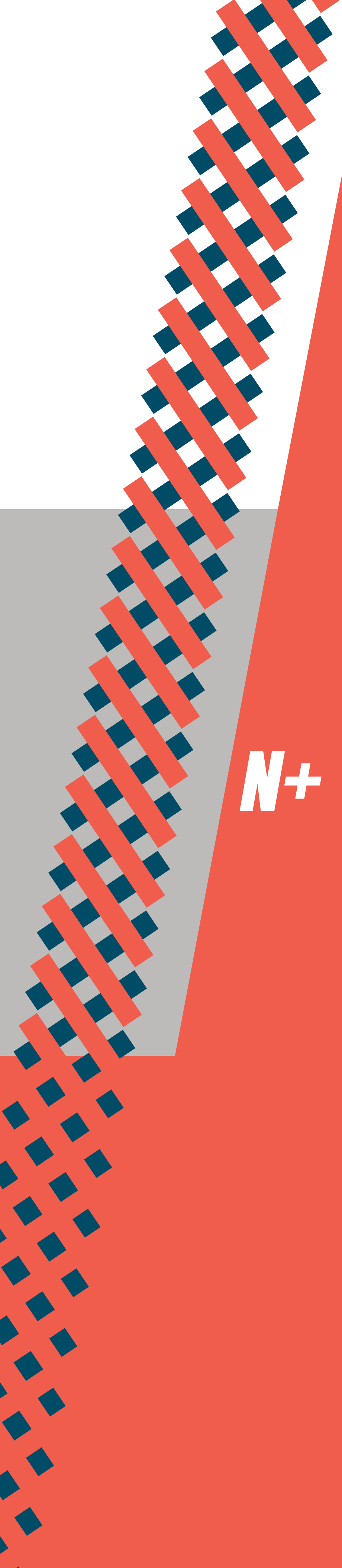

N+

Marc Wilkinson
Design Report
Wilson School of Design
Kwantlen Polytechnic University
Spring 2017
Bachelor of Design - Product Design

Thank you to my family and friends for their support. To my instructors who caved to my stubbornness.To the people who reached out and offered to help, to the internet for always being there, to communities of people sharing altruistically. To my photographer and barista. This was for you.

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BACKGROUND

fig. 1 - Concept rendering

PREFACE

This is a story about changes - the changing world around us, the changes in ourselves, and the ever changing paths we all follow and stray from. In the last two decades, the rate of change in the world has kept blistering cadence, each period of seeming stagnation punctuated by new technologies that redefine the pace of life. Computers, once used to process data evolved into consumer goods, and consumer goods become less tangible, driven by the data, they create. Old systems are giving way to greener alternatives, and the very concept of yours and mine does the same.

For the final undertaking of my degree, I wanted to focus on something I am passionate about - bikes - the type of which changes with the frequency that is expected of my time and place in the world. Mountain bikes around the neighborhood, BMX in the streets, road bikes with gears and without, more than I can reasonably possess. To myself and others like me, the notion of only one bike can't begin to capture the possibility they imply. The formula for how many bikes one should own is as follows:

n= number of bikes currently owned
number of bikes needed = n+1

This makes for a reasonable parallel to the project. After the project proposal to explore variable flexion footwear, I couldn't help but feel it wasn't enough - it left more possibilities on the table. It seemed like solving that problem, as real as it is, wouldn't involve the type of risks I'd spent the four years prior telling myself I should one day take. I want to share what I have come to understand about the potential of rapidly changing technologies' ecological double edge sword; embrace them too quickly, or not quickly enough.

When I embraced the challenges creating a shoe presents, my own message changed. I set about on an unmarked path that would eventually push me to not simply create a new product, but a platform to engage users that would enable them to fulfil their own needs. The *N+* platform allowed me to explore the potential of new manufacturing technologies, and consumers' changing expectations for product ownership models.

BIKEPACKING TREND

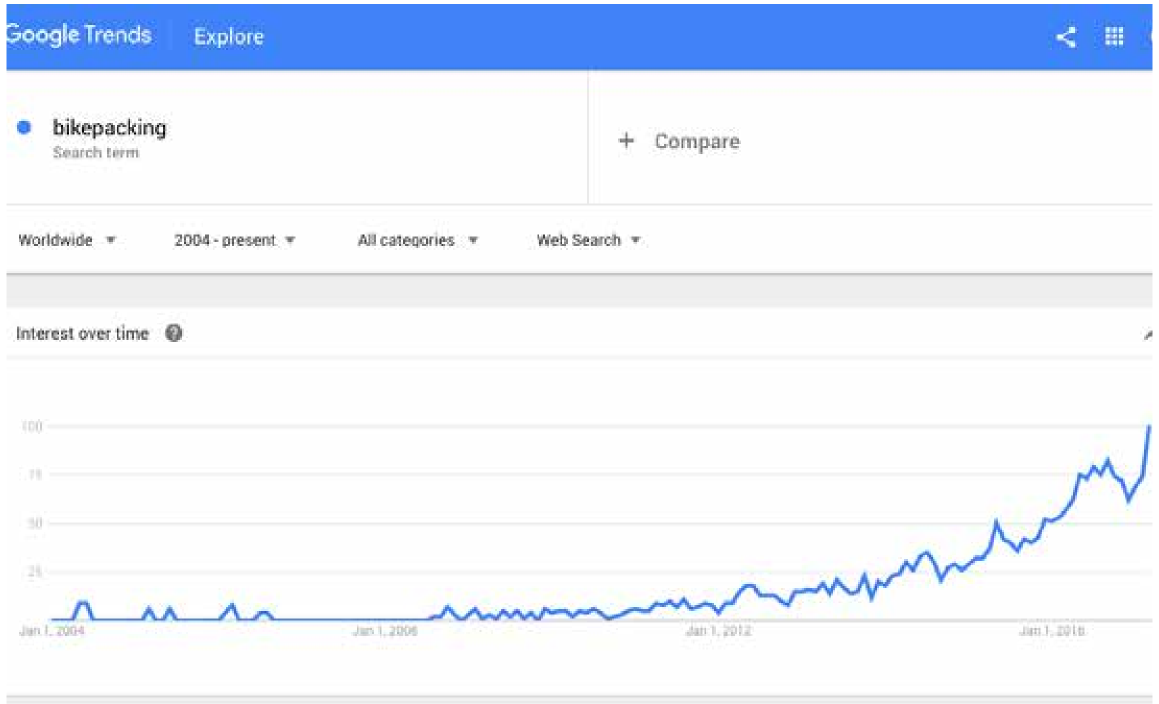


fig. 2

There's a grassroots push toward strapping bags to bikes, heading into the wild and having the best time possible. While overland travel by bicycle is certainly not a new idea, in recent years it has experienced a sort of renaissance (fig. 2) due in part to new technology and fresh interpretations of old ideas. The once nerdy touring bicycle gave way to the hip and well appointed 'randonneur' bike, and then a slough of form-fitting frame bags gave those cyclists the stability and control that traditional bike luggage had castrated.

This reclaimed control allowed for new experiences, and new paths were forged into the woods. Cyclists no longer worried about heavy side bags catching on the foliage. Industry trends like plus-sized tires and simplified wide range cassettes suited this style well. The emerging discipline of bikepacking allows for camping trips over an extended range with the added pleasure and convenience of mountain biking. Capable off-road bikes loaded like packhorses propel riders into the adventurous wild.

fig. 2 - Bikepacking search results (Google Trends)

PACKING LIST

With experience comes the ability to distinguish what is essential and the shortcomings of their gear. And the element of tuning comes into play. It starts with the bike; will it be dry or muddy? That might influence the tire choice from slicker fast tires to knobby fat ones, respectively. An experienced rider might adjust tire pressure for the terrain. Maybe the planned route has lots of technical climbs, which could mean switching from clip-in pedals with special cleated shoes to platform pedals that make it easier to put a foot down. Bringing along the proper equipment ensures riders get the most from their outing. Some seasoned riders are boldly willing to customize existing gear or even make their own, tapping into the resources available online and connecting with the Make Your Own Gear (MYOG) community.

CARRY-ON BAGGAGE

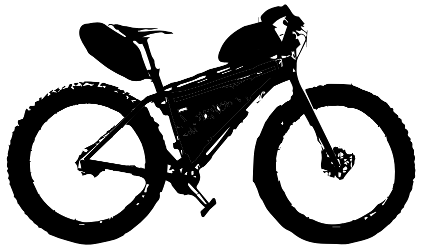


fig. 3

The equipment needed for bikepacking differs from other cycling disciplines. The type of bike used can vary from a trusty turn-of the-millennium mountain bike to modern carbon fibre bikes with the latest trending tire size. It's not a race but dependability matters off the beaten path, where a mechanical gear failure can make for a long walk home. Bags mounted in the frame, at the handlebars or under the saddle require some creative packing to accommodate food, cooking gear, tent and sleeping bag, clothes for the duration of the trip, and any other small luxuries you might hope to bring along. Frame bags have been plucked from obscurity and into the mainstream. One website, *Cyclingabout.com*, lists over 60 Bikepacking bag makers in their far from exhaustive guide ("A Complete List of BikePacking Bag and Frame Bag Manufacturers with Prices," 2015).

Bikepackers feel the weight of their poor packing decisions, not unlike other self-sustained wilderness pursuits. Because of the limited space, gear decisions must be intentional and the more utility one can get from each item means a lighter load and a more enjoyable journey, and that's easier on the rider and the bicycles components.

fig. 3 - Bikepacking rig, fully loaded

RESEARCH

A TALE OF TWO SHOES

On a long range bike trip, often segmented by hiking sections and camp time, finding a perfect shoe creates somewhat of a paradox. On a bike, the key is power to the pedals and dampening for extended riding comfort. Bikepackers can often spend over 6 hours pedaling on consecutive days. This is achieved through a rigid shank in the shoe sole. Inexpensive cycling shoes usually use a strong plastic or fiberglass reinforced polymer, while more expensive models, like those used by professionals at the highest level, tend to use a carbon fiber matrix (Jarboe & Quesada, 2003). In sections not suitable for riding a bike, side hikes, or loafing around camp, the user needs moveable articulation and walkability. Some rides can involve hours, even entire days, of 'Hike-A-Bike' sections what are unpassable by bike. Pushing a gear - clad bike through these sometimes technical hiking sections can be very demanding, and the traction and stability offered by ergonomic articulation make for a more natural and comfortable hike.

fig. 4

fig. 4 - Bike Shoe & Hiking Boot forms

OUTSOLE STIFFNESS

fig. 5

HIKING SHOE ATTRIBUTES

- Aggressive lugged outsole for grip in mud and loose conditions.
- Supportive ankle cuff with high lacing.
- Good flex for walkability, but firm enough to support challenging walks and heavy loads.

BIKING SHOE ATTRIBUTES

- Smooth, flat outsole for good pedal contact.
- Shallow grooves to interface with pedal pins or a mounting point for clip-ins.
- Reinforced rigid base to prevent hot-spots and energy lost to flexion while pedaling.

fig. 5 - Outsole Stiffness comparison

flex·ion
noun
the action of bending or the condition of being bent, especially the bending of a limb or joint.

FLEXION & RIGIDITY

ri·gid·i·ty
noun
inability to be to bent or be forced out of shape.

This paradox became the focus of my research. Can a shoe sole provide proper articulation for walking, while also being rigid enough for all day riding comfort?

Can one shoe provide enough rigidity for all day riding, while flexing enough to hike comfortably?

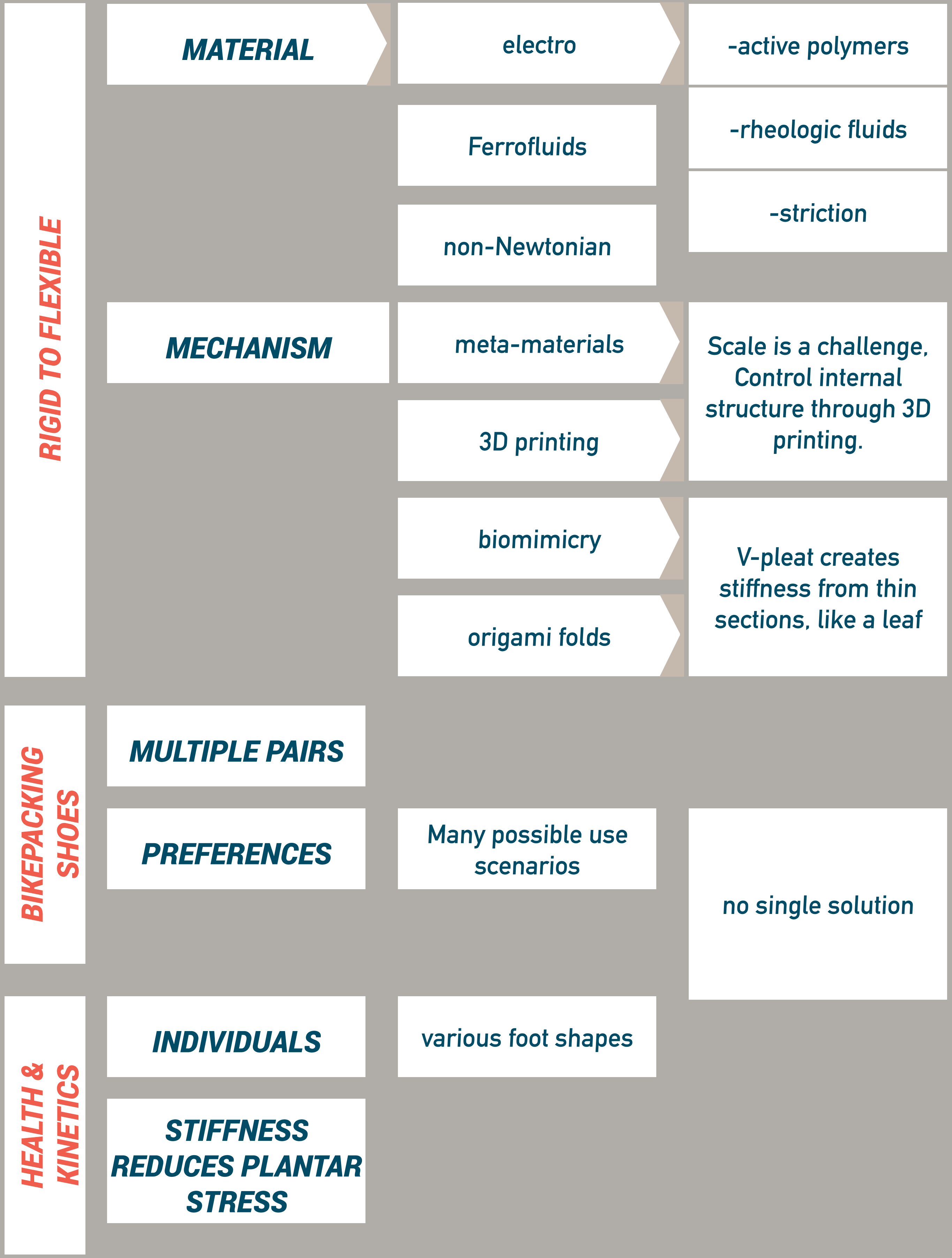
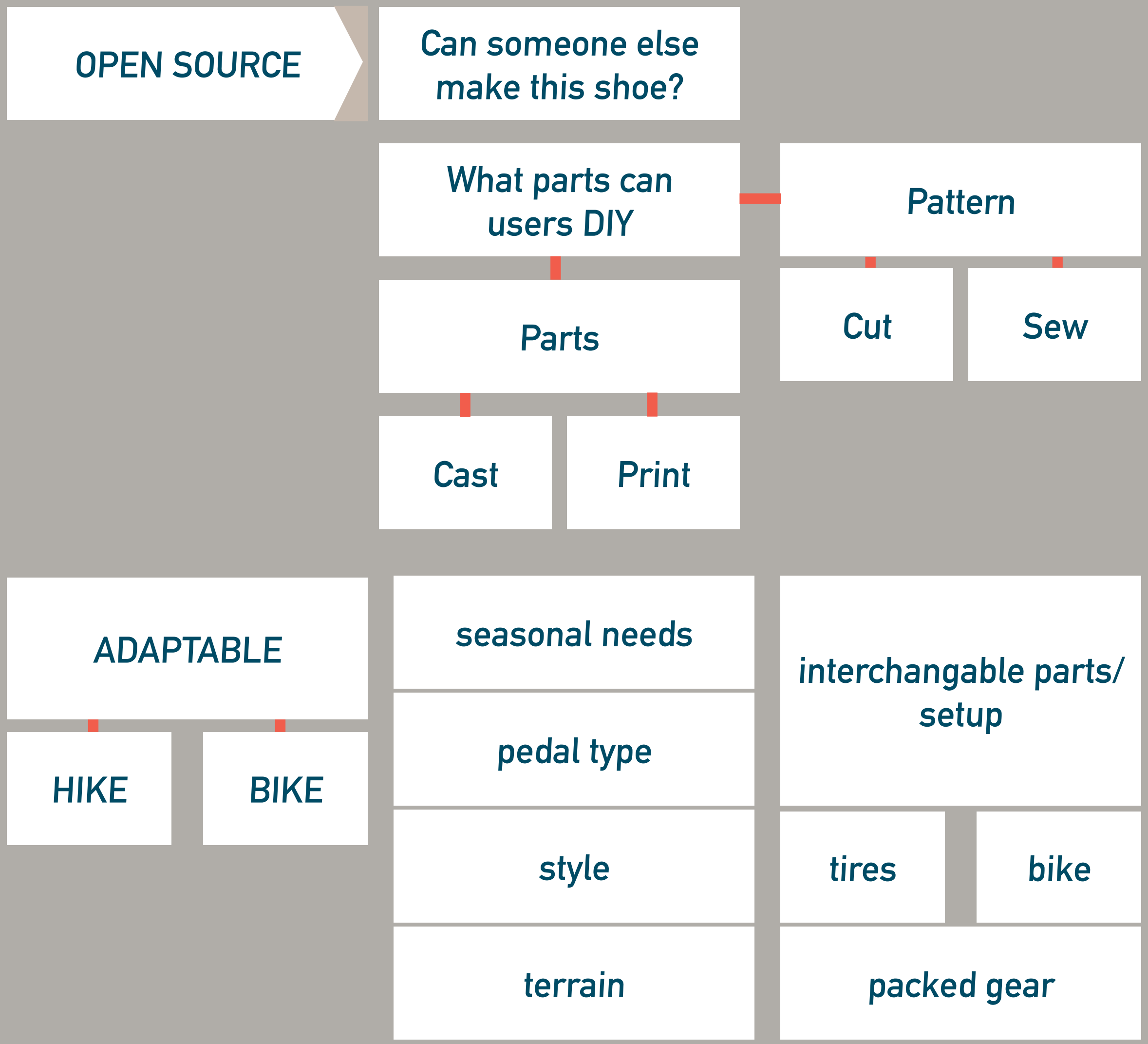


fig. 6 - Research Summary



RESEARCH SUMMARY

In seeking to achieve the paradoxical properties of rigidity and flexibility within a shoe, my initial inclination was to look at things outside of the footwear world that are both flexible and rigid. I identified 2 categories by which these properties could be achieved, then further refined the selection based on what would meet the scenarios unique criteria.

Finding a material that is both flexible and rigid has numerous potential applications, and to this end it is a shared objective for many fields of research. The methods can be categorized as Materials, where the material properties or a specified combination of material that allow for this transition of state; or Mechanisms, which rely on some function of physics and mechanical properties like structural arrangement, or mechanical actuation.

MATERIALS

CUTTING EDGE VARIABILITY

Materials with the ability to transition between rigid and flexible states could become more commonplace in coming decades. They have potential in robotics, transportation and more. Electricity is the main driver of rheological changes, and while efficiency and power supplies have improved, the materials driven by electricity require larger than ideal power supplies.

Ferrofluids, fluids containing nanoparticle sized ferrous matter, and their larger ferrous particle filled partners, magnetorheological fluids, become viscous through a magnetic field. An electromagnet can be used to align the ferrous particles suspended in the fluid creating a less fluid matter. Outside the laboratory, this has been used to create variable suspensions for heavy trucks (Jolly, Bender, & Carlson, 1999). In a shoe this concept could be actuated by an sensor that determines walking and cycling motions, but the level of power required to run the electromagnets means adding batteries to the already considerable weight.

Electroactive polymers (EAP's) promise to give human-like movement to artificial muscles. Conductive fluid between two layers of polymer are activated by electric current and the non-conductives undergo electrostriction. (Vincenzini et al., 2013) By varying the thickness of the polymer layers, as well as electric current, EAP's can be tuned to flex in predictable patterns. Dielectric Elastomeric Actuators fall within this category. DEA's reverse the structure, coating two sides of an elastomeric film with electrodes. Under current the electrostatic pressure creates the strain. (Köckritz et al., 2016) Because of their simplicity a DEA is the most relevant for my application, but as with other electrically actuated materials the power requirements rule it out.

Because carbon fiber is commonly used in cycling shoes, tuneable carbon materials were interesting. While they still require too much power for bikepackers, they have high mass specific strain properties. (Shao et al., 2012) Some research has shown flexural stiffness morphing with hybrid layered beams with woven carbon fiber reinforced polymer composite and shape memory polymer layers. Displacement is created when the materials warm up through electrically resistive heating. For that reason it's not well suited to bikepacking, but one day it might be great for a winter boot.

DESIGNING WITH MATERIAL CYCLES

High-performance footwear is especially challenging for *woke* designers. Today the manufacture of most cycling shoes involve countless separate pieces in a mélange of materials, all bonded together with harsh adhesives. Even worse than conventional shoes, they have a rigid shank of carbon fibre or a lesser composite firmly ingrained into the sole. (Brown, 2006) They're nearly impossible to dispose of properly, as the textile components are small and well sewn, while the soles are irreversibly thermoset elastomers. The rates at which these components degrade are usually mismatched. Everyday shoe users know rubber soles wear down from regular use, and the bicycles platform pedals aggressive traction pins can chew the underfoot apart in a few hours of ride time. The textile uppers require some care for hygienic reasons. A well made carbon composite component can last for decades without noticeable degradation. It's also understood that traditional shoe construction methods where the sole is glued to the textile uppers are not entirely inline with the priorities of the people who are passionate about wilderness and the outdoors; minimal impact on ecological systems, preservation of resources, the natural cycle. (Herva, Álvarez, & Roca, 2011)

Would people be willing to throw out your entire bike when the tires went bald, or if every time even one handlebar grip wore down, a new handlebar, brake levers, and shifter set was needed? Why do cyclists tolerate having to throw out a $300 pair of shoes? Likely because they've never been given much of a choice. Trying to design a shoe based on conventional archetypes will always leave some users out. (Gordon & Blackwell, n.d.) The insights from the users and their habits presented an opportunity to explore the relationship between a rider and their shoes. The amount of care and preparation that riders put into their other gear should be reflected in footwear options.

Opposite:
Shoe guts

Photo 1

Photo 2

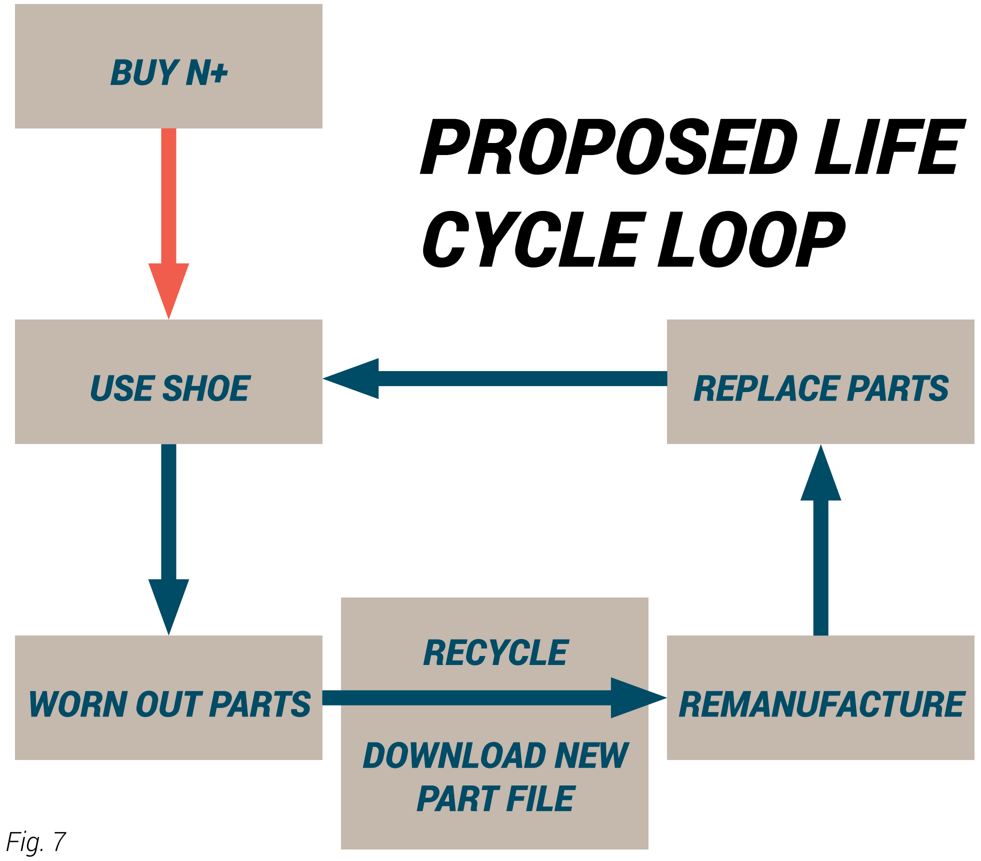


Fig. 7

MECHANISMS

VARIABILITY FROM STRUCTURE

Mechanical means of flexural variation are a particularly interesting field. Unique metamaterials contain complex inner structures and arrangements that allow for atypical properties, some are very close to the type of flexural variability I was seeking. (Christensen, Kadic, Kraft, & Wegener, 2015) Researchers at the Hasso-Platner Institute were able to create single material tools and mechanisms such as a pair of pliers, a door handle and latch, and a pantograph. (Ion et al., n.d.) Using varied wall thicknesses along a grid structure to enable controlled movements.

Material researchers have also developed interesting properties based on the principles and insights of origami, which could also be classified as metamaterials. At an architectural scale, Johannes Oververlde and his colleagues have developed a 3D actuated transformable metamaterial with multiple degrees of freedom (Overvelde et al., 2016) which sounds promising, however the origami actuation requires clearances that a shoe sole can't provide. Another researcher used an origami fold in sequence to create stiff, reconfigurable structures that bend along the fold line. (Filipov, Tachi, & Paulino, 2015)

The materials that can transition across the desired level of rigidity require further development to become appropriate for footwear in this context. The great future promise is, for now, limited to laboratories and experiments.

The mechanisms of variable flexion discussed are difficult to scale small enough to function in footwear. Because bikepacking takes place off the beaten path, dependability is critical. Riders could be days away from a replacement, and gear failures can leave them high and dry. If the mechanism or material for flexion is not durable and dependable, than it's not appropriate for this sport regardless of any other incredible properties.

SOCIAL INPUT

FORUM DISCUSSIONS

To gain a better understanding of the current trends and needs of bikepackers, I analyzed available discussions pertaining to footwear on the most active bikepacking community forums. I also engaged the communities and facilitated some discussion around the topic. This gave insights into the preferences and needs that bikepackers had, and helped to better understand the users.
Forum posts covered the wider discussion of bikepacking footwear. (see appendix A)

A few key insights;

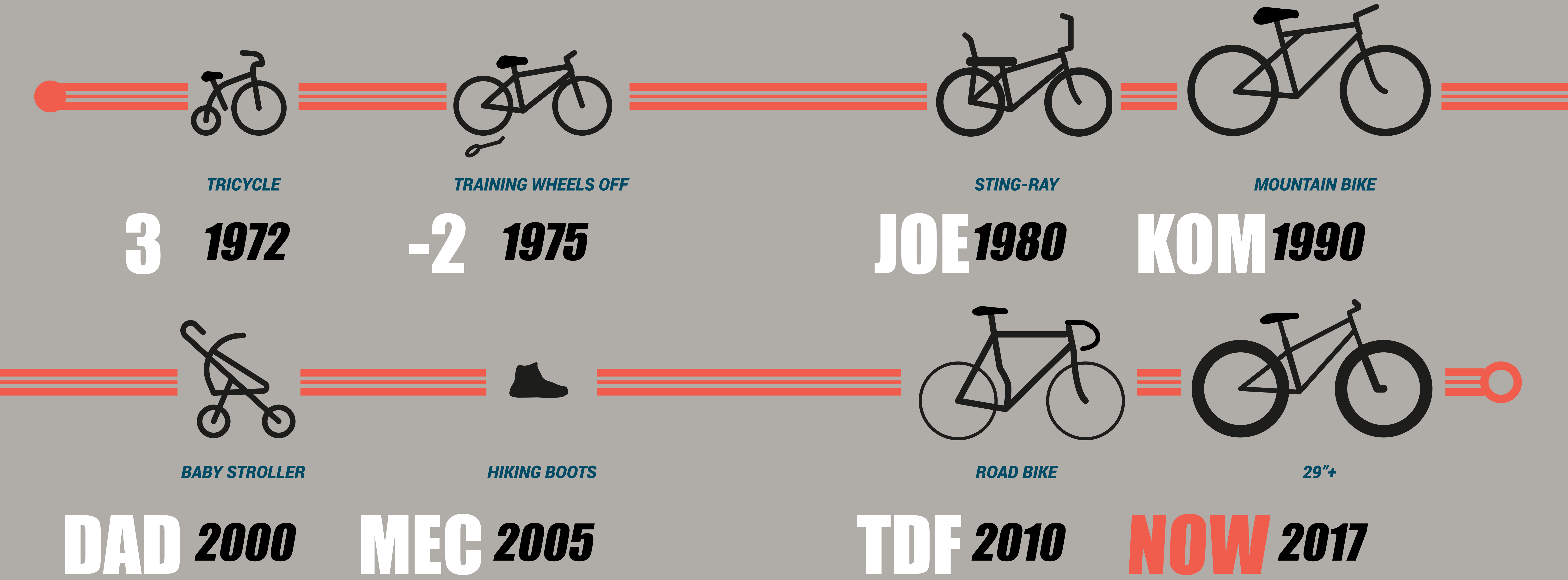
- Some trips can involve hours of hike-a-bike terrain. In order to access some spectacular riding terrain, it's often necessary to earn it by making a hard ascent. Some climbs that would be possible by bike are made more challenging with the added weight of gear, and taxed muscles, which makes hiking the easier choice sometimes.

- What works for one individual could be completely wrong for another. Ergonomics and preferences play into the decision. A single offering couldn't suit each rider.

- The 'right' shoe for a winter trip is not the right shoe for a coastal summer adventure. Similarly a shoe ideal for a weekend trip might not hold up on a ride from Alberta to New Mexico (Tour Divide). The conditions and duration of a ride influence footwear choices.

- Many riders carried two pairs of shoes. While some riders felt comfortable walking in a cycling shoe with a more flexible shank, others found the same shoe too soft for all day riding. Some riders used platform pedals with hiking boots or runners and found that to be comfortable enough. Many opted to bring a second pair of footwear, such as a pair of runners, for long stretches of hiking and walking.

- Footwear is subject to significant wear and tear on extended rides over such variable of terrain.



RIDE HISTORY

fig. 8 - Bike history of a typical bikepacker

THINK/FEEL

- ... for themselves.
- The weight of their gear decisions.
- Plantars
- Hotspots
- Moisture
- Cold
- Warmth
- Discomfort

SEE

- Nature
- The world
- Waste
- Trends come and go
- The latest gear
- Technology
- Fashion
- Wildlife

HEAR

- “What works for me...”
- “Bring a seperate pair for...”
- Personal opinions
- “Reasonably good for _____.”
- Marketing

SAY/DO

- Regular maintenance
- Refine their kit
- ‘Leave no trace’
- Service their bike
- Plan for trips
- ...what bothers them
- Maintain
- Pack intentionally

PAIN

Heavy gear
Extended hikes in stiff soled bike shoes
Riding in hiking boots
Discontinued shoes
Destroying nature

GAIN

Simplicity
Freedom
Minimal impact
‘One Shoe Quiver’
The right tool for the job
Pedal contact
Walkability
Functionality

EMPATHY MAP

fig. 9

ORTHOPEDICS

PEDAL TO THE METATARSAL

The foot to pedal interface is the most critical of the five contact points between the body and the bicycle, through which force from the body is transferred to the drivetrain. One can pedal without hands, or standing, but pedalling without feet just isn't happening. This fact has makes it a focal point for study related to cycling efficiency. The most common type of bicycle pedal is the platform pedal, which grips to a normal soft soled shoe with friction. At a competitive level most shoes are 'clipless' style, which have cleat in the outsole that clips into an interface on the pedal. Clipless pedals provide a very secure connection and allow the rider to generate additional force on the upstroke of the pedals. Clipless pedals add some efficiency, but make it harder to detach yourself from the bike. (Gregor & Wheeler, 1994)

The common wisdom among serious cyclists and cycling shoe manufacturers is that a rigid sole like those found in high end race shoes provide the most efficient transfer of power to the pedals. Nathan Jarboe explains "damping losses reduce the overall efficiency of the cyclist/bicycle combination by absorbing the energy used to flex the shoe without returning that energy elastically after the load is removed." (Jarboe & Quesada, 2003) This is evident in the price-points and materials manufacturers offer. Most riders who have spent a few hours in the saddle understand that a stable interface between the foot and pedal helps keep cadence, while a well braced foot reduces unwanted movement, along with the friction and hot spots it creates. While these rigid shoes are well suited to cycling, they are make for clumsy and awkward walking shoes.

While personal preference generally dictates foot placement on the pedals, the 'sweet spot', where power can be generated the forces of the ground can be absorbed safely is under the ball of the foot. The interface and placement of the foot effect the output of the muscle groups, and clipless interfaces which ensure the foot is in this sweet spot are seen to be an optimal range. (Hug & Dorel, 2009)

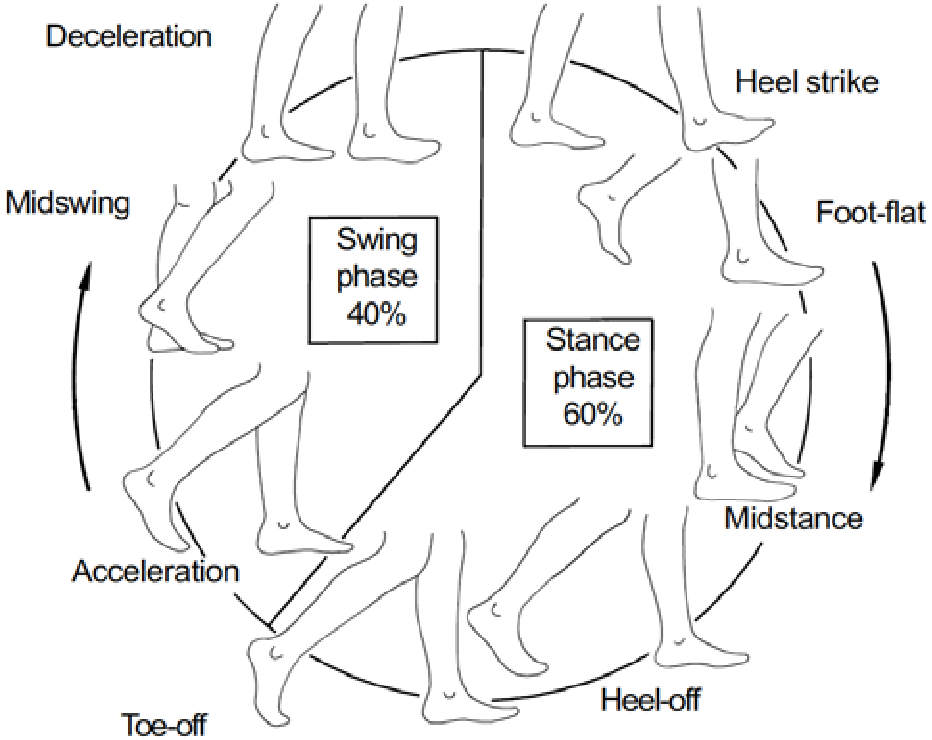


Fig. 10 -
Eight main events of the gait cycle
(Vaughan, Davis, & O'Connor, 1999)

The human gait cycle describes the process of human locomotion. It consists of the stance phase (60%) and swing phase (40%). (Vaughan, Davis, & O'Connor, 1999) In the transition between stance and swing, the push-off, the metatarso-phalangeal joints (MPJ) of the toe flex and generate force. (Goldmann & Brüggemann, 2012) Without this point of flexion, the potential to generate force is lessened. Inclines tend to accentuate this toe flex, and a stiff sole can be especially problematic. A rigid sole walking up an incline would turn the MPJ into a fulcrum, and the leverage leads to heel lift if the shoe isn't properly secured. That means the rider won't be loosening their shoes to give the feet some room to breath during the hike.

To facilitate comfortable walking, some flexibility is required in the sole (Roy & Stefanyshyn, 2006), but a rigid connection with the pedals, with minimal flexion in pedaling ensures comfort and efficiency on the bike.

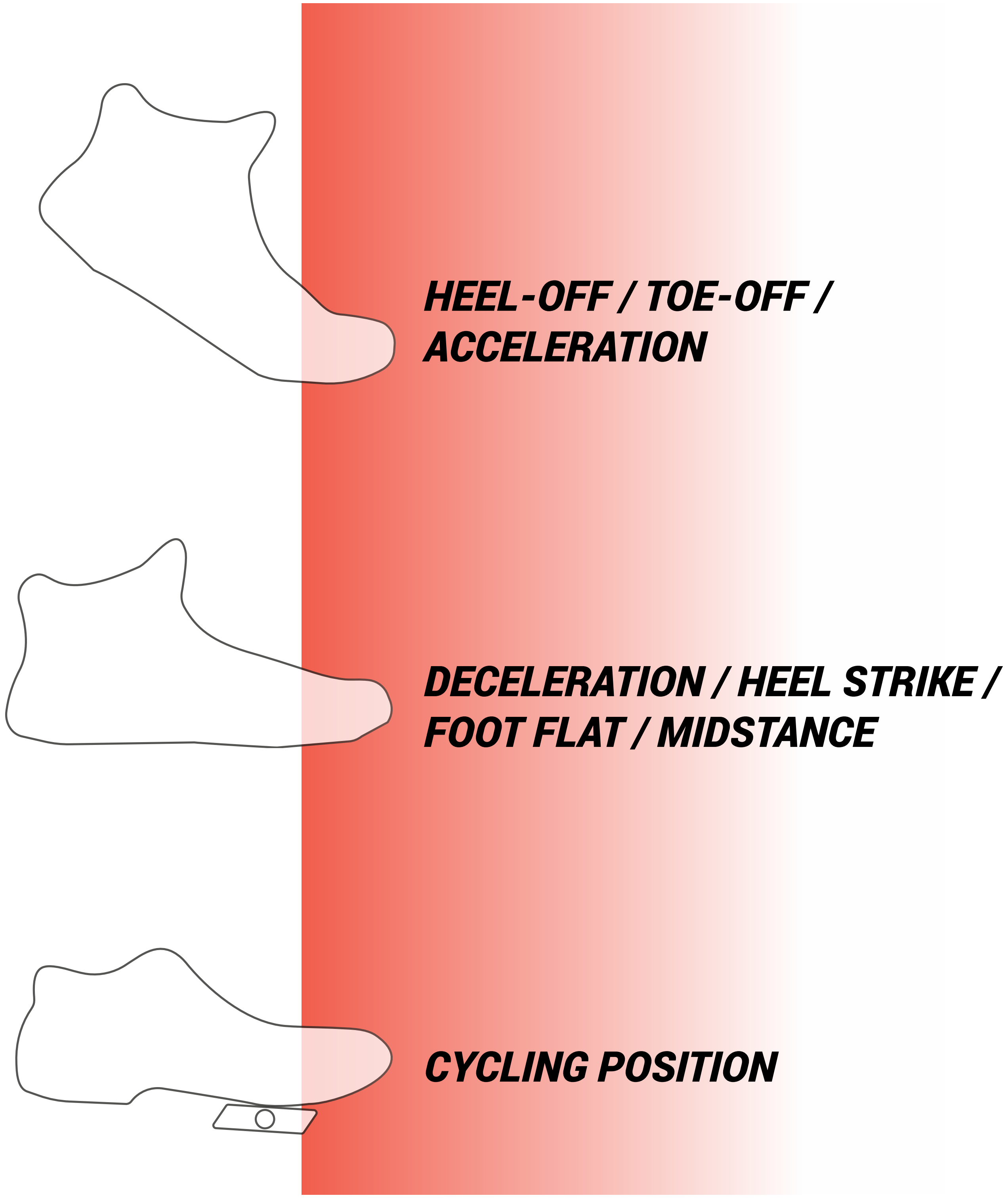
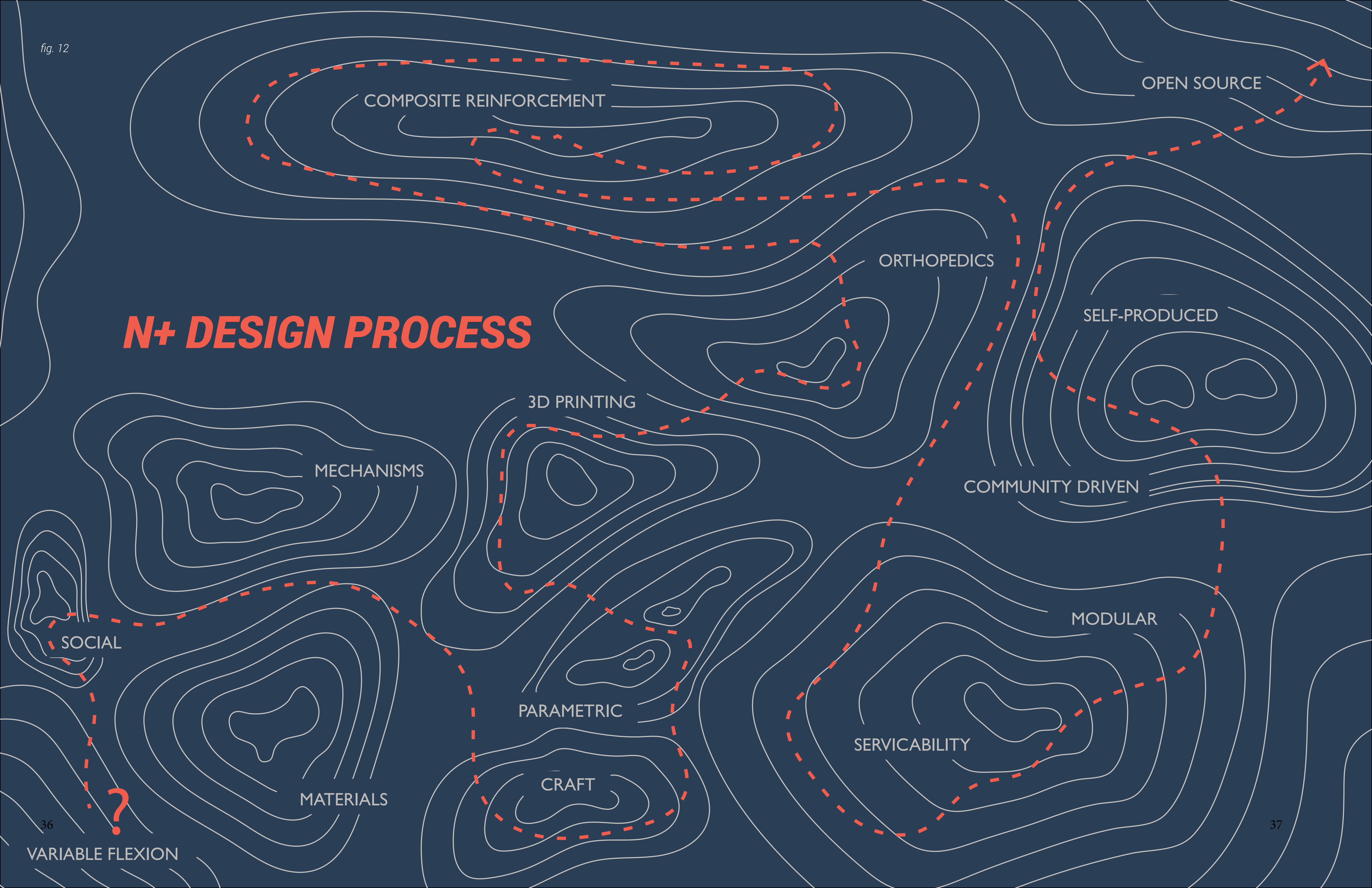


Fig. 11
Foot articulation,
cycling vs. walking

PROCEDURES

fig. 12

N+ DESIGN PROCESS



THE NEW TOOLS

3D printing technology is becoming more accessible with capable printers available under the $300 mark. The technology has largely failed to live up to the expected hype and growth some predicted, due in part to the learning curve of 3D modelling software. Many of the available models are of limited practicality, and while there are hundreds of thousands of models shared online for free today, the functionality of most leave something to be desired. But the potential still remains, untapped and discounting everyday like a 5-pack of blank DVD-RW discs in a Silicon Valley Wal-Mart. The biggest shoe companies in the world are circling around this new technology nervously in hopes that it will soon start making sense for production, which may be a ways off.

2016 was a debut year for 3D printing tech in sneakers. Nike announce a partnership with tech company Hewlett-Packard (HP)("At Nike the Future is Faster, and it's 3D," n.d.), New Balance released the Zante Generate, a $400 selective laser sintered midsole runner ("The Future of Running is Here," n.d.), and before the year's end Adidas enlisted 3D printing company Materialise to propose shoes individually printed midsole to customers specific cushioning specifications, the FutureCraft shoe, by the same SLS process ("adidas breaks the mould with 3D-printed performance footwear," n.d.). The SLS printing process used to create the Adidas and New Balance shoes are neither accessible or inexpensive, but use a Thermoplastic Polyurethane (TPU) similar to filaments readily available for Fused Deposition Modeling (FDM) type printers that consumers would have access to.

For the users at home a variety of free software enables complex workflows, generating tool paths according to the desired settings. Slicer programs convert STL files into a series of commands for the printer to follow. This is where layer height, wall thickness, infill and more are determined.

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

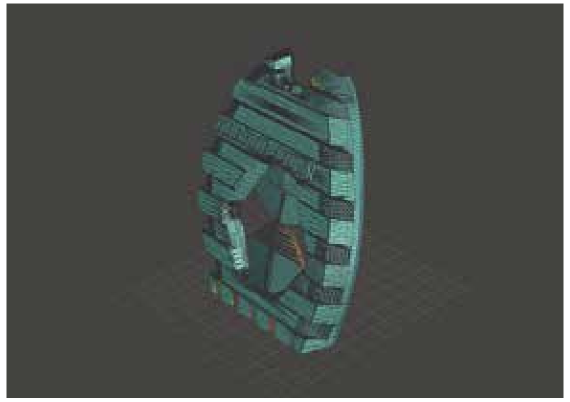


Photo 8

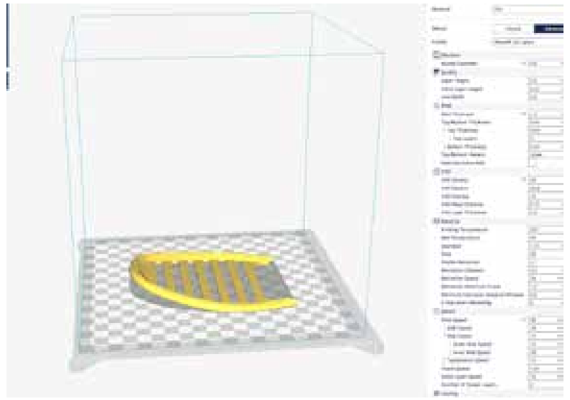
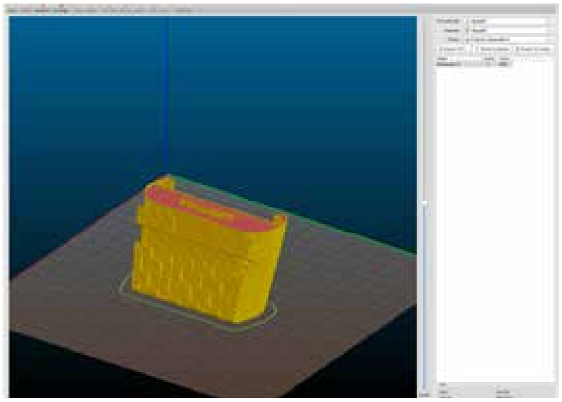


Photo 9



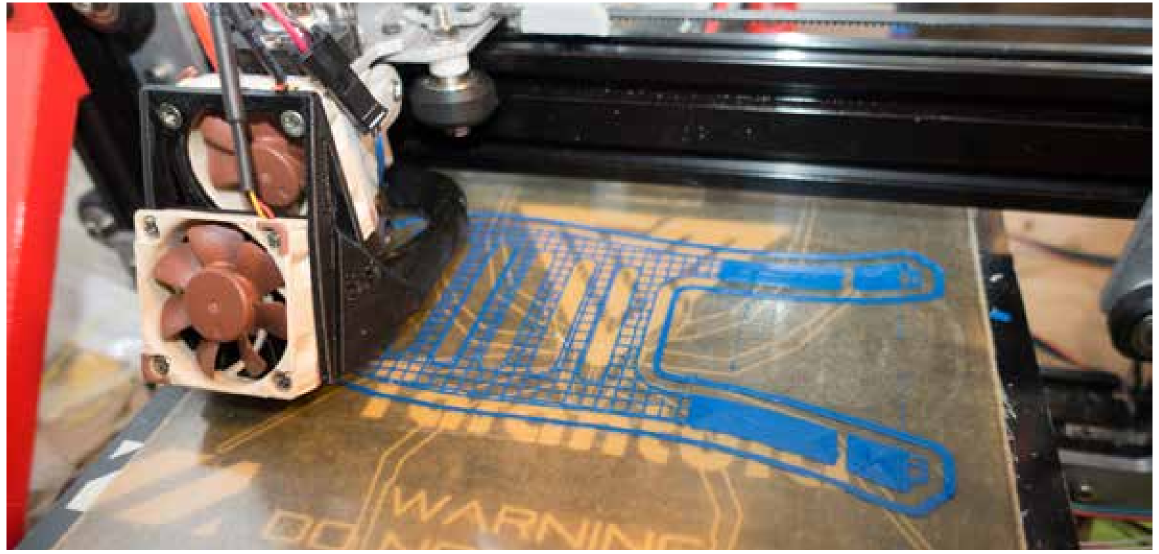
Clockwise from top: Early ridges model; dual density PLA with TPU insert; Rigid insert; Woven pattern; Meshmizer software; CURA slicer software; Slic3r software

PROTOTYPING PHASE 1

Because my summer vacation was spent in the windows of Solidworks, I was ready for a break, so I used this project as an opportunity to put Autodesk Fusion 360 through its paces. Leveraging CAD I generated several early concepts for a variable flexion sole component. The most notable theme was the use of creased edges to create a V-pleat, inspired by research in metamaterials and origami structures(Christensen, Kadic, Kraft, & Wegener, 2015)(Fuchi, Diaz, Rothwell, Ouedraogo, & Tang, 2012)(Overvelde et al., 2016) which in theory would allow for more rigidity from a thinner structure. I printed a variety of prototypes as tangible explorations of the computer generated concepts. *(Photos 3-6)*

I set out to explore the applications of fused deposition modeling (FDM) technology as a potential tool in creating consumables and components in footwear suitable for cycling. To ensure these processes were accessible to as many people as possible, I purchased a printer at the lower end of the price spectrum, which gave me constraints that I will discuss in the next section. I began testing various filament types I was able to procure from Canadian distributors. I tested the filaments for layer adhesion, flexibility, and strength to determine which ones would be suitable for this footwear design.

Photo 10 - Initial layer of FDM printer



FINDINGS ON 3D PRINTING

Developing a method of production enabled by conventional FDM 3D printers imposes some parameters to consider. Successful designs should be optimized for printing within the temperature and build volume range of a fairly regular printer. The printer should have a build volume of 200mm on at least one axis. Ideally it would have a heated build platform to allow for uncomplicated use of flexible materials and certain plastic filaments.

FDM printing can produce detailed models at good resolutions but the strength is considered less than that of molded parts. (Rogers, n.d.) Some materials were found to bond with the previous layer better than others, or be less prone to warping. From these findings I was able to determine the most suitable rigid materials for different parts of the shoe.

Flexible Filaments are challenging for conventional printers. The feeding path of the filament to the hot end is often indirect (bowden extruder), and I noticed the softer filaments tend to find any small gap as a chance to deviate from the feed path and causes it jam. The longer path also allows for printing issues that arise from the hysteresis of compressed filament. Direct drive extruders do well to eliminate these problems, but the added weight of the motor on the moving hot end would make most inexpensive printers wobble like crazy. Even my own printer with a bowden extruder needed upgraded brackets (printable or purchased from a third party) to steady the printer.

Photo 11

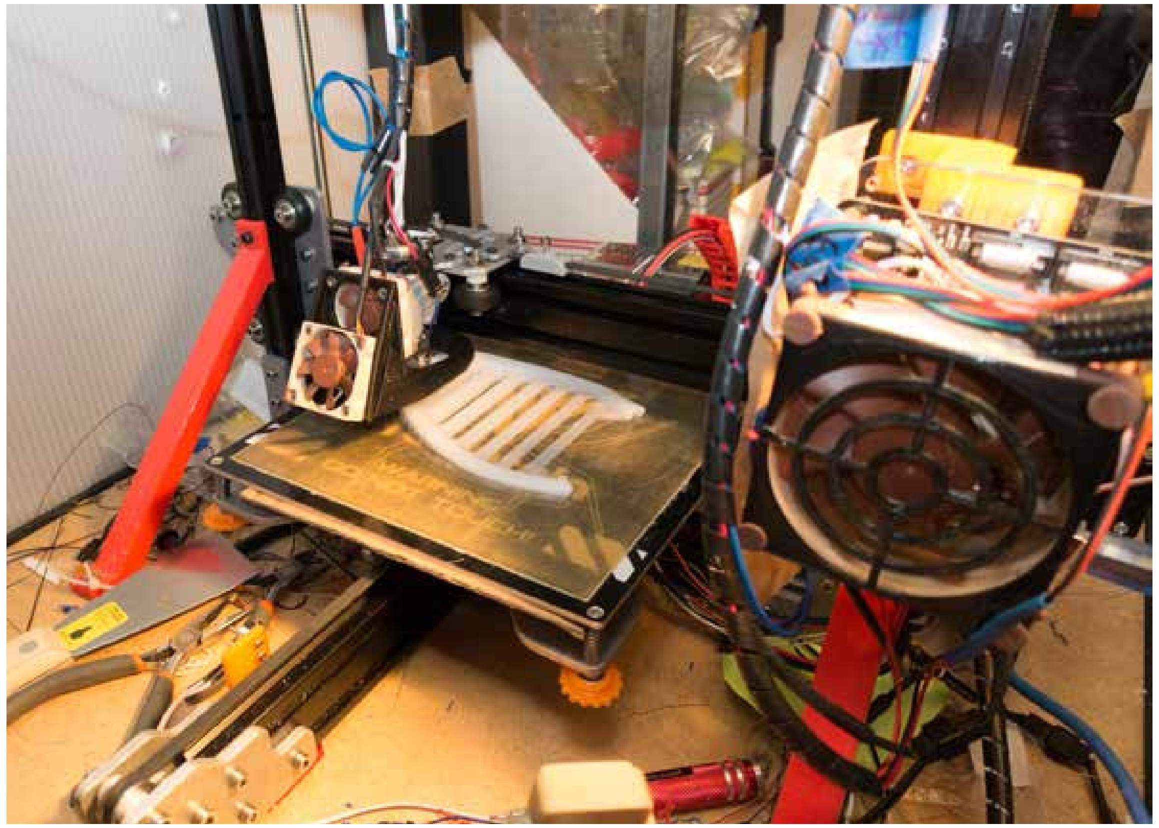


Photo 12

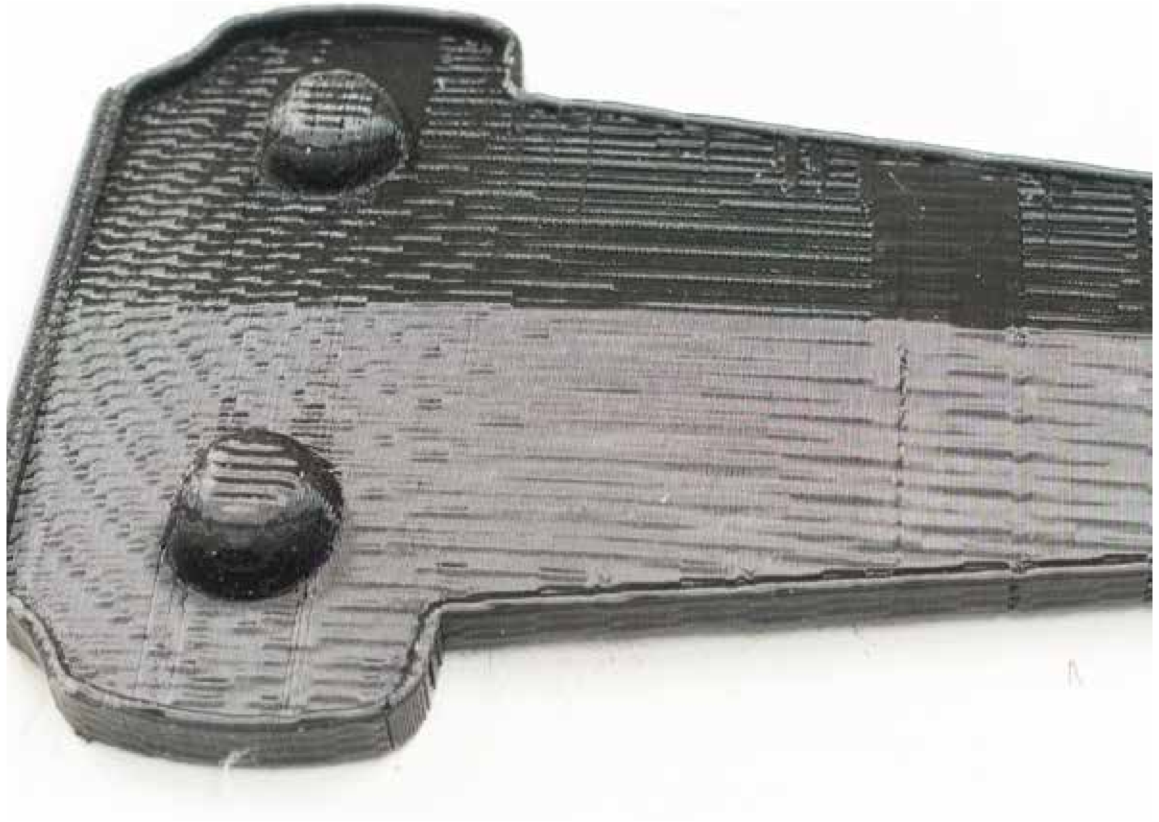


Photo 13-24

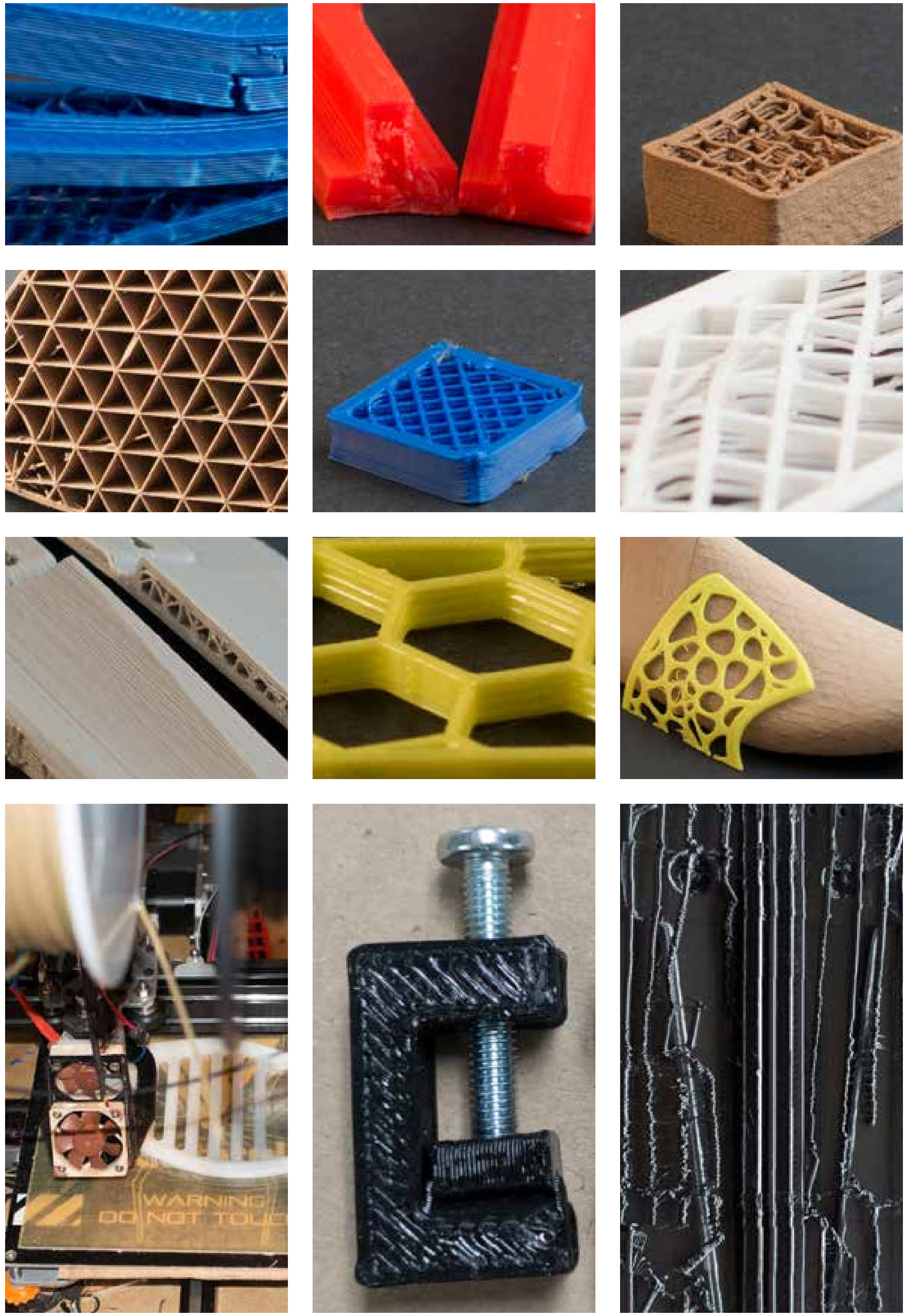


Photo 25-30

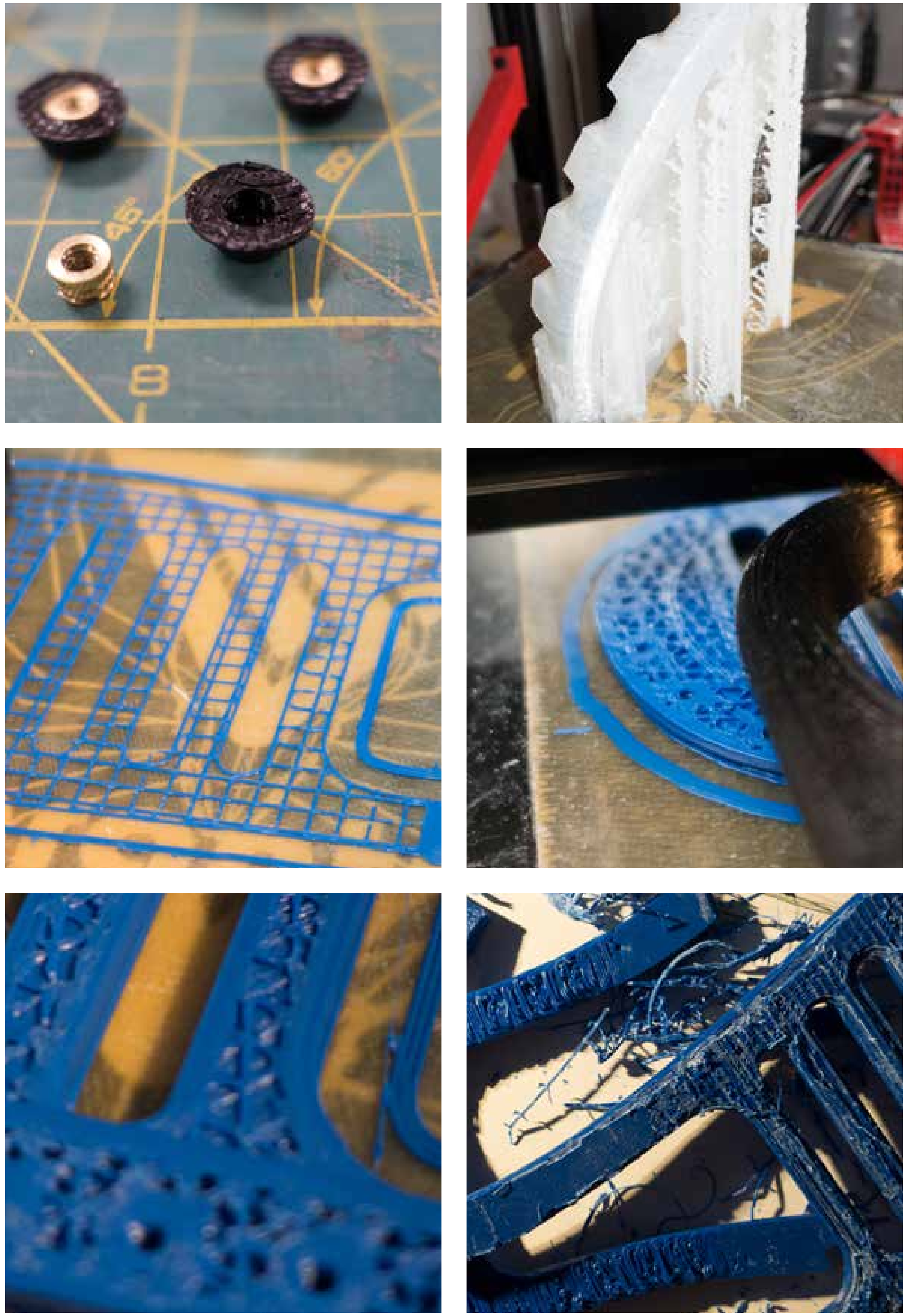


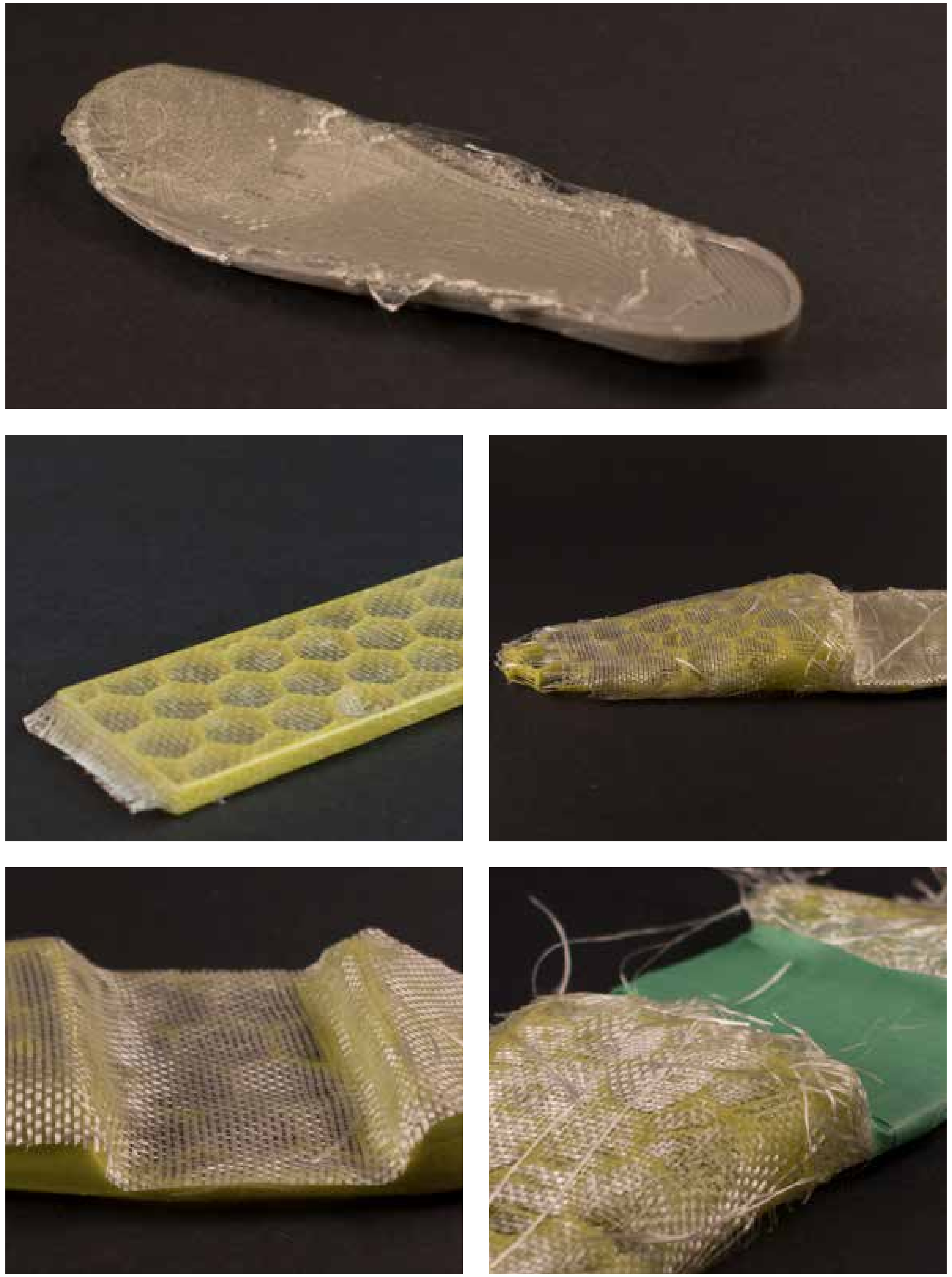
Photo 31

PROTOTYPING PHASE 2

It was determined that none of the materials tested, even the strongest in testing, could be relied on to deliver the rigidity required under pedalling forces. This led me down a path of inquiry that combined 3D printing with composite support structures.
The initial test was simple. I applied resin and e-glass (woven fibreglass) to an existing ABS print and allowed it to cure. The added strength was immediately evident. Because it was only a single layer it allowed for some flexing but it endured past the point where other ABS parts had failed. I then came across a blog called ‘boguerat.wordpress.com’ sharing his experiences 3D printing the internal structure of a surfboard and laying it up with fiberglass. It seemed like a perfect technique that could be applied to create structural composite shank for the cycling shoe. In practice however, this was not an easy process to scale. The same issues that plagued the surfboard were immediately apparent - delamination caused by poor adhesion between the printed core and the fiberglass. Any strength added by the fiberglass layers was lost as it failed to keep the frame in place. The thickness required also made it difficult to integrate into the shoes sole. In the physical models it became clear that between the midsole, shank, and outsole, there isn’t much space. Minimizing the thickness of the rigid layer to fit inside the sole would lead to the next iterations.

Photo 32

Photo 33-37



PROTOTYPING PHASE 3

Using a 3D printer to produce the tooling seemed like the next logical step. The most common FDM printers are based on an open source project called RepRap, whose creators dreamed of a printer that could print the parts required to replicate itself. This platform gave way to countless iterations and companies producing printers using their blueprint, with their own improvements and modifications. Because accessibility was a priority with this 3D printer exploration, I was eager to avoid going out and spending hundreds of dollars on tools to produce a rigid composite shank. If I could manage to create one using easily procured resources, than the file and instructions could be easily distributed to anyone with an internet connection. In this way the product could live outside of the brand.

The strength of fiber composites comes from the interacting forces of the fibres trapped together in resin. A directional fiber allows for controlled stiffness patterns, but for overall rigidity, an arrangement of many layers of fiber in different orientations is key. Layers of fiber bonded together with epoxy resin is the simplest way to create thin rigid structures. To maximize the strength to weight ratio, the minimum amount of resin required to saturate the fibers is ideal. This can be accomplished with pressure in a 2 sided mold, or more commonly a vacuum system. The best method for minimizing resin is called a resin infusion, where the dry fibers in a mold are bagged up and a vacuum is formed. The resin is then drawn into the bag and through the fibers until they are fully saturated.

Photo 38-40

My first attempt involved printing a mold with ports for the resin and air to flow modeled in. The first 8 hour print in PLA filament completed with a poor top layer. The infill created by the software that converts 3D models into printing code, or slicer, was too sparse, which allowed the surface to sag and cause air gaps.

A second attempt was made, this time rotating the print orientation to stand upright and printing at a fine enough resolution to seal the perimeter. It was with this mold I made my first attempt at a resin infusion. I printed some PLA inserts and seated heat-press threaded brass inserts inside them. After the first layers of fibre were in place, the insert is positioned in the mold and the remaining layers are placed on top. Using vinyl tubing attached by a 3D printed adapter by a 6.5HP shop-vac. The bag is prepared and sealed. Protruding from the bag are two hoses with clamps to seal the flow. A vacuum was pulled and then the clamp was released to allow resin to flow into the mold. Immediately the resin started to flow, but minutes in there was no visible wet-out of the fibres. After nearly 20 minutes under vacuum only a coin sized patch had appeared. The amount of resin that had been depleted from the pot seemed to be more than what had appeared. I began to suspect a leak in or around the flow ports that allowed resin into the mold body before it reached the fibres. So as to not completely waste the now partially saturated fibres, I opened the ziploc bag and poured the remaining resin over the fiber. Again, I applied a vacuum and pushed some resin around, and left it to cure. The result was poorly saturated with large dry patches and visible voids on exterior surface, as well as thick, overly saturated patches where resin had not been pressed from the fibres. The mold design that took a full day to print had failed.

Photo 41, 42

The voids created from the hollow mold body were all too tempting for resin to flow into, and made it difficult to achieve a good vacuum effect. It was back to the drawing board on the mold. Instead of seating the impression in a solid block as you would a traditional mold, I created the impression with a thin shell around it which would allow for solid printing, closer forming of the bag around the mold, and I also moved from a protruding post to seat the threaded nubs to a through hole in the mold where they could be fastened from beneath with a screw. This did double duty as it kept the threads sealed, held them in the proper position, and also created a channel for resin to flow, so that the threaded inserts would get adequate exposure to resin as it flowed though.

I moved from using a double sided tape and hose setup with a shop-vac to a venturi device, which created vacuum from an air compressor. I used a wet layup method instead of infusion because it seemed the weight savings were marginal on such small components. I 3D printed a bag valve that I downloaded from Thingiverse.com “Vacuum Frog by Prot0typ1cal” under the creative commons license, which allowed me to seal the bag with less hassle than the initial setup.

Photo 43, 44

This mold was used for a few iterations with laser cut fiberglass weave and AmpliTex, which were all too flexible. I eventually caved and bought a yard of carbon fiber woven fabric.

Because carbon fiber isn’t suited to laser cutting, the best approach is to allow the fiber to extend past the molds edges and cut and sand the final profile after it has cured.

Photo 45

The next attempt had a number of surface imperfections along the top, the most noticeable was directly beneath the vacuum valve. Some air bubbles were still apparent along the edges, and the fibers appeared to have been caught up on the edges at the tip and tail of the mold. I also tried using AmpliTex as an outer face fabric for aesthetic reasons, but it didn’t have the right hardness or resin saturation for an external face.

Photo 46

One further attempt was made, this time trimming the fibers slightly once they were layered in the mold with resin. The vacuum valve was placed on the bottom side beneath the two front holes. This was the most successful as resin was drawn away from the top layers and pulled towards the holes. The fiber layers were pulled downwards into the mold, not away. The surface finish was good and even. The combination of nylon mesh and quilt batting to disperse vacuum pressure and absorb excess resin worked well as an alternative to specialty breather cloth and peel ply.

Photo 47-51

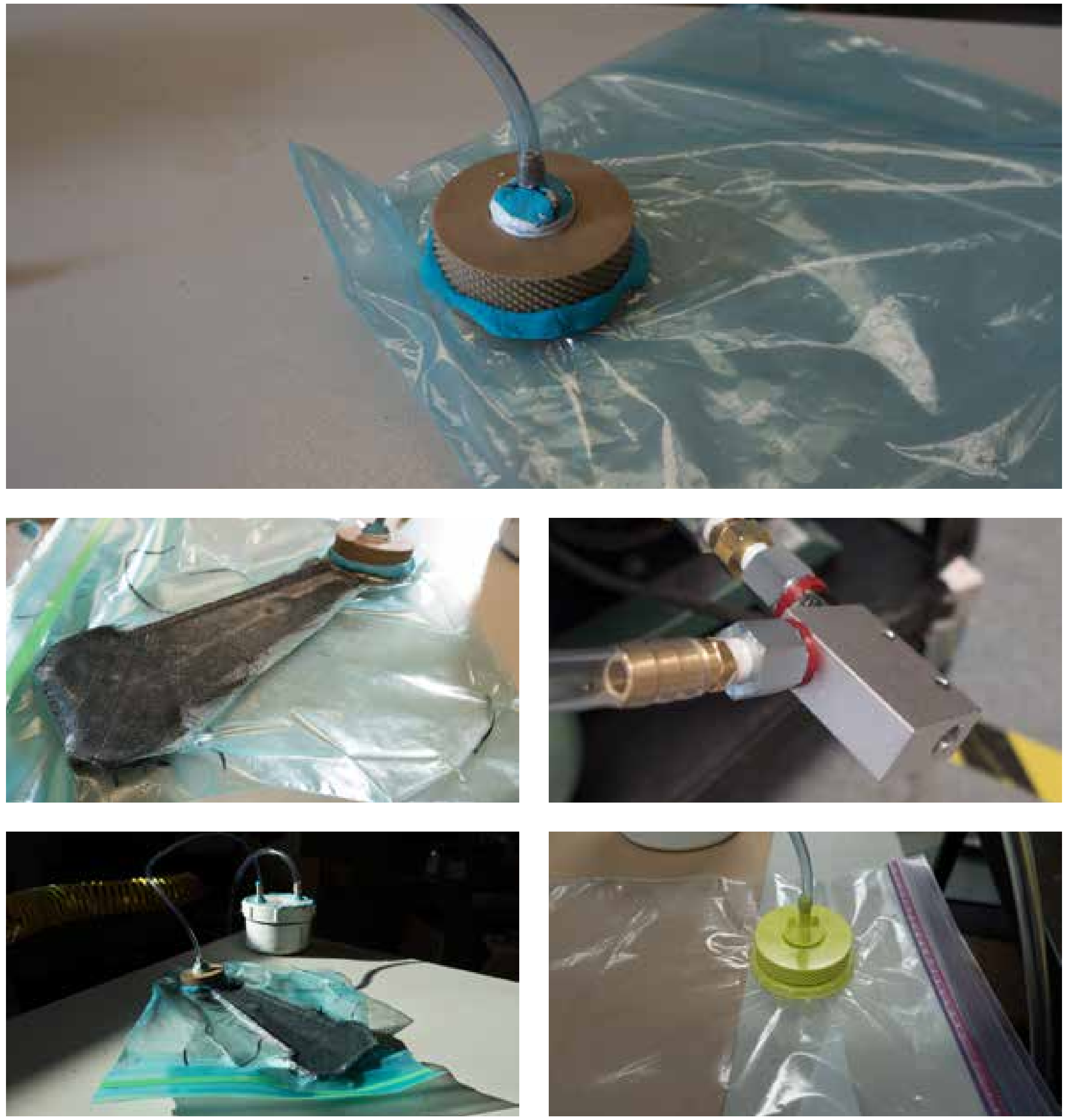


Photo 52-56

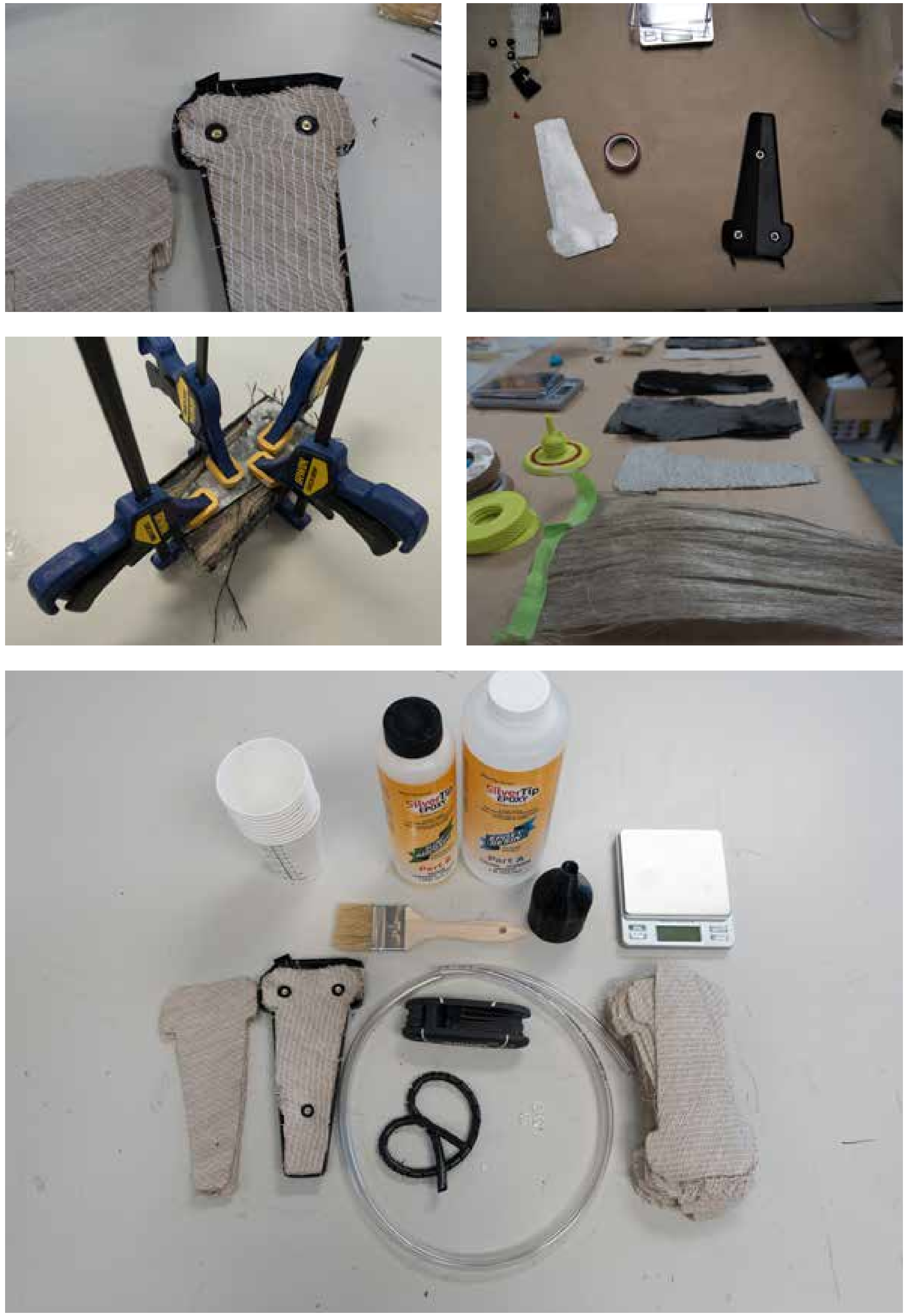


Photo 57-60

Photo 61-68

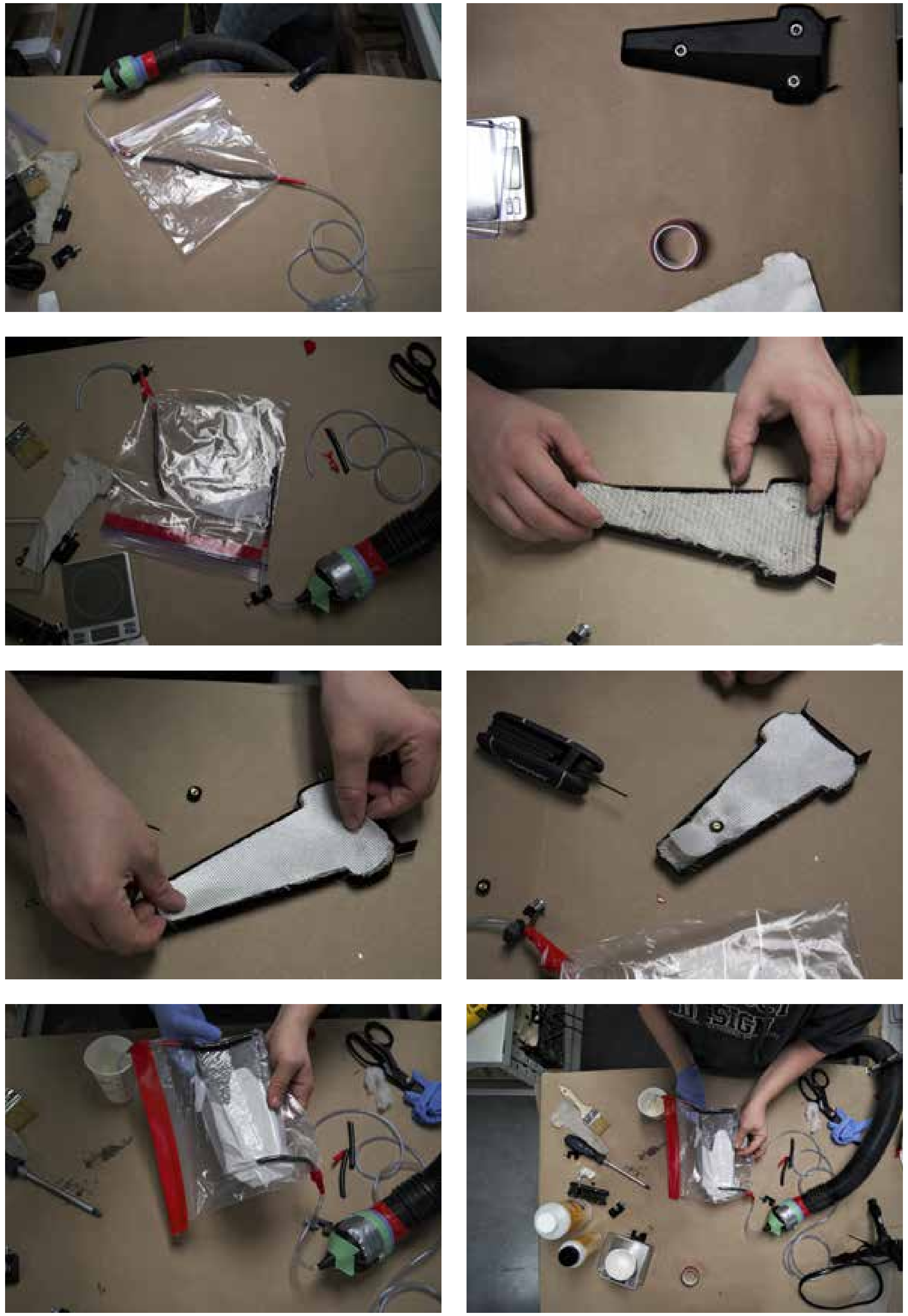


Photo 69

Photo 70

FIBER OPTIONS

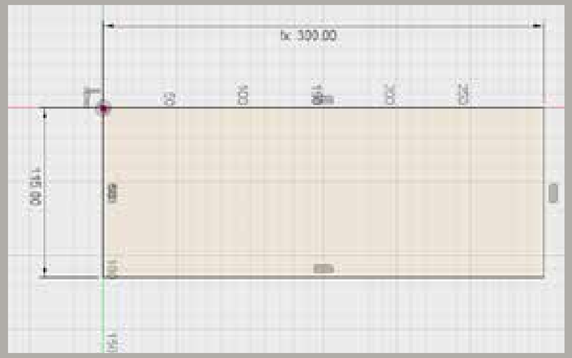
E-glass woven fabrics are often used in fiberglass construction and make a suitable choice for their price and performance. They were an ideal base for my inexpensive early experimentation and prototyping. Carbon fiber on the other hand is costly, but for good reason. The lightweight fibers allow for unparalleled stiffness, which is why most higher end cycling shoes, parts and bikes are defined by their carbon fiber content. This high degree of stiffness also makes for more direct energy transfer, which we've mentioned was great for pedal power, but this same property works two ways. Vibrations from the ground in walking and riding resonate more directly to the foot, which is why a softer shoe is sometimes considered the 'safe' shoe. (Jarboe & Quesada, 2003) In searching out more ecological alternatives to these fibers I came across a flax weave from the Swiss company bComp. Their AmpliTex fiber comes in a variety of weights and when combined with carbon fibres, adds some degree of dampening. (Assarar, Zouari, Sabhi, Ayad, & Berthelot, 2015) The flax fiber has a lower density than carbon, so it is an interesting option for adding volume to a composite in fewer layers.

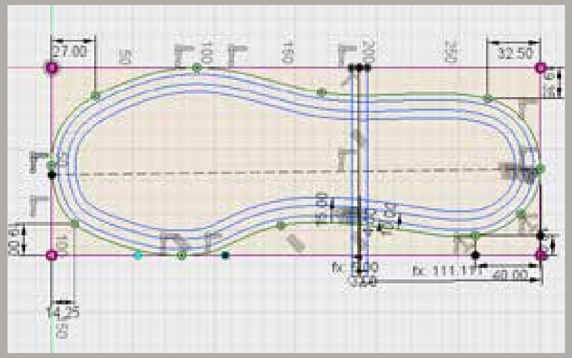
These fibers are available in woven or unidirectional form. Unidirectional fibers look like strands of hair, and in many applications allow for engineering precise control of properties. Stiffness can be aligned in a single direction, or dispersed by a scattered arrangement of layer directions. For a more dispersed and even composite biaxial or triaxial woven fabrics are used. They are made up of interwoven strands of fiber that give structure across two or more planes. (Suresh Kumar, Ambresha, Panbarasu, Kishore, & Ranganath, 2015) A typical functional carbon fiber composite usually contains several alternating layers of woven fibers, which creates rigidity in all directions. Because the cycling shoe needs lateral and medial stiffness, I will be experimenting with bi-axial woven fibres.

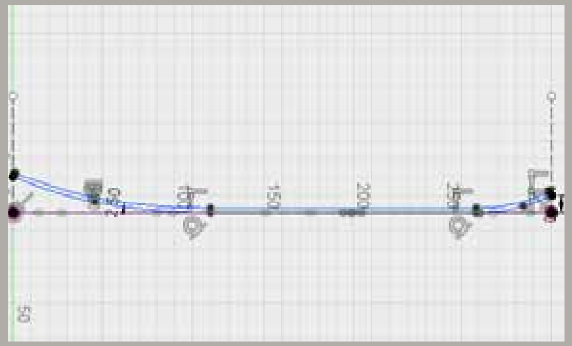
PARAMETRIC DESIGN

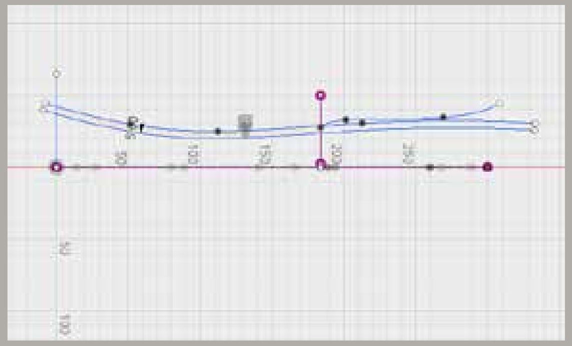
Parametric modeling is a style of 3D modeling within CAD software accommodate different foot sizes the model should be easily manipulated in most regards, especially length and width and the shape of the footprint. A number of iterations in model construction and order were explored to find a base sketch that could be reliably manipulated with minimal downstream failures. The shoe can be adjusted for length and width, and the curl of the toe and heel can also be tuned. This means a platform pedal user could tweak the model to lay flat to the ground like a skateboard shoe, or a more race-like profile for a race like the tour divide - all on a single platform.

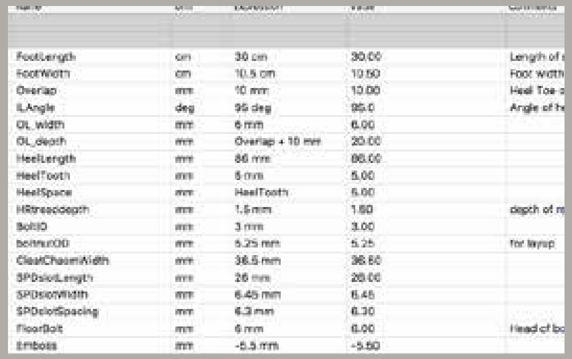
Photo 71-75











FootLength	cm	30 cm	30.00	Length of
FootWidth	cm	10.5 cm	10.50	Foot width
Overlap	mm	10 mm	10.00	Heel Toe
ILAngle	deg	95 deg	95.0	Angle of
OL_width	mm	6 mm	6.00	
OL_depth	mm	Overlap + 10 mm	20.00	
HeelLength	mm	86 mm	86.00	
HeelTooth	mm	5 mm	5.00	
HeelSpace	mm	HeelTooth	5.00	
HRtreaddepth	mm	1.5 mm	1.50	depth of
BoltID	mm	3 mm	3.00	
boltnutOD	mm	5.25 mm	5.25	for layup
CleatChasmWidth	mm	36.5 mm	36.50	
SPDslotLength	mm	26 mm	26.00	
SPDslotWidth	mm	6.45 mm	6.45	
SPDslotSpacing	mm	6.3 mm	6.30	
FloorBolt	mm	6 mm	6.00	Head of
Emboss	mm	-5.5 mm	-5.50	

Clockwise from top: Initial size sketch for length and width; Footprint shape and offset parameters; Bottom curve sketch; top curve sketch; parameter table

N+ PROPOSAL

MARKET OF N+1

The very different needs of each individual rider makes it difficult to describe the perfect shoe. The most suitable a shoe will be able to respond to the needs and preferences of the user. Because of that idea I will focus on the articulation point of the toe independent of the rigid sole. The platform will be easily adapted to different configurations and customizable with a conventional 3D printer.

Photo 76

Figure 13

The rigid shank of the platform covers the underfoot area up to the metatarsal joint. There's a solid interface between the foot and pedals, while the toe is free to move with the natural walking motion of the foot. It's a comfortable connection to the bike that moves with the rider while still delivering maximum power to the pedals.

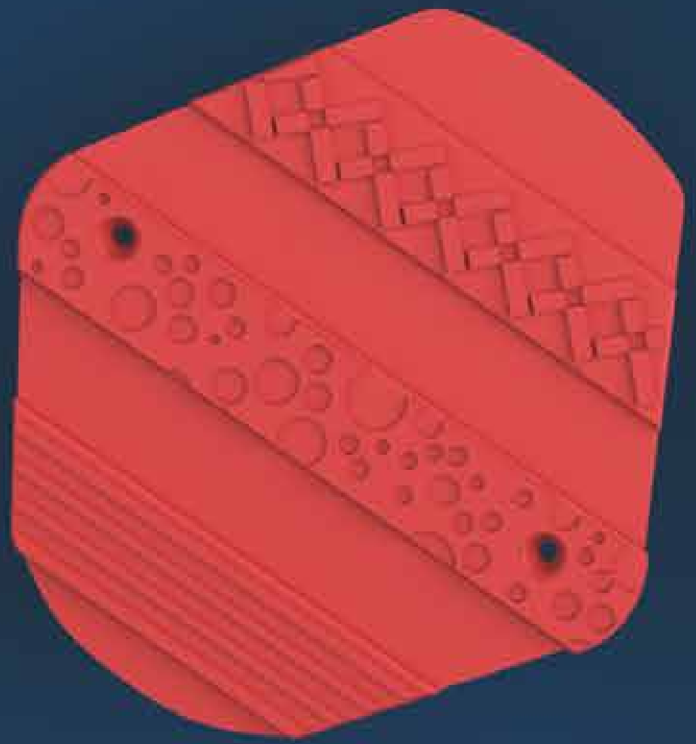
Metatarsal articulation

Additive enabled platform

The additive enabled platform makes the N+ shoe accessible to anyone. The rigid core of the shoe is made from carbon or other fiber reinforced polymer in a 3D printed mold, and vacuum bagged using 3D printable tools. The customizable frame and tread are entirely 3D printed by the end user or a printing service, and the textile uppers are stitched onto the frame by hand. Through 3D printing iterating and adapting models to users unique needs is made possible, which means the product exists and evolves entirely on the customer's terms.

Serviceable

The zen-like connection forged by greasy hands and spinning wrenches doesn’t have to stop at the bike. The N+ platform is fully serviceable, with interchangeable printed frame parts, swappable consumables like the tread and pedal interface. All of these parts are made from thermoplastics that can be recycled into material for new parts. The textile uppers can be repaired, replaced, or customized to suit riders’ needs, so adding some insulation, or a reinforcement to that spot you’re constantly blowing out are one of many options.



Open platform

The N+ has an anti-plan for future growth. The totally open platform is open to interpretation, driven by the community. The textile patterns will be available for anyone that wants to make an upper, which means your next shoe could be a perfect match to your frame bags. You can print a tread pattern that's perfectly suited to your local loam, or tweak an existing favorite for the trip you're planning. And it's open for business too, so entrepreneurs can develop and produce on the platform so people without printers or CAD skills can be involved, bag makers can add a SKU to their catalogue, even tire makers can develop a new size for their range - *N+* treads.

OPEN PLATFORM

OTHERS INVITED TO DEVELOP FOR PLATFORM

OPEN INNOVATION

CAPTIVE MARKET

COMMUNITY SHARING

LONGEVITY, ADAPTIBILITY, SELF-DETERMINATION

BUYS ONE PAIR

LOCALIZED PRODUCTION

REPLACE NECESSARY PARTS

CUSTOMIZED TO NEEDS

Figure 14

DECLARATION

Driven by the belief that one size doesn’t fit all.

Serviceable shoes on an **open** platform, created and evolved through self-determined community contribution.

Anyone who engages in this community;

- Should have the freedom to download, create, copy, distribute, study, share, change and improve their footware for any purpose, without paying licensing fees.
- Should be able to create their shoes through a variety of methods
- Should work with available materials
- Is able to adapt it to their unique needs

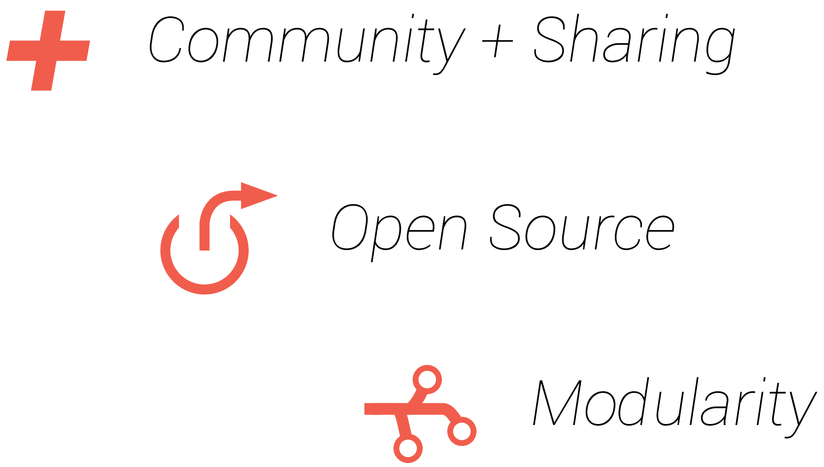


Figure 15

WHAT’S NEXT?

Redefining consumer’s relationship to a product, N+ gives the user their perfect shoe by putting them in control. *N+* is an honest reflection of the traditional development process, where the true evolution happens after it’s in peoples hands. To adapt a famous quote from Lao Tzu, this design process has no fixed plans and is not intent on arriving. Without the constraints of traditional manufacturing the development can continue after the initial launch of the project, similar to software development.

I ask that you sit for a moment and consider the ambiguity of an underdefined design. Is it the journey or the destination we set out to discover? In the coming weeks I will begin the process of distributing this project across the Internet, engaging other web users, convincing them to develop a shoe to call their own - the shoe they need. The punctuation of this project will be the beginning of something new that anyone can be a part of.

Embrace change, because it’s one of the few things to come that you can count on.

TESTING

METHODS OF TESTING

Participants

Male volunteers with foot size corresponding to the test and prototype shoes were recruited on campus at Kwantlen Polytechnic University.

Test Order

Before the participant was present, letter A or B was randomly assigned to the walk and bike shoes before the test. The participant was asked to choose a letter and that determined the test order. The chosen activity was performed in the test shoe then the prototype shoe. The second activity was performed in the prototype shoe first, followed by the test shoe to minimize shoe changes.
Participants completed a survey ranking the prototype shoe against its counterpart for the intended activity, as well as comfort relative to each shoe tested.

Walking Test Shoe
Salomon XA3D Ultra 2, size 44 EU / 10 US

Biking Test Shoe
Pearl Izumi X-Alp Seek VII, size 44 EU / 10US

Prototype Shoe
TPU outsole, Carbon Fiber shank, size 27.5cm

Bike Flexion Assessment

To determine the range of flexion on pedals participants were seated on a mountain bike in a stationary trainer with platform pedals. Wearing the bike test shoe or the prototype shoe they were asked to pedal for 10 seconds at a moderate pace from a seated position, the bike was then shifted to a more difficult gear and they stopped pedaling until the wheel came to a rest. They were then asked to pedal with moderate exertion from a standing position for 10 seconds. The test was then repeated in the second shoe. A Sony RX-100 camera on a tripod recorded the pedaling.

Photo 77-79

Using Tracker, a free video analysis tool the angle of flexion on the pedals was determined. Using a frame capture from the upstroke of the pedal (1-6 o'clock position) a digital protractor marked the unweighted angle of the shoe from 3 distinct points on the shoe; the end of the toe, where the outsole met the rearmost face of the pedal, and at the end of the heel. These same distinct points were marked again when the pedal was under force (7-11 o'clock position) in a frame capture showing the highest degree of flexion. The highest flexion was observed when the rider was in a standing position.

The difference in those two measurements gave the degree of flexion, or how many degrees the shoe deviates from the norm under pedaling load.

Degrees of flexion = angle under pedalling load - static angle

Walk Flexion Assessment

A one meter carpeted test ramp was secured up two stairs with a handrail at an a approximate incline of 22°. Participants were asked to take a step onto the ramp leading with the left foot which faced the camera, and step through as normally as possible to the step above the ramp. They then came back to the starting point and repeated the procedure again. A camera at foot level recorded the step. The Tracker software was used to analyze the video and the angle from the more pronounced of the two steps to the incline ramp was measured. The measured angle was taken at the video frame just before the shoe's outsole stopped flexing and the toe-off portion of the gait begins. (Vaughan, Davis, & O'Connor, 1999) The procedure was completed for both the test and prototype shoe.

Statistical Analysis

The data shown is derived from the mean of all participants results. The results were evaluated in separate paired, two-tailed T-TEST statistical analysis to try to determine statistical significance ($p<0.05$).

Test 1 looks at degrees of flexion cycling, comparing the walking test shoe to the prototype shoe.

Test 2 looks at degrees of flexion walking, comparing the cycling test shoe to the prototype shoe.

The survey results are only used to gauge the test participants perspective about the shoes performance and will not be subject to statistical analysis.

RESULTS AND DISCUSSION

Participants

A total of 6 participants completed the entire test protocol. The randomized test order led to 4 users beginning with the bike test, and 2 started with the walking test.

The number of participants was fewer than ideal, as at least 10 would have lent credibility to the results and may have smoothed the values.

Walk Flexion

The flexion of the walking shoe ranged from 32.5° to 60.7°. The very soft sole of the shoe allowed for a full range of motion, so variation in this shoe was more related to each individual's stride. The prototype shoe allowed for a flexion of 33.7° to 62.4°. On average the prototype shoe achieved 2.4° less flexion than the walking shoe.

While the tested design failed to achieve the same degree of flexion, it still provided enough for most of the stride. Some participants may have unintentionally walked in a softer than normal stride, knowing that the shoe was a prototype. A more accurate test would involve a longer incline ramp and more steps, which would give the test subject time to normalize their walking. Because there was only a single inclined step participants seemed tense, or overly focused on that single step.

Bike Flexion

The negative flexion of the shoe over the pedal indicates a more flexible sole which is less ideal for extended pedalling. The Pearl Izumi X-Alp Seek VII test shoe flexed between -3.8° and 0.4°, with a mean flexion of 1.78°. The prototype shoe showed considerably more flexion across a larger range, between 7.7° and -1.6°, with a mean flexion of 4.6°. On average the prototype flexed 2.8° more than the test cycling shoe. Would those few degrees make a significant impact?

The bike test was challenging to measure because of the frame rate of the captured video (approx. 29 frames/second) and the blurring of the still image.

While care was taken to capture a clear frame at the highest flexion point, getting an accurate measure across the outsole and pedal had margin for error. Foot placement also varied between participants. Positioning the user's feet, larger platform pedals, and or even a static weighted vs unweighted comparison of the shoe flexing over a fulcrum might achieve clearer measurements. Indicator points could also be attached to the shoe and bike apparatus for analysis in the Tracker software.

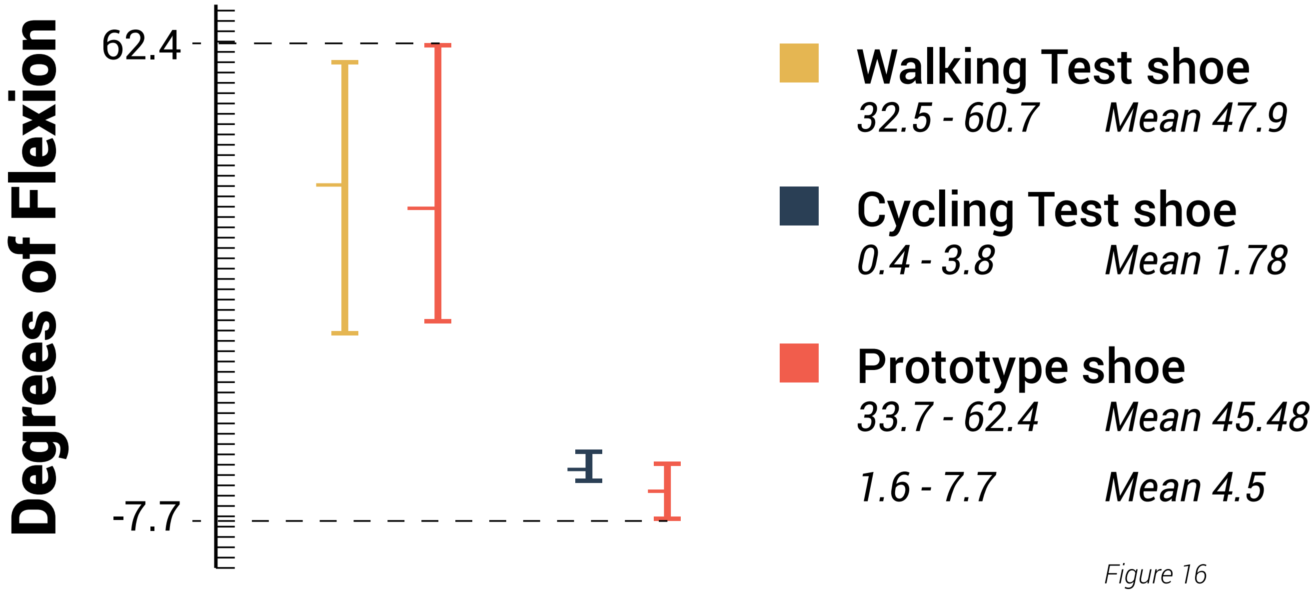


Figure 16

Photo 80

TESTING CONCLUSION

The prototype shoe performed well against the walking shoe in regards to toe articulation. Although the range of motion was slightly less than the test shoe, it is assumed to be better than the bike shoe would perform in the walking test. This anecdotal conclusion highlights a fault of the study, which is the lack of comparative data for the bike shoe in the walking test, and vice versa. Further testing that includes more participants, wearing all three of the shoes examined is warranted. More data about the participants, such as weight, dominant foot, and even a baseline measure of foot flexion without shoes on the incline would give a better understanding of the results.

Relative to the bike shoe the prototype failed to deliver the same rigidity. Flexion corresponding to areas of the shoe where no rigid shank was present, forward of the metatarsal phalangeal joint and in the heel, was evident. This might not be noticeable for most riding conditions, which are from the seated position at moderate exertion.

Similar faults to the walking test regarding comparative data to the walking shoe leave room for speculation. Anecdotally the rigid core would still provide more power transfer to the pedals, with less energy being absorbed in the flexing of the entire sole. The prototype design might still benefit extended pedalling, as some forgiveness in the sole can reduce plantar stress. (Jarboe & Quesada, 2003) This forgiveness may limit the amount of energy coming from the ground being directly absorbed by the foot when compared to a stiffer cycling shoe. Nothing suggests that further participants would improve the prototype shoe performance relative to the rigidity of the bike test shoe.

FIGURES AND PHOTOS

Figures

Photos

GLOSSARY

Bikepacking - “cyclists travel over a variety of surfaces and topography on a single route, with a single bicycle. Focusing on freedom of travel and efficiency over varied surfaces, cyclists often adopt an ultralight camping approach and carry their own minimal gear” Wikipedia

Hike-a-bike - Unrideable sections of a trail that require the rider to walk while pushing the bike.

Plus-Sized tires - Oversized tires that run on low air pressure

Pedal Types
Platform - A normal pedal with no retention mechanism, holding the foot by friction.
Clipless - Any pedal that retains the foot through a pedal/shoe interface. The most common standard for mountain biking is Shimano SPD.

Fused Deposition Modelling or FDM - A 3D printing method which deposits sequential layers of melted plastic filament to build up a model.

Hot end - The heated component of a 3D printer where the plastic is melted and the plastic is extruded from the nozzle.

Direct drive - A 3D printer extruder setup where the extruder pushes the filament directly into the hot end. The extruder motor and mechanism travel with the hot end.

Bowden extruder - A 3D printer extruder setup where the filament is pushed through a long PTFE tube before reaching the hot end. The extruder motor and mechanism are mounted in a stationary position away from the hot end.

Parametric Modelling - A style of modelling where features are derived from defined sketches, and changes are recorded in a timeline. Updates to the early driving sketches are reflected downstream in the models history.

CAD - Computer Aided Design, most commonly referring to 3D modelling and 2D drafting.

GLOSSARY

Autodesk Fusion360 - A 3D CAD software from Adobe with capabilites in solid modeling, surface modeling, CAM, simulation, animation and rendering.

Breather Cloth - A permeable cloth used in vacuum bagging. Breather cloth allows for the vacuum pressure to disperse across the surface of the object, while absorbing excess resin.

Peel-ply - A fine mesh disposable used in vacuum bagging. Used to create an even surface finish and allows the breather cloth to be peeled off with ease.

Shank - The rigid component of a shoe, limits flexibility of the sole.
Uppers - The textile portion of footwear, which attaches to the sole of the shoe.

Outsole - The component of the shoe that makes contact between the foot and ground. Commonly made of rubber or leather.
Midsole - The shock absorbing component in some footwear between the foot and outsole.

Metamaterials - A type of synthetic composite material with a complex nanostructure, constructed so as to have unusual properties that do not occur naturally. A particular type consists of materials that have a negative refractive index. There has been a considerable amount of research into using these as ‘invisibility cloaks’ for microwaves and possibly visible radiation.(Oxford Reference)

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PREVIOUS DOCUMENTATION

- *FALL RESEARCH PRESENTATION*
- *CONCEPT PRESENTATION*
- *PROPOSAL PRESENTATION*

Adaptable Footwear

Variable Stiffness Outsoles

By Marc Wilkinson
follow this @milkywilky

The research explored possible applications for variable stiffness footwear, where users needs vary througout the activity. Multiple cycling disciplines were identified where users need stiff, supportive outsoles for riding hours in the saddle, but would benefit from a flexible, walkable outsole at other times.

Can we create an adaptable shoe that performs hiking and biking?

Ankle & Foot Movement

Dorsiflexion
Toes Bending Upwards
Climbing, Walking, Scrambling, Pushing

Normal Position
Toes Inline with Heel
Stable, Rugged Terrain, All-day Pedaling

Plantarflexion
Toes Pointing Down
Running, Jumping Technical Terrain

Outsole Stiffness

Shoe Attributes

Hiking

Aggressive lugged outsole for grip in mud and loose conditions. Supportive ankle cuff with high lacing. Good flex for walkability, but firm enough to support challenging walks and heavy loads.

Biking

Smooth, flat outsole for good pedal contact. Shallow grooves to interface with pedal pins or a mounting point for clip-ins. Reinforced rigid base to prevent hot-spots from pedaling.

Three Types of Cyclists

Whose Journey Involves Transit by Foot

Tourist

Roads, Paths, Parkways

Riding with loaded pannier bags, often covering over 60 km/day. Walking in shops and taking in scenery along the way.

Wanderer

Backroads, Valleys, Parks

Rolling along the hillside seeking the thrill carrying mainly essentials. Stopping for conversations, swimholes or a smoke.

Bikepacker

Backcountry, Trails, Ranges

In the backcountry with bike mounted bags. Pushing the bike up unrideable sections of hike-a-bike.

Next Steps

Avenues for Further Exploration

Mechanisms

Biomimicry

Finding inspiration from natural structures that resist bending.

Origami Folding

Using folds and creases to achieve stiff structures that can flatten and bend.

Metamaterials

Creating materials with complex nanostructures that can exhibit unusual properties.

Materials

Tuneable Composites

Nanoporous-carbon-based hybrids which can deform from electric bias generated shear.

Electroactive Polymer

Electrodes sandwiched in plastics that move like an artificial muscle under electric load conditions.

MR Fluids

Fluid that contains ferrous particles, which increase in viscosity within a magnetic field.

Bikepacking.

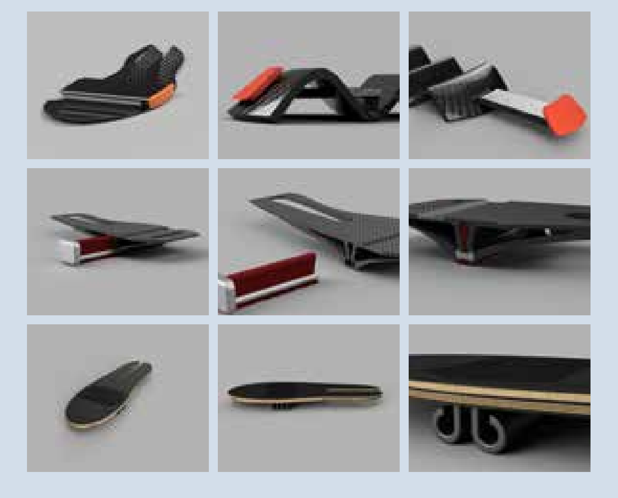
Soles.

Forms.

Style.

Form.

Insert.

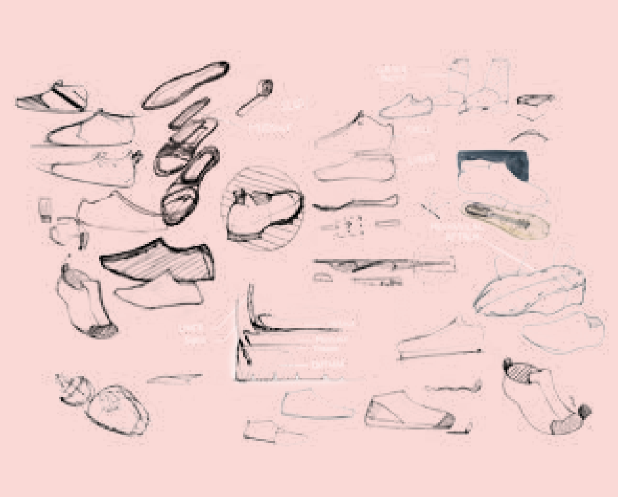


Extras.

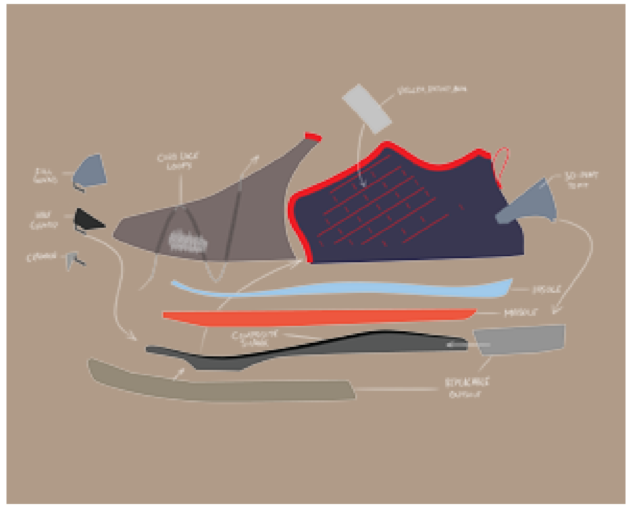
Moods.

Fastners.

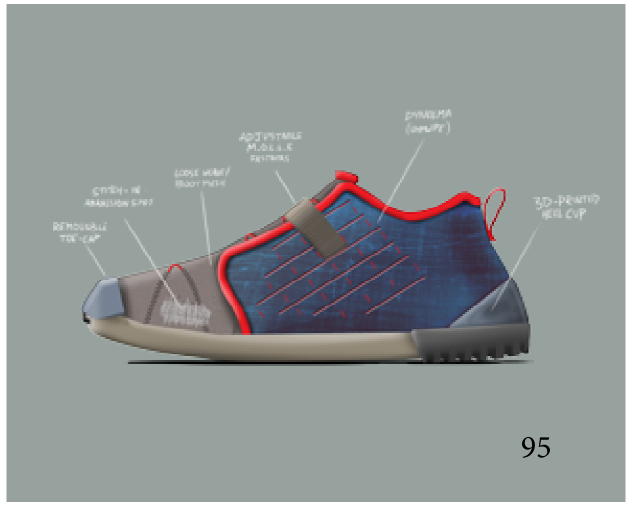
System.



Exploded.

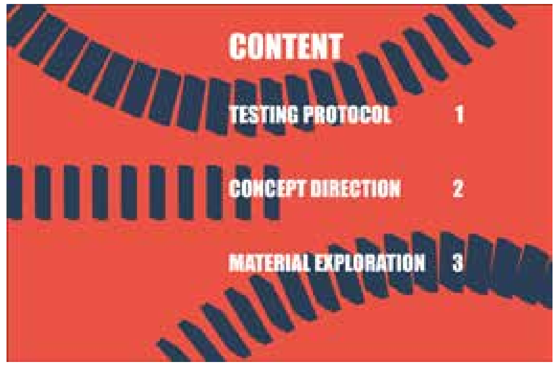


Concept.



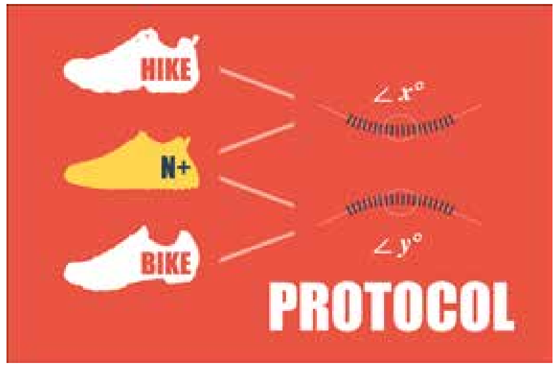
HIKE BIKE
SHOE

N+



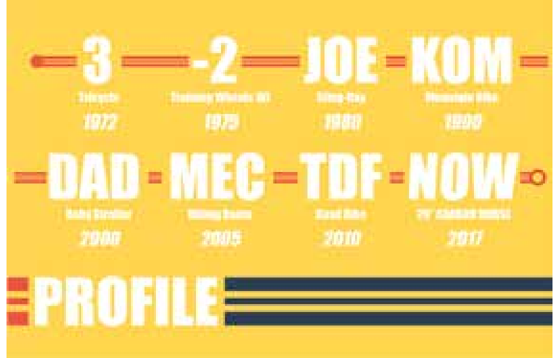
CONTENT
TESTING PROTOCOL 1
CONCEPT DIRECTION 2
MATERIAL EXPLORATION 3

OBJECTIVE



PROTOCOL

TEST

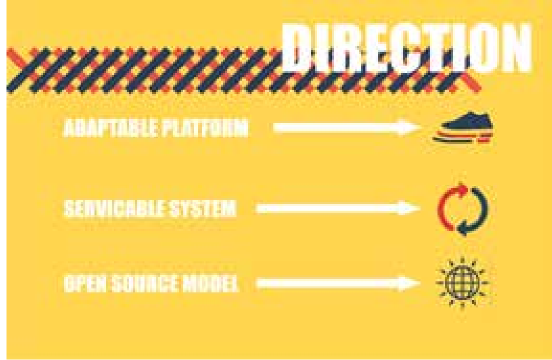


3 — -2 — JOE — KOM
Tricycle 1972 · Training Wheels Off 1979 · Sting-Ray 1980 · Mountain Bike 1990
DAD — MEC — TDF — NOW
Baby Stroller 2000 · Hiking Boots 2005 · Road Bike 2010 · 2017

PROFILE

CURRENT

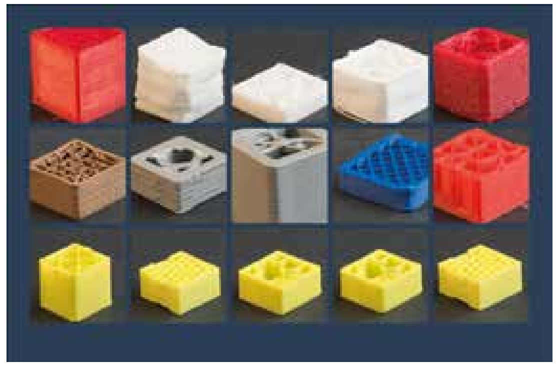
CHOOSE ONE, OR DON'T ←
MOST FOOTWEAR ←
THE RIGHT SHOE GETS DISCONTINUED ←

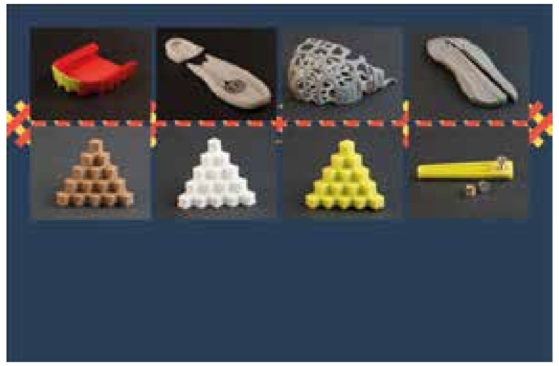


DIRECTION

ADAPTABLE PLATFORM →
SERVICABLE SYSTEM →
OPEN SOURCE MODEL →

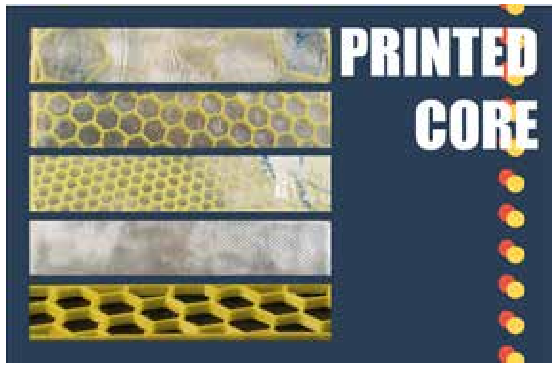
3D PRINTING
INFILLS





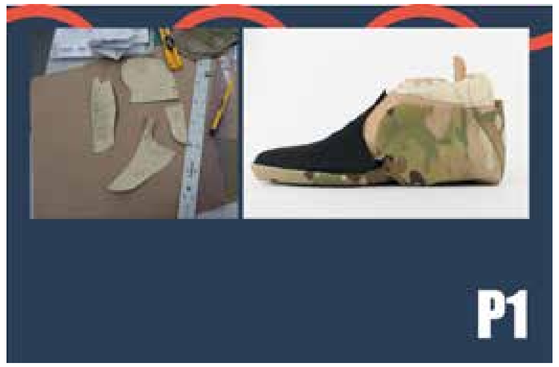
BREAK TEST

REINFORCING
THE IDEA

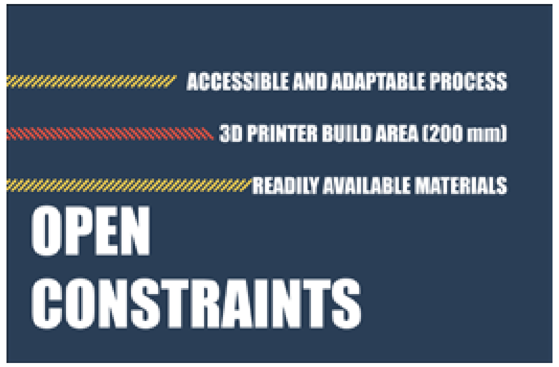


PRINTED
CORE

STICK TO
THE CORE
PRINCIPLES



P1

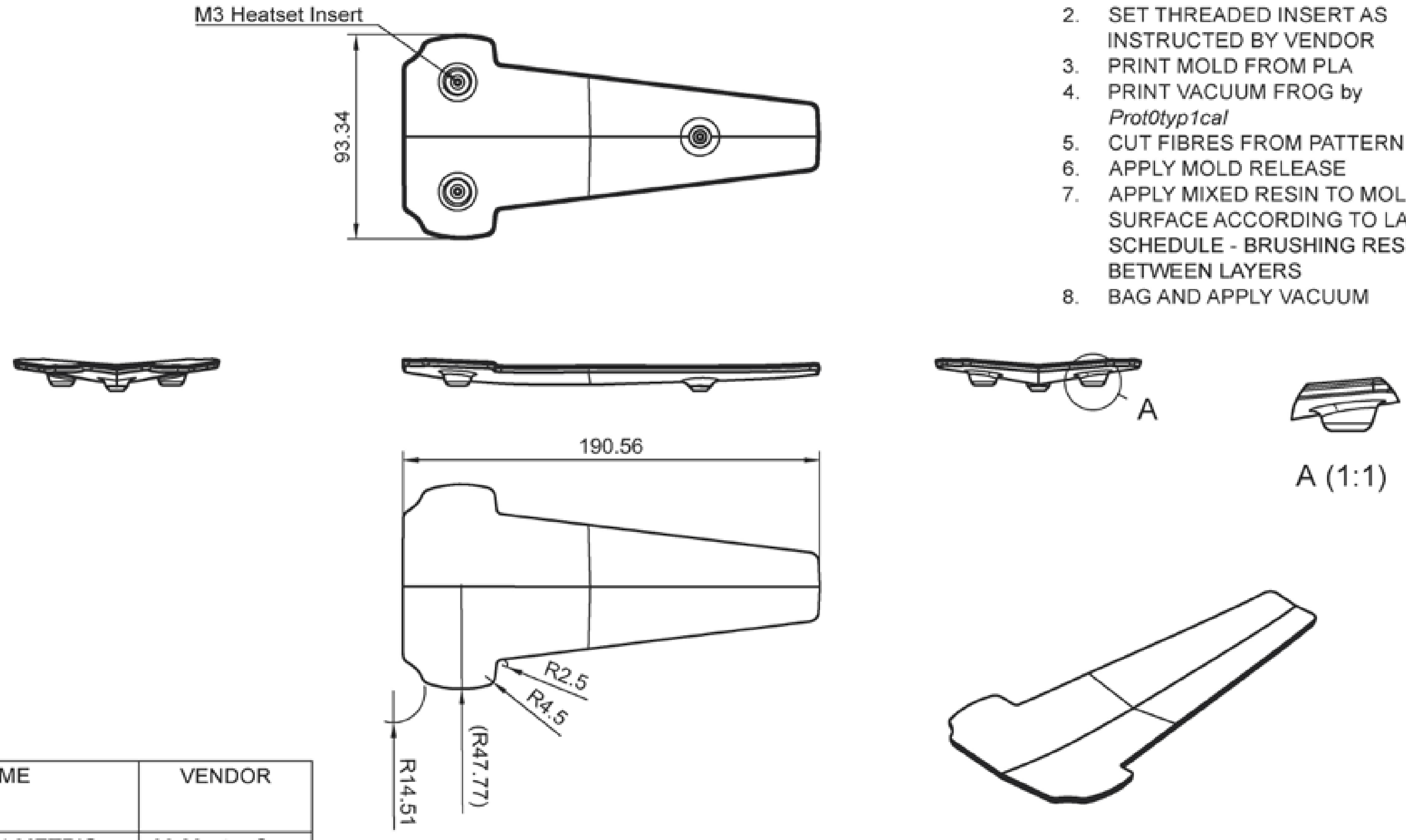


ACCESSIBLE AND ADAPTABLE PROCESS
3D PRINTER BUILD AREA (200 mm)
READILY AVAILABLE MATERIALS

OPEN
CONSTRAINTS

P2

P3



1. PRINT SIDE & MIDDLE INSERTS FROM PLA
2. SET THREADED INSERT AS INSTRUCTED BY VENDOR
3. PRINT MOLD FROM PLA
4. PRINT VACUUM FROG by *Prot0typ1cal*
5. CUT FIBRES FROM PATTERN
6. APPLY MOLD RELEASE
7. APPLY MIXED RESIN TO MOLD SURFACE ACCORDING TO LAY UP SCHEDULE - BRUSHING RESIN BETWEEN LAYERS
8. BAG AND APPLY VACUUM

QTY.	NAME	VENDOR
3	94180A331 METRIC BRASS HEAT-SET INSERT FOR PLASTICS	McMaster Carr
3	90° CARBON WEAVE	Industial Plastics & Paints
3	45° CARBON WEAVE	I.P.P
1	AMPLITEX BIAXIAL	BComp
2	SIDE INSERT	Printed .STL
1	MIDDLE INSERT	Printed .STL

LAY-UP SCHEDULE

1. LAY 90° CARBON WEAVE
2. 45° CARBON WEAVE
3. 90° CARBON WEAVE
4. THREADED INSERTS
5. AMPLITEX FLAX BIAXIAL
6. 45° CARBON WEAVE
7. 90° CARBON WEAVE
8. 45° CARBON WEAVE

Dept.	Technical reference	Created by	Approved by
		Marc Wilkinson 2017-03-21	

Document type

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