreno, L., & Charter, M., (2023). Findings from Online Survey: Cricket Gear Users/Players. Available at: https://cfsd.org.uk/wp-content/uploads/2023/09/Survey-of-Cricket-Gear-Users_Players_August-2023.pdf

ii) Whilst initial prototype development of the batting pad exterior case indicates that the PBVL selected (Piñatex Light) can be easily stitched and supports the insertion of the internal padding, further research is required to test the PBVL batting pads under standard game conditions to assess durability, abrasion capacity and breathability.

iii) The process for producing batting pads with second-life components can be replicated. However, this process requires further iterations to improve for example, the time and effort related to reinserting the internal padding, and the time and effort to harvest used parts and components.

iv) Worn-out Velcro and straps can be replaced to extend the life of the overall product relatively easily. Further exploration of other parts and components that can be repaired and/or reused is recommended. This is aligned to the findings presented in the player survey that indicated player interest in repair for both environmental and economic reasons.[36]

v) The internal batting pad kneecap can be relatively easily 3D printed using both a PLA filament and a nylon filament derived from fishing gear (Fishy Filaments). Both prototype kneecaps visually matched existing kneecaps, and a simple in-house compression test[37] indicated that they are fit for purpose. Technical testing is required to confirm this.

vi) Identifying the relevant skills to produce the batting pad prototype represented a challenge as cricket gear is primarily manufactured overseas. It is thus suggested that to bridge this gap, appropriate training materials and programmes to support local upskilling could be developed. The benefits of this would include the potential creation of jobs for local communities and the reduction of embedded carbon associated with overseas manufacturing.

vii) The commercial viability for the innovations presented in this report requires a detailed cost analysis. CfSD intends to produce a cost analysis of circular cricket gear in future projects which will be made available on the CfSD website.

[36] See Sanchez-Moreno, L., & Charter, M., (2023). Findings from Online Survey: Cricket Gear Users/Players. Available at: https://cfsd.org.uk/wp-content/uploads/2023/09/Survey-of-Cricket-Gear-Users_Players_August-2023.pdf

[37] Compression resistance was tested by adding manual force to various points across the kneecap to assess the component's integrity. Further testing is required to assess whether it meets existing Personal Protective Equipment (PPE) standards.

ANNEX 1: Prototype Visuals

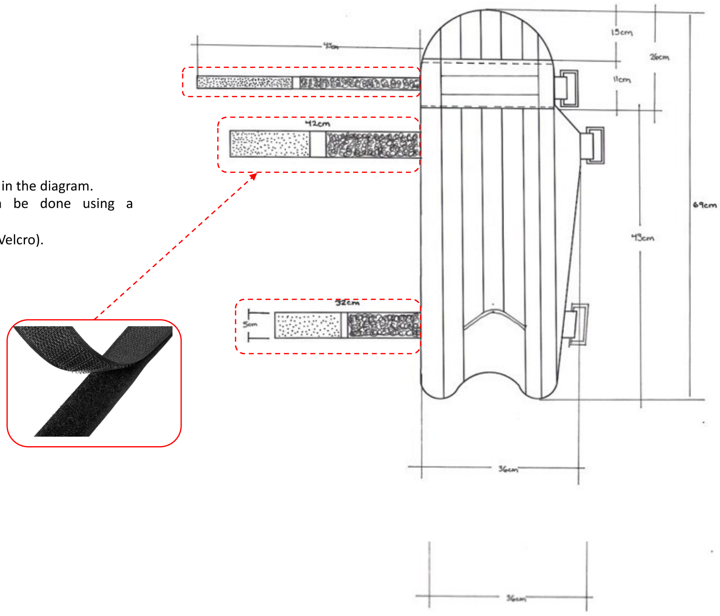
Innovation #1: Repairing Velcro on Existing Straps

List of materials and quantities required:

- Velcro (60cm) x2 for a pair of batting pads
- Seam ripper

Process:

1) Unpick Velcro manually using a 'seam ripper'.
2) Cut new Velcro to exact size using the specifications provided in the diagram.
3) Sew the new Velcro onto existing straps, which can be done using a domestic/industrial sewing machine.
   *Identify potential use for the new waste stream (replaced Velcro).



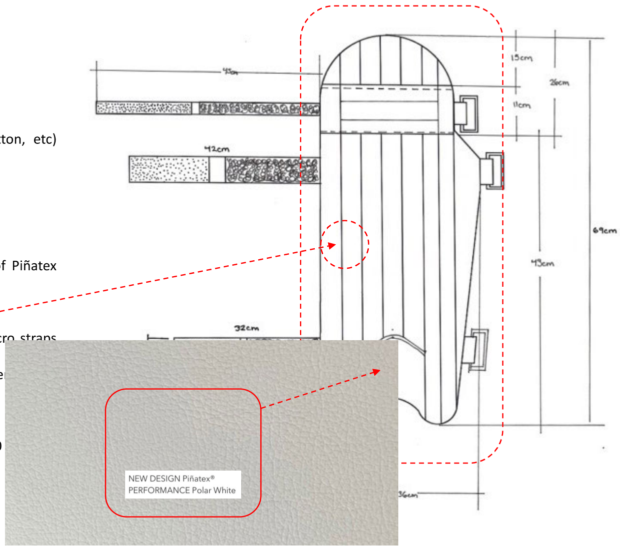
Innovation #3: Develop Exterior Case using a Sustainable Alternative to PU Leather (material replacement)

List of materials and quantities required:

- PU leather substitute (Piñatex Light) 100cm x 90cm (200cm x 180cm)
- Textile backing (currently polyester/ identify alternative, e.g., Linen, cotton, etc) (1000cm x1000cm)
- Metal cane to reinsert various internal components (80cm x 3cm)
- Diamond shaped needle
- Metal cane (80 x 3cm)

Process:

1) Using the pattern provided, trace and cut the pattern onto the sample of Piñatex Light, leaving a seam allowance of at least 2cm.
2) Using the same pattern, repeat step 1 with textile backing (cotton, linen, etc)
3) Mark the distance required between each 'spine'. This is 3.8cm x 7.
4) Place front section (piñatex Light) and backing together and place the Velcro straps between the front and back layer.
5) Sew along the edges and bottom, leaving an open in the top section for inse internal padding.
6) Sew along the previously marked 'spines' from bottom to top.
7) Add reinforced edge to the batting pads.
8) Insert internal padding with the assistance of a metal cane (approx. length 80



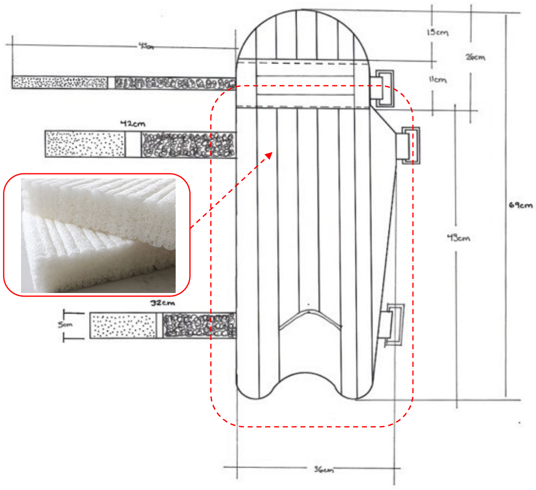
Innovation #4: Replacement of Existing HDF with a Sustainable Alternative/Packaging Waste

List of materials and quantities required:

- Seam ripper
- Internal padding (HDF substitute) (200cm x 180cm)
- Metal cane to reinsert various internal components (80cm x 3cm)

Process:

1) Unpick the top section of the batting pads.
2) Remove existing internal padding.
3) Using the internal components removed, trace and cut the new internal padding components. The internal padding will be sourced from for example, waste packaging or a PLA based foam.
4) Once the new paddings have been cut to exact shape and size, these will need to be reinserted with the assistance of a metal cane (approx. length 80 cm).
5) Sew the top section using an industrial sewing machine.



Innovation #5: Reuse of Knee Protector/Replacement of Knee Protector using a Sustainable Material Alternative

List of materials and quantities required:

Option 1:

- Used batting pads to harvest knee protector
- Seam ripper.
- Non-woven flax fibre
- Bio resin

Option 2:

3D printing filament

Process:

Option1:

1) unpick the knee protector padding component with a seam ripper.
2) Extract the polyurethane knee protector.
3) Use existing knee protector as a mould to develop a flax fibre solution.
4) Place the non-woven flax fibre onto the existing knee protector mould.
5) Apply the bio resin and leave to dry.
6) Cut and sad down the new piece accordingly.
7) Reinsert the component into the the knee protector padding component.
8) Sew the knee protector padding component.

Option 2:

1) Create CAD file for knee protector
2) 3D print component