Contextual Information for REF2021

Liz Ciokajlo

OurOwnsKIN: The development of 3D-Printed Footwear Inspired by Human Skin

Output number: LC02

Ravensbourne University London

Contents

Output and Description

OurOwnsKIN project (2015-17) Innovate UK and Arts Council England funded, Bloomsbury Academia published, utilised human skin performative properties to inspire the design 3D printed footwear structures.

Fig. 1: Photo of simple OurOwnsKIN foot structure photo from Gambell's et all OurOwnsKIN film

Outputs include:

- Iterative prototypes and material samples for development and exhibition
- Film conveying the behaviour of the footwear structures https://vimeo.com/530720473
- Published book chapter - Papastavrou M., Ciokajlo L., Solomon R. (2020), 'OurOwnsKIN: The development of 3D-Printed Footwear Inspired by Human Skin' in Townsend K, Solomon R, Briggs-Goode A, Crafting Anatomies: Archives Dialogues, Fabrications London: Bloomsbury Academia, pages 191-210.

  Chapter available in open access at Ravensbourne Research Repository: http://rave.repository.guildhe.ac.uk/id/eprint/90

The outputs are evidenced in:

- **Bloomsbury Academia published** (2020) collaborator team co-authored chapter 'OurOwnsKIN: The development of 3D-Printed Footwear Inspired by Human Skin' in book Crafting Anatomies: Archives Dialogues, Fabrications. Output available in open access at Ravensbourne Research Repository: http://rave.repository.guildhe.ac.uk/id/eprint/90
- **Exhibitions and talks** Wild at Somerset House, London (2016), Material Anatomies at Digit2Wigets, London as part of The Design Festival (2017)
- **Industry interest/engagement** included Clarks, Puma, Nike and the collaborative team was hired on a Kings College London Research scoping project Reboot to design footwear for people with EB/Epidermolysis Bullosa (2016-17).
- **Funding** - Innovate UK, MVWorks Makerversity London (PO Arts Council England, Innovate UK, w/support KTN Knowledge Transfer Network), Ravensbourne Research.

Tom Fiddian, Head of Artificial Intelligence and Data Enterprise, InnovateUK stated that:

> *Of the projects we funded, this one stood out originally because it is novel and the direction it was seeking to travel…it went well and is the standout project… it was a very good project from an InnovateUK point of view.*

Research Narrative

Funding

- **£4000 Ravensbourne Research (10/2016-06/2017)** Ravensbourne Research which established early concept design, and research (data collection) to explore and establish early design and computation.

- **£10,000 MVWorks Makerversity London (01/2016-06/2016)** (with funding/ support from Innovate UK, Arts Council and support from KTN Knowledge Transfer Network) open call - Nine of 110 applicants were chosen based on applicates whose proposals had the best balance of research underpinning projects with understanding of commercial potentials and relevance. Short film on criteria of how awardees were selected: https://vimeo.com/146783934

Funding enabled costly initial material samples and prototypes to be made of the design and computation approaches established so far and produce Somerset House, Into the Wild, exhibition materials.

- **£24,669 (10/2016-06/2017) Innovate UK, Arts and Technology Pilot Fund**; grant number: 132416. Innovate UK and the Arts Council England funding for MVWorks Makerversity also funded two other makerspaces similar Near Now in Nottingham and MadLab in Manchester. Each makerspace managed the specific funding structures for awardee's delivery.

At the end of the all three funding programs (MVWorks, Near Now and MadLab) all awardees, around 35 awardees across all three makerspaces could apply for up to 25K grant from Innovate UK. 35 applied, 15 were awarded including OurOwnsKIN which was the "standout project" (see Fiddian quote above).

This funding enabled further design development and exploration, printing into flexible polymers, prototyping novel electrospun material around the structures, disseminate and research ways to commercialize skills and product.

Introduction

Collaborators, Ciokajlo, Ravensbourne University London (lead concept/footwear designer), Papastaverou (computational specialist/designer) and Solomon (artist/researcher - human skin), put human over machines as design directives for 3D print lattice by design of:

- a parametric framework, inspired by skin's tension lines
- responsive, 'springy', auxetic cells inside parametric framework
- a one-unit structure to seamlessly cover the top of the foot and project lattice depth for sole

The computation was finely 3D printed into a holistic part with a responsive structure allowing the 3D printed material to behave more flexibly than conventionally expected. The design approach capitalized on the fineness of 3D print SLS (selective laser sintering) process taking the approach design structures can impact material behaviours.

Prior to this...

PI Ciokajlo had been consulting as a designer for Clarks, Street, UK with the product development department exploring design for 3D printed footwear. The stipulate was the designs were to employ only and all 3D print. The rationale for this limitation was to capitalize on the potential of 3D print to shift from longer supply and demand chains towards shorter demand and supply. By combining 3D print with for example leather a more complex longer term (18month pre order) supply materials were needed and therefore would still require larger stock piles.

Solomon had worked on Wellcome funded Skin or Cloth? A film comparing Plastic Surgery and Pattern Cutting techniques (2012) captured in this https://vimeo.com/70548672. In this project Solomon facilitated knowledge transfer conversations. Following this Solomon connected with Ciokajlo to apply this knowledge transfer to footwear.

Ciokajlo raised footwear already utilizes skin knowledge in pattern cutting, however it is the skin of another animal. Ciokajlo frustrated with 3D print material properties in comparison to leather and looking for something more than 3D print machine or conventional footwear construction to inform meaningful innovation, sparked the concept to investigate if our own skin (human skin) can inspire the design of 3D printed footwear.

Papastaverou was invited to collaborate with Ciokajlo and Solomon. Papastaverou PhD was on 3D printing for bone transplants and with this brought knowledge of translating biological structures to inspire 3D print designs using parametric computation.

Research Narrative

Literature Review

Each collaborator brought to the team their specialism from their own practice.

Fig. 2 Skin or Cloth? A film comparing Plastic Surgery and Pattern Cutting techniques (2012) by Solomon.

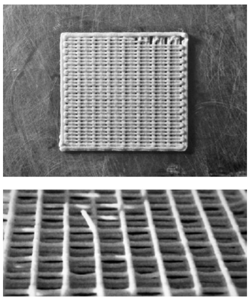


Fig. 3 Bio-ceramic lattice structures fabricated using an extrusion based AM technique (2016) by Papastavrou.

Fig. 4 GreyFeltShoes with additive binders, creating 3 levels of density over a continuous surface (2013) by Ciokajlo, photographed by Stephanie Potter Corwin.

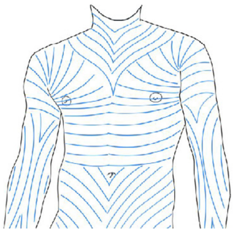
Solomon arranged for Ciokajlo to meet with reconstructive surgeons, the people who work with the properties of skin as a material.

Literature was found in particularly architectural practices,

- of utilizing biology to inform Design Fabrication of Heterogeneous Materials, (Oxman, 2010)
- manufacturing moving towards new territories whereby 3D printing is allowing us to construct exceptionally fine and intricate features with high accuracy “enabling design to take place concurrently at scales ranging from the micrometre to the metre” (Beckett & Babu, 2014).

Little was written on the application of translating the understanding of human skin to footwear. Only one paper was found Fontanella, C.G. et al., (2014). Investigation of the mechanical behaviour of the foot skin. Skin Research and Technology, 20(4), pp. 445–452, which analysed the mechanical behaviour of foot skin, but did not apply/transfer this knowledge to design computation for 3D print.

Therefore, the team looked at research to build an understanding of foot skin from Langer lines (the direction which collagen runs).



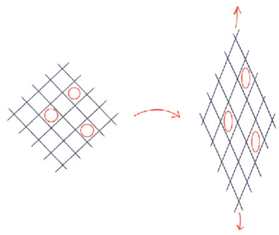


Fig. 5 (left): Illustration showing Langer’s Lines mapped across the human body (2018) by Papastavrou

Fig. 6 (right): Illustration showing Langer’s Lines mapped across the human body (2018) by Papastavrou

The turning point was after reading Ridge, M.D. & Wright, V., 1966. The directional effects of skin. A bio-engineering study of skin with particular reference to Langer’s lines. *The Journal of investigative dermatology.*

This paper from 1966 provided a theoretical guide which could be applied to parametric structure that could inspire design computation.

Research Question

Could a deeper understanding of how our skin behaves as a material inform the design of 3D printed shoes?

Whilst inspiration for future footwear will undoubtedly be informed by new materials and technologies, in order to make designs more relevant to our anatomy and more relatable to humans, the OurOwnsKIN project argues that influence must also come from ourselves, the materiality of our own bodies…Our skin.

By studying the interface that connects us most intimately with our material world, can we perhaps propose new design approaches that inform materials, machine, and resultant products?

Research Method

Research methods were computational and design development via iterative prototyping

1. Data collecting to understand mechanics of skin

2. Establish a computational framework inspired by human skin, that was both responsive and dynamic.

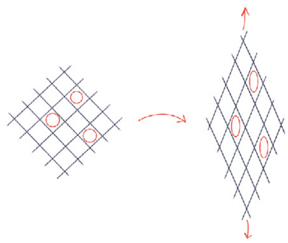
3. Auxetic lattices and footwear prototypes

4. Electrospinning

1. Data collecting to understand mechanics of skin

Following the literature review the team embarked on collecting data around the stretch of skin when walking using arduino providing a range understanding which could inform a framework.

2. Next was to establish a computational framework inspired by human skin, that was both responsive and dynamic.



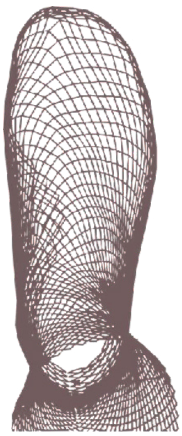
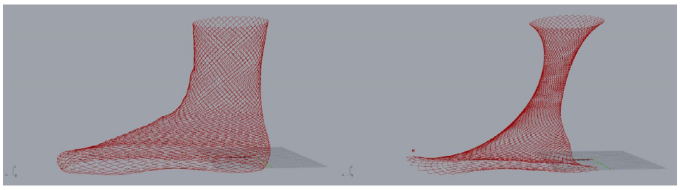


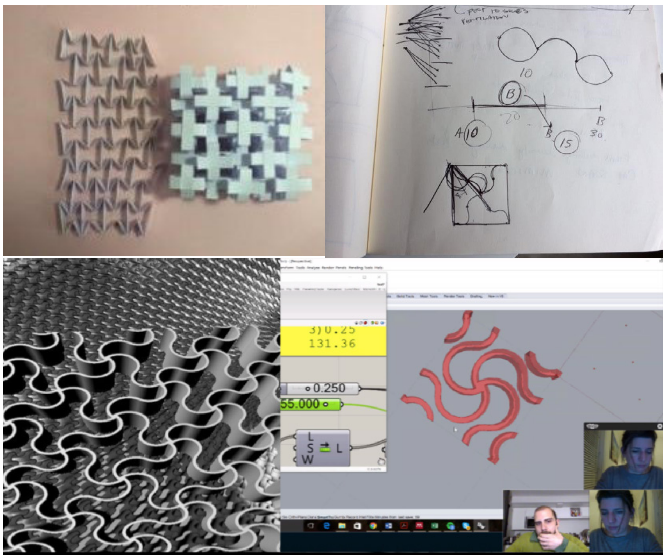
Fig. 7 (left): Simplified model of the mechanical behaviour of skin under tension proposed by Ridge and Wright (2019), illustration by Papastavrou
Fig. 8 (centre): Directional grain of Langer's Lines as positioned on the human foot skin (2019), illustration by Papastavrou
Fig. 9 (right): OurOwnsKIN diagrid framework generated over scanned surface of the foot using Grasshopper for Rhino (2017)

Ciokajlo's feet were scanned and Papastaverou applied Ridge & Wright (1966). The directional effects of skin rhomboids to a framework and draped over the scanned foot. Skin lines of tension can be drawn through the rhomboids axis.

The mechanical behaviour of skin has been described by Ridge and Wright using a simple orthogonal mesh positioned diagonally in relation to Langer's Lines (Ridge & Wright, 1966) (Fig. 7). The mesh is stretched more in one direction than the other, causing its cell units to deform into Rhombi (diagrid).

Using Grasshopper for Rhino, the OurOwnsKIN team generated a diagrid lattice on a surface obtained from a foot scan (Fig. 9). Each member (or strut) of the lattice behaved like a spring under tension or compression - an approach which has the advantage of manipulating a 'digital skin', by assigning different values of elasticity (stretching force) in each section of the foot, and making possible the complete customisation of fit.





3. Auxetic lattices and footwear prototypes

Fig. 13 (centre): sketch plan for Chiral cell (2016)
Fig. 14 (right): Papastavrou and Ciokajlo working remotely on Rhino and Grasshopper (2016)

In order to vary the stiffness in structures springy lattice cells called Auxetics were placed in the 'framework'. Auxetics are a family of lattices with a unique mechanical behaviour; when stretched, they become thicker. Similarly, when compressed, they shrink and become stiffer.

The project employed two of the most popular types:

- The 'Bow Tie' Lattice - consisting of Bow Tie shaped cell units.
- The 'Chiral' Lattice - consisting of Chiral shaped cell units.

Each type of Auxetic cell unit was inserted into the diagrid mesh framework in order to design and fabricate, what is called in the footwear industry a series of footwear 'socks'. This framework allowed for the variation of scale and the distortion of cell units; adapting to the contours of the foot in different areas whilst following the skin's tension lines.

Conventionally Chiral lattices are 3 spoked so a 4 spoke Chiral was designed and researched via 3D printed material samples the curliness and thickness needed for the spokes before printing costly full size pieces.

Samples using these structures were initially 3D printed in a low-cost Nylon material, using Selective Laser Sintering (SLS). This was found, however, to be too rigid. The team decided to pursue using Thermoplastic Polyurethane (TPU) for further print outs, which offered an alternative material that was both durable and flexible.

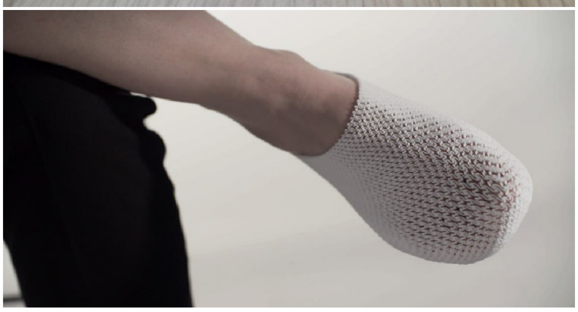


Fig. 15: Initial Bow tie Sock Printed in kind at Clarks with Powder Z Core, broke up but proved to curl (2015)
Fig. 16: OurOwnsKIN 3D printed 'Sock' using Chiral Auxetic pattern (2017) film by Craig Gambell and George Ellsworth.

These samples fully exploited the capabilities of 3D printing by rejecting a conventional Upper and Outsole footwear construction system. Printed in one part, from a continuous mono material, they enveloped the foot in its entirety, creating a structure that was not only responsive to both movement and pressure but also integrated a closure system, requiring no need for traditional laces. The use of auxetic cells and personalised production processes (working from scans of the foot), also provided a bespoke fit and enhanced comfort for the wearer.

Subsequent stages of the project protruded the sole of the Auxetic framework to make maintaining a purity of code and form.

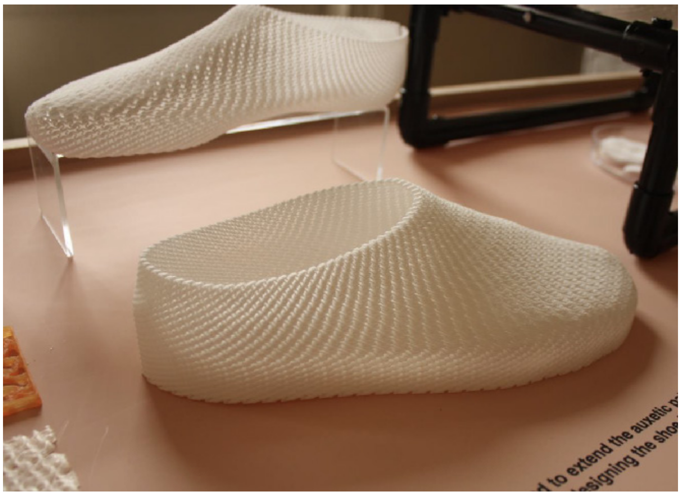


Fig. 17: OurOwnsKIN 3D printed with extended sole (2016) photo Papastavrou.

The skills of additional CAD designers were also drawn upon to explore further variations of mesh

Jason Taylor, of make X design, coded the Ciokajlo's design form into a structure onto a last, resulting in an evolved aesthetic for the shoe. The rationale for this exploration was to investigate manufacturing opportunities that might encompass the standardisation of production, following the advice from PUMA.

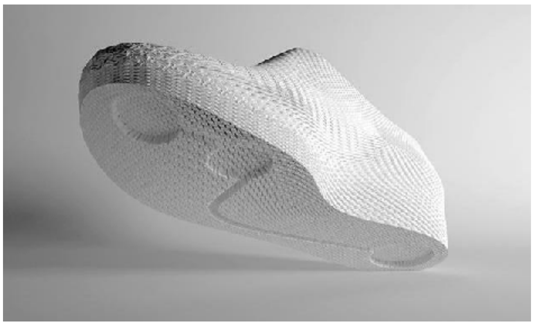


Fig. 18 OurOwnsKIN on last Jason Taylor, of make X design

Tom Mallison, of Digits2Widgets, developed a series of prototypes directed by Ciokajlo which added complexity to the structure by using three dimensional Auxetic lattices; the aim being to enhance the performance of the shoe in areas under step impact.

Fig. 19 OurOwnsKIN 3D printed outsole with a 3axis lattice (2016) Tom Mallison, of Digits2Widgets

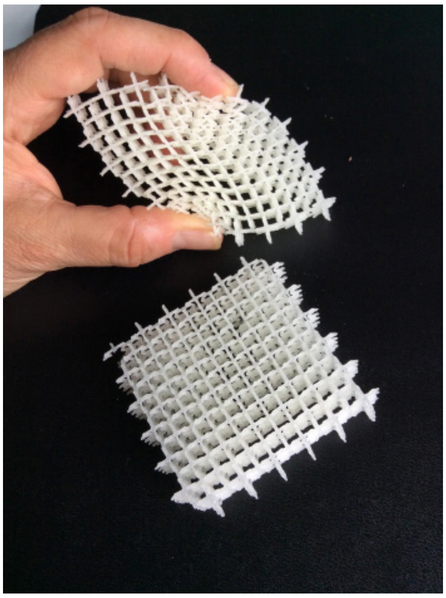


Fig. 20 material samples of TPU 3axis lattice

4. Electrospinning

As a way to waterproof/ cover in some the structures and avoid using infill materials (which might have impacted on the stretch and responsiveness of the Auxetic framework) one of the socks was Electro-spun; creating a non-woven, coating to the shoe.

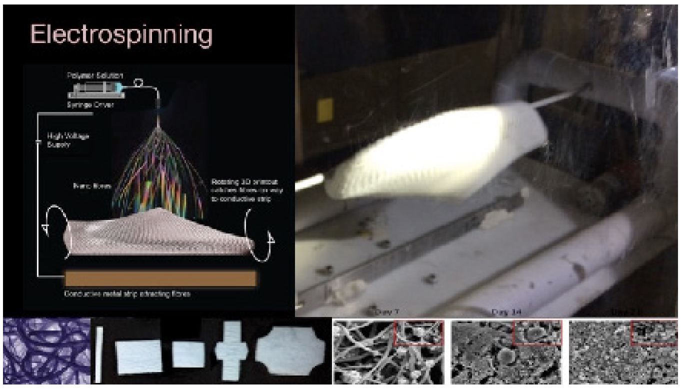


Fig. 21: Electrospinning diagram, material samples, image of being spun and examples of the material taking growth of biological matter at 7, 14, and 21 days (2016)

This process was also carefully selected so as to maintain the project’s principle of rejecting conventional footwear manufacturing processes; moving away from sheet formed material and keeping an additive approach.

Electrospinning is a method which uses electrostatic forces to draw charged threads of Polymers onto an oppositely charged surface. A thin coating of an highly elastic, Co-Polymer PLA + Polycaprolactone (PCL) formulation was applied to the shoe as it rotated on a lathe to create a fine non-woven scaffold. The thickness of the material can easily be tuned through altering the duration of this process.

Used frequently in medical applications in the production of wound care products, implant coatings and drug delivery systems, electro-spun fibres hold incredible material properties as they support the growth of biological materials and can also be sustainable. The introduction of these fibres has opened opportunities to the OurOwnsKIN project to combine digital and biotechnological approaches to production. The next phase of the venture will be to grow materials into the micro structures of electro-spun, 3D printed shoes.

Research Outcome

Future manufacturing opportunities

The OurOwnsKIN project has attracted interest from international research groups and major footwear companies through its bid to subvert current industry practices.

Benefits of methods such as this include shorter production timescales, by significantly reducing the number of processes, tools and machines required, in turn lowering financial investment.

Parametric design also enables industry to make changes more easily and cheaply during the early design phases of a shoe, allowing for mass customisation and tailored fit. When coupled with Additive Manufacturing this means that products can be produced for specific user groups, in small runs of production.

The OurOwnsKIN project in particular allows for the customisation of fit to be distributed across different elements of a shoe (contour, material and structure) resulting in a design that fits a wider population for mass production scenarios.

Conclusion

OurOwnsKIN is a speculative project that positions the human body as the blueprint to instruct future design form and digital making processes. It is an approach that flies in the face of traditional sheet production techniques; one that is not driven by conventional materials, machines or established design forms, but is driven by our own anatomical make up.

Its proposed concept raises deeper questions than solutions around the potential of technologies to disrupt our emotional connections to the items that we choose to consume and wear.

Whereby once humans have appropriated the skin of another animal, now there is opportunity to wear our own skin, or 'cloth' inspired by its materiality.

- Will this enhance our intimacy with things - building resilience into associations between people and products.. Or will this purely repulse us?

- Can a technique such as this, in which the materiality of the human body is reconsidered to produce commercial goods, somehow integrate us back into nature, enhancing our empathy for the ecosystems in which we currently co-exist?

- If leather and its associated processes have been the driving force behind footwear manufacturing to date, can our own skin become the material that drives 3D printed design form constructions of the future?

Dissemination

Fig. 22: Into the Wild, Somerset House, London (2016), Invite

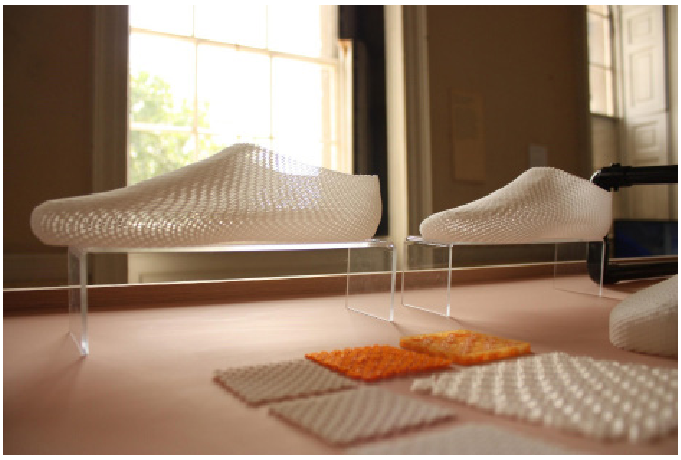


Fig. 23: Into the Wild, Somerset House, London (2016), Exhibit

Book Chapter

- Bloomsbury Academia published (02-2020) collaborator team co-authored chapter 'OurOwnsKIN: The development of 3D-Printed Footwear Inspired by Human Skin' in book Crafting Anatomies: Archives Dialogues, Fabrications

Exhibitions and talks

- Into the Wild, Somerset House, London (2016)
- Material Anatomies, Digit2Wigets, London as part of The Design Festival (2017)
- SKIN 2 London College of Fashion Symposia, London (2018) – Speaker
- Global Fashion Conference 2018, London College of Fashion Symposia (2018) – Speaker
- Design for Disability Summit 2017 London - speaker

Industry interest/engagement

- Collaborative team was hired on a Kings College London Research scoping project Reboot to design footwear for people with EB/Epidermolysis Bullosa (2016-17).
- Industry interest Puma, Clarks, Ecco, Adidas, VivoBarefoot - but no contracts

Reception

The Project received very positive feedback from the above dissemination with interest (Industry reaching out to us) which is significant in the saturated high turnover footwear industry, but we were not able to secure any contracts to develop the work.

After seeing the work passed on by a designer who was at one of Ciokajlo's talks, Puma flew us out to Germany. The feedback from the material scientist was this was the direction to explore, the head of innovation decided to invest their funds in a speculative biodesign project with MIT. He felt we lacked the emotional story to the work which would enable him to sell the concept to Puma's marketing department without an established name/ brand.

Clarks sent their Product Development team up to London to attend our Design Festival event and expressed interest to do a project but Clarks did not follow up.

Adidas in New York contacted us and once asked about remuneration (no figures at this point) they went quite.

Vivo Barefoot contacted us to be part of a design research project and after discussions, it was evident they were looking for a CAD technician to deliver a project they were working on with a footwear designer in Gent.

Ecco also expressed interest but again after much liaising and sharing of knowledge no project materialised.

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