Running Footwear In-Situ Exploration For A Carbon Neutral Tomorrow

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Introduction

The idea of carbon neutrality grew out of an older concept called ecological footprint, which was invented in the early 1990s by William Rees and Mathis Wackernagel at the University of British Columbia (Selin, 2020). Carbon neutrality can be defined as achieving net zero carbon dioxide emissions into the atmosphere by cutting emissions to the very limit and compensating for what can't be eliminated (Anzilotti, 2018). For a long time following the introduction of the idea, reducing carbon emissions remained just a vague concept. However, it is now a widely adopted goal in efforts to combat climate change.

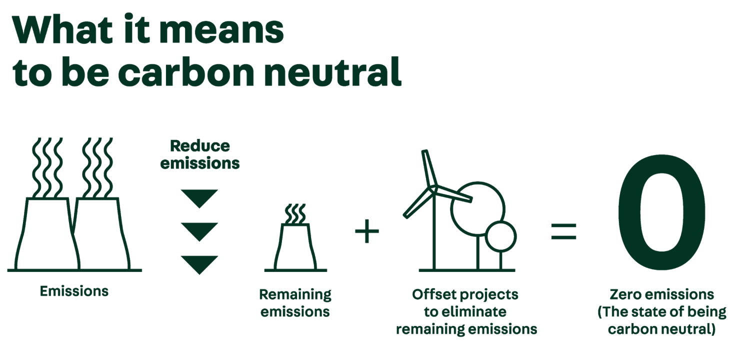


Figure 1. Diagram explaining carbon neutrality (Climate Active, n.d.)

Over this past year, multiple countries like Canada, China, and most recently, Japan have joined the commitment to go net zero with their carbon emissions (Denyer, 2020; Frangoul, 2020; Subramaniam, 2019). Major companies such as Apple, BP, and Delta Airlines have also declared to go carbon neutral, but why now (Calma, 2020; Hordari, 2020; Thorbecke, 2020)? The world's leading scientists have made it a point that to prevent the worst effects of climate change we need to stop adding carbon to the atmosphere (Rott, 2019). Now after a summer of numerous wildfires and devastating hurricanes, we may have reached the tipping point for society's realization of the impact we have on our environment. This has put an increasing amount of pressure on major business and global legislation to substantially counteract the carbon footprint of products, locality, or means of production.

Figure 2. Firefighters dealing with the west coast wildfires in California (CNN, 2020)

Now this movement has carried over to consumers, where they have a heightened awareness about the impact of product production on the environment. Now more than ever, companies are having to change their ways and think about new alternatives for a cleaner future. Future products will begin to feature recycled, low carbon materials, and will be designed as energy efficiently as possible. As countries continue to focus on carbon neutrality, more and more bio-based solutions will arise.

The footwear industry is well aware of the global push for carbon neutrality. Although, efforts are still lacking within the industry as it is still responsible for over 700 million metric tons of carbon emissions annually (Danigelis, 2020). Companies like Nike, Keen, Allbirds, and Adidas are some of the companies within the industry that have either pledged to go carbon neutral or embarked on projects addressing their own carbon emissions (BSR, 2007; Danigelis, 2020). However, there is still more work to be done. According to a Grand View Research report, the sustainable footwear market is estimated to reach $11.8 billion USD by 2027 – growing at a CAGR of 5.8% from 2020 to 2027 (James, 2020). *As carbon neutrality and environmental responsibility begin to drive the future of our world, this capstone will utilize in-situ exploration and localized natural sourcing to create sustainable, bio-based footwear solutions for the young male and female recreational runners in order to compete for a carbon neutral tomorrow.*

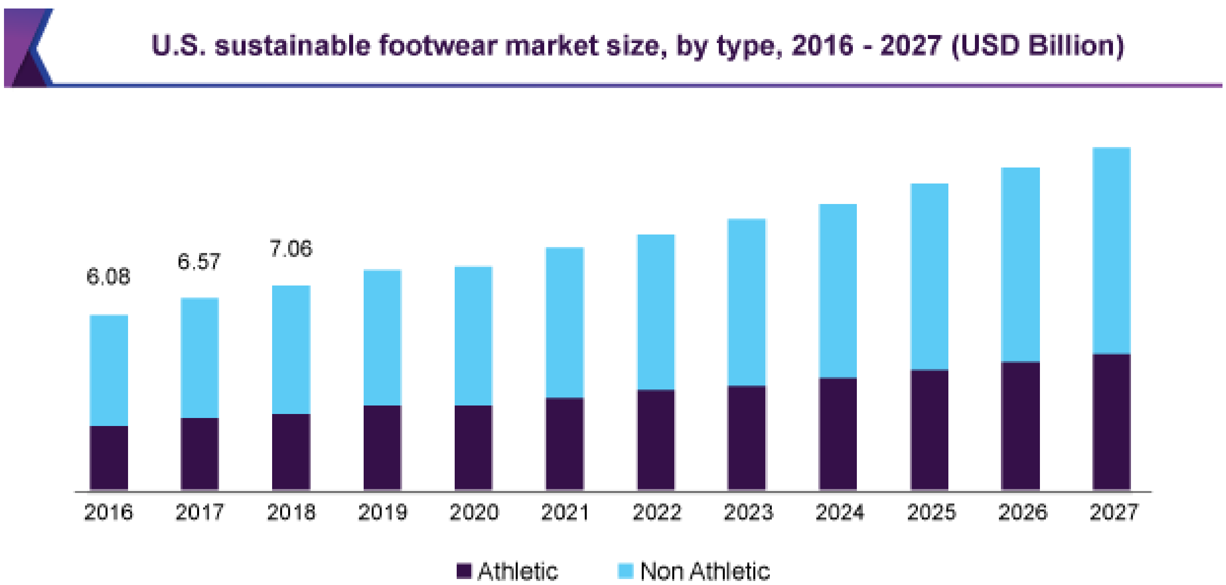


Figure 3. Projection of the sustainable footwear market in the U.S. over the next 7 years (James, 2020)

Sustainable Sports Product History

Sustainable initiatives within the sports product industry can be traced back to the fall of 1993 when Patagonia began to use recycled polyester made from plastic bottles to create clothing (Patagonia, 2015). Later that spring, recycled polyester found its way into the footwear market via the Deja Shoe line (Turk, 1993). These shoes were made entirely from recycled materials, including plastic soda and water bottles, tires, magazines and polystyrene cups (Turk, 1993).

Nike also began their sustainability journey in 1993 with their Reuse-A-Shoe program, which used recycled material from old shoes to create new sports surfaces (Nike Better World, 2012). They continued their momentum in 2002 by developing an environmentally preferred rubber that contained 96% fewer toxins by weight than the original formulations (Nike Better World, 2012). In 2012, Nike developed their Flyknit technology, a digitally engineered knitting process used to create one piece, form-fitting uppers (Nike News, 2018). Soon after its introduction, Nike completed their transition of all core yarns used in production to recycled polyester (Jane, 2016). In 2013 Puma launched their “InCycle” line, which featured a shoe made from biodegradable polymers, recycled polyester and organic cotton (O’Neill, 2013). In 2015, Adidas and Parley for the Oceans launched a single shoe at the United Nations as a part of a long-term eco-innovation partnership (Adidas News, 2020). The shoe featured recycled polyester made from ocean waste. As time went on, industries got more creative with their sourcing (Adidas News, 2020). In 2016 companies like Under Armour (ArchiTech Futurist 3D) and Reebok (Liquid Speeds) began to release footwear that incorporated 3D printing technology (Engle, 2016). All of these innovations would go on to create the framework for future sustainable experimentation.

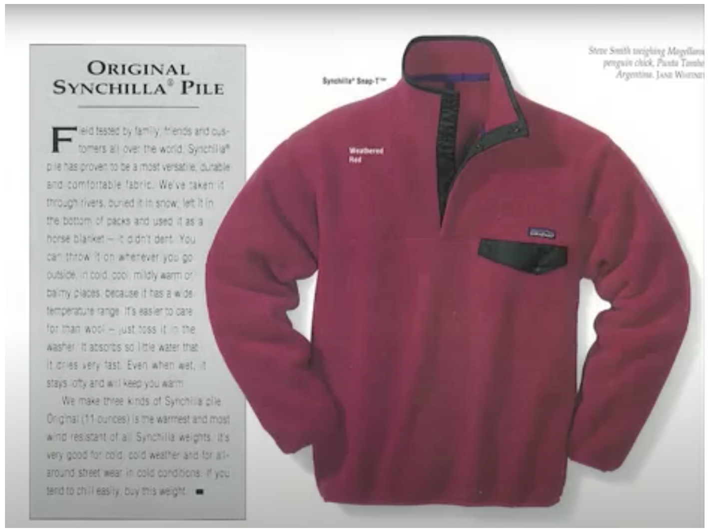


Figure 4. A 1993 Patagonia Synchilla made from recycled polyester (Patagonia, 2015)

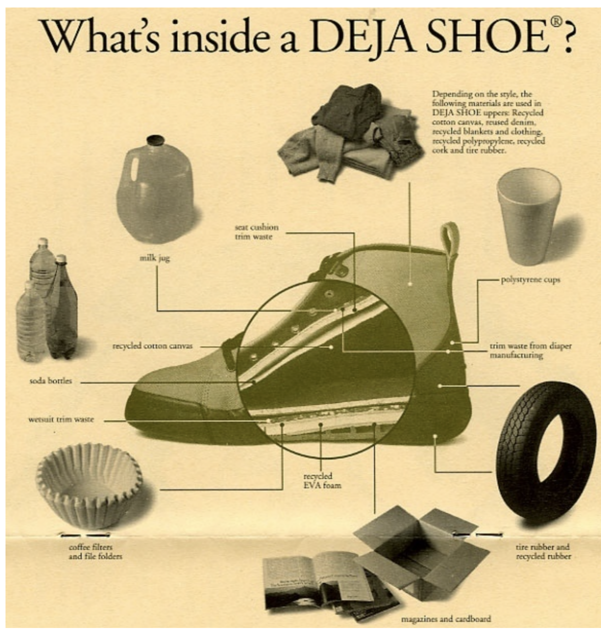


Figure 5. Breakdown of The Deja Shoe and it's recycled components (Outdoorinov8, n.d.)

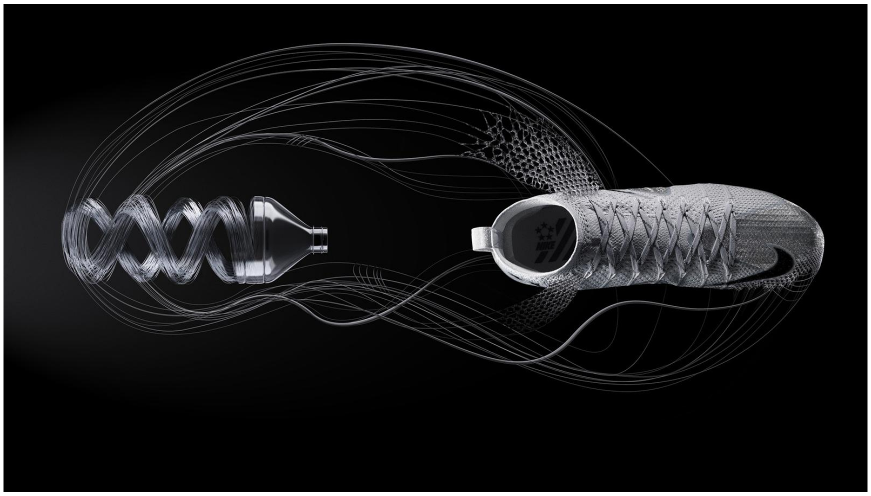


Figure 6. The Nike Vapor Untouchable, the first Flyknit cleat made with recycled polyester yarn (Nike News, 2014)

Figure 7. Puma's sustainable footwear option called the "InCycle" (Technabob, 2013)

Figure 8. Adidas Parley for the Oceans shoe launched at the United Nations (Parley TV, 2015)

Figure 9. The Under Armour ArchiTech Futurist with a 3D printed midsole (Kicks On Fire, 2017)

New brands like Allbirds and Veja entered the market using new bio-friendly materials like merino wool, castor bean oil, vegetable tanned leathers, wild rubber, jute, and hemp (Parr, 2020). As the idea of carbon neutrality grew, companies started to get more creative. Just within the past year, industry leader Nike developed a new shoe called the “Space Hippie” which was created out of recycled waste materials from the production of other shoes as a result of Nike’s move to zero initiative (Nike News, 2020). Adidas announced their 100% recyclable running shoe called the Futurecraft.Loop that is made entirely out of TPU (Adidas News, 2019). On Running has premiered a similar concept with their Cyclon (Dixon, 2020). Reebok has developed their eco-friendly solution, a plant-based shoe consisting of an upper made from eucalyptus trees, an algae sockliner, a natural rubber outsole, and a midsole made from castor beans (Buco, 2019). Allbirds has recently released their new running shoe that features eucalyptus tree fiber, wool, and a midsole foam made from sugar cane (McGuire, 2020). Allbirds has also partnered with Adidas to develop a shoe with the lowest carbon emissions yet (Farra, 2020). Lastly, Veja launched their first ecological running shoe made from 53% recycled materials (McGuire, 2019).

As we continue into a world of added importance on the environment and carbon neutrality, companies will be forced to innovate into "greener" areas. This is evident by the recent boom of sustainable design within the footwear industry. New regulations will be established as brands shift to more ecocentric measurements of manufacturing such as the Higg Index and carbon dioxide equivalent emission measurements (CO_2e). All of this will push companies to continue to search for the latest and best technologies the environment has to offer, heightening the importance of continued bioinnovation.

History of Running

In 1896, the International Olympic Committee (IOC) was formed, and running as a sport began to take shape (IOC, n.d.). That same year the IOC developed the first modern Olympic Games that was held in Athens, Greece (IOC, n.d.).. This Olympics featured multiple running events including a marathon competition as a nod to the ancient Greek messenger who ran from Marathon to Athens (Casey, 2019). A year later, the first-ever Boston Marathon was established

(Rockay, 2019). In 1926, Violet Piercy recorded the first women's world best in the marathon on the Polytechnic Marathon course between Windsor and London, however, women before such as Stamata Revithi and Marie-Louise Ledru her had participated and even won marathons of the past (Runner’s World, 2014; Lovette, 1997; Rockay, 2019). Running continued to gain in popularity, specifically there was an uptick in participation during the 1970s in response to the popularity of successful national team distance runners like Frank Shorter and Steve Prefontaine. Other books like *The Complete Book of Running* furthered the conversation as people started noticing the added health benefits of running (Edwards, 2015). By the 1990s running for exercise became fairly normalized and more options emerged for non-elite runners (Abbate, 2017). Even American celebrities such as Oprah and President Bill Clinton could be seen running for exercise (Casey, 2019). In 2019, world renown distance runner and Nike athlete, Eliud Kipchoge, ran an unofficial marathon in under 2 hours (Hawksins, 2019). A feat similar to that of Roger Banister’s 4 minute mile, in that it was once believed to be impossible, but now is an inspiring feat to many. Today over 55 million people in the U.S. are currently running or jogging, and that number continues to grow as more and more gyms close around the country due to the pandemic (Gough, 2018).

Figure 9. The Complete Book of Running by James Fixx (Goodreads, n.d.)

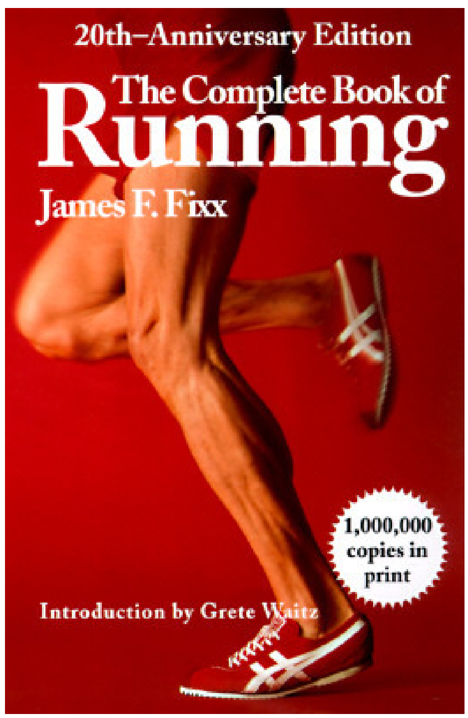


Figure 10. John J. McDermott wins the first ever Boston Marathon in 1897 (Applewood Books, n.d.)

Figure 11. President Bill Clinton running during his time in office (Hammond, 2016)

Figure 12. Eliud Kipchoge makes history by running sub two-hour marathon (Murray, 2019)

Project Scoping

Recreational running is primarily an individual sport, but a person may run with others. Currently, running is one of the most popular and practiced sports worldwide (Gough, 2018). The growing popularity is most likely due to the sport's simplicity and convenience, as anyone can go for a run at any time and at any location. There are no direct rules to running, which is one of the reasons why it can be extremely liberating and a stress reducer for some (Deelen et al., 2019). The sport is what the participant makes of it (distance, pace, route, etc. are all determined by the athlete). However, there are a few best practices in terms of form and safety.

Environment

As running increases in popularity, new environments are discovered. Some of the most common geographical locations used for running are public spaces such as parks and trails. Running surfaces consist of sidewalks, roads, trails, tracks and treadmills. Runners also tend to stray away from any hindrances such as pedestrians and cars (Deelen et al., 2019). This project will focus on footwear made to run on roads and sidewalks, which are made from asphalt and concrete respectively. These surfaces are the most common surface that all runners have access to and they are easy to measure distances on.

Temperatures in the U.S. range from below freezing to over 100°F. In 2019 the average temperature was around 52°F (NCEI, 2019). Therefore, this project will focus on moderate temperatures between 40-60 °F since this range occurs the most frequently throughout the year and is the most preferred for running. Similar characteristics will apply for the weather and humidity of the running environment. Since the goal of this project is bioinnovation within footwear, the focus will be on ideal running conditions. This includes clear, dry weather conditions (as opposed weather conditions involving wind, snow, sleet, or ice) as well as relatively low humidity.

Rules

There are a few general guidelines that can help keep runners safe. The first and foremost is to listen to your body. Ease your way into longer distances and faster pases, as your body will let you know when you are straining yourself. The most important thing you can do as a runner is to ensure that you don't over do it. Over exerting yourself will result in injury (Run Society, 2019). One should also do all they can to remain safe in their running environment. This includes following city, state, and federal laws, especially traffic laws for running in the street. As well as following local health department rules and social distancing guidelines from the Centers for Disease Control and Prevention (Le, 2020). Runners should always be on the lookout for cars and any other obstacles. It may be safest to jog facing traffic as much as possible. Runners should try to wear bright colors or reflective clothing to increase visibility.

Athlete Demographic

Around 55.9 million people in the U.S. participated in running or jogging in 2017. Of this population of runners and joggers, 24% reported that they started running or jogging for exercise (Gough, 2018). 18-29 year olds had the largest share of American respondents who recorded that they went running or jogging over the course of 2018 at 29% (Statista Research Department, 2019). 30-49 year olds had the second largest share at 20%, and 50-64 year olds had a 10% share (Statista Research Department, 2019).

Due to this research, this project will target an up-and-coming demographic called "the catalysts." This group of young, eco-anxious, and hyper-localized consumers are taking it upon themselves to create the change they want to see. The athletes within this group are 18-29 year old, which research shows is the largest share of individuals that went running or jogging this past year (Statista Research Department, 2019). These individuals, as well as all of society, have had much to be fearful of this past year, one of which is eco-anxiety. Eco-anxiety can be defined as a chronic feeling of worry about the impact of global warming (Bell, 2020). In fact, a 2019 WGSN climate survey found that 90% of global respondents said the thought of a climate crisis made them feel uneasy about their future (Bell, 2020). However, this group of individuals are transforming their fear into action. They are changing how we view activism as a whole, proving that the youth doesn't need to be angry to be heard. Instead, they are taking a more joyful approach to activism to combat emotional burnout while still making an impact (Bell, 2020). From planting a trillion trees to improving voter turnout, these young activists are working towards a better future for themselves and generations to come .

Another way this group is changing things is through continued support of their local community members to drive a new circular economy. During the pandemic people relied on hyper-localized social commerce to supplement income during shelter-in-place orders (Bell, 2020). This is projected to continue after the pandemic, which will create a shift in consumers to prioritize local products and manufacturing.

While it has been found that women are more committed to green behavior than men (Brough & Wilkie, 2017; Hastings, 2019), the targeted athletes within this group will be a novice 18-29 year old female and male runners. Both recently began running or would like to start since their gym remains closed and the lingering effects of the pandemic continues to impact the fitness market. Their motivation is to remain active and keep healthy, but they never miss an opportunity to support a better future. They jog a few miles a week whenever they can fit it into their busy schedule.

Market Size

The sustainable footwear market was valued at USD 7.5 billion in 2019 (James, 2020). It is estimated to reach $11.8 billion USD by 2027 – growing at a CAGR of 5.8% from 2020 to 2027 (James, 2020). The current market growth can be attributed to advancements in the sustainable space as well as material and technological innovations. The future projected growth will derive from an increased awareness of the environment and product production by the consumer, pushing manufacturers to innovate alternative and sustainable means that give better offerings. The rise in population of the younger generations at a global level paired with the purchasing power of this group will continue to develop this market space (James, 2020).

As mentioned, 18-29 year olds is the age group with the most people that went running or jogging over the course of 2018 at 29% (Statista Research Department, 2019). Based on the 2010 U.S. Census the population of individuals in the U.S. that are between 18-29 years of age is around 51.5 million (U.S. Census Briefs, 2011). Thus, a proper estimate of the overall market size for this project based on the athlete demographics will be somewhere around 29% of the 51.5 million, which is is around 15 million people.

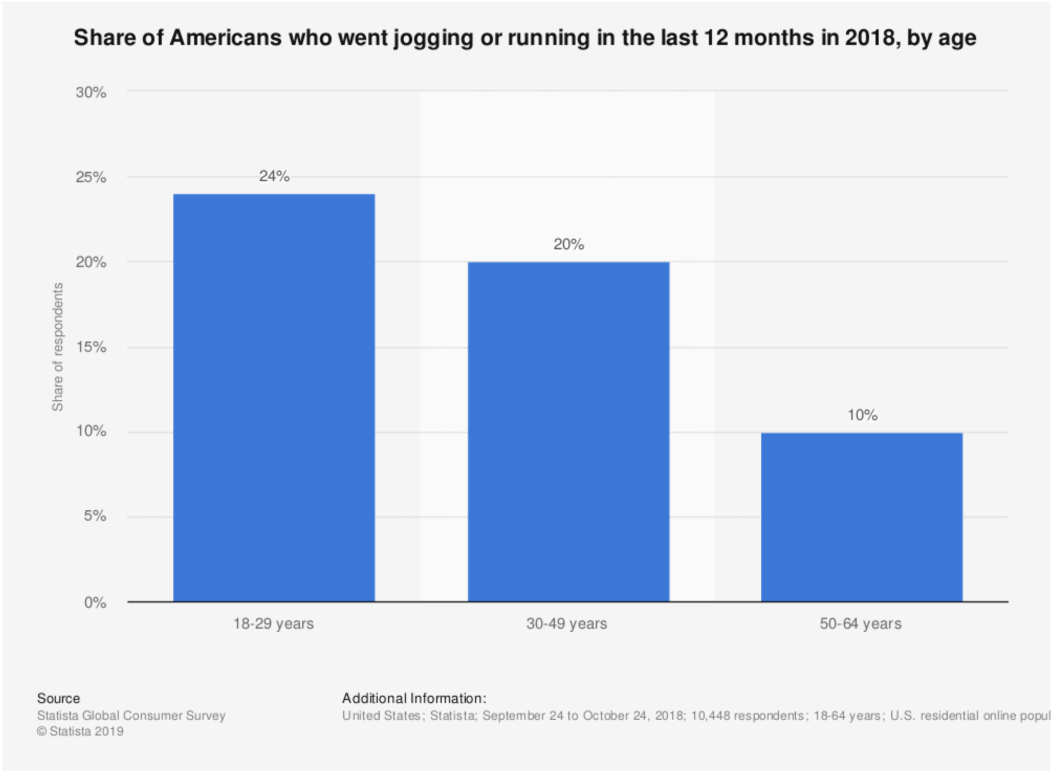


Figure 13. Share of Americans who went running or jogging in 2018, by age (Gough, 2018)

Product Anatomy

Functional state-of-the-art recreational running shoes work to help prevent injuries and promote comfortable exercise. Modern sustainable running footwear consists of three major components: the upper, midsole, and outsole. The upper can be classified by everything above the sole. In typical running footwear the upper has a variety of parts such as a vamp, collar, heel counter, lining, tongue, quarters, eyelets, & laces. The upper is shaped to the foot and serves to protect the foot from its surrounding environment as well as to keep the foot secure and stable (Beverly, 2020). State-of-the-art sustainably focused uppers utilize lightweight bio-based materials to achieve breathability. Traditionally an upper is made from layers of fabrics and mesh glued or sewn together, however, more modern uppers have used knitting and printing techniques to create one-piece uppers that fit better and produce less waste.

The midsole can be classified by the foam material between the outsole and the upper. It is designed to cushion the runner from impact forces from the ground and guide the foot through the stride. Midsoles should be neither too soft nor too firm and without excess weight (Beverly, 2020). The midsole may also feature encapsulated technologies for added cushioning or flexibility. Underfoot cushioning may be influenced by sockliners and strobel construction (Sokolowski, 2019). The sockliner is the removable pad inside the shoe that helps with cushioning.

The last major component of running and running footwear is the outsole. The outsole is the part of the shoe that comes into contact with the running surface. Thus this part of the shoe needs to be durable and provide traction for the runner. The outsole is often made out of rubber or are extensions of the midsole foam compounds that can be placed in strategic areas to increase wear life and enhance bounce or flexibility (Beverly, 2020).

Competitor Analysis

There are a plethora of running footwear options in the market with varying price points and features. However, of these options, only a handful have a sustainable focus. Modern sustainable running footwear can address sustainability through bio-based design or through closed-loop thinking. Below is a selected list of sustainable footwear options for the recreational runner that feature either bio-based materials or closed-loop solutions. While this list can serve as an overview of the current sustainable footwear market, this project will specifically focus on addressing the bio-based side of things.

The typical price points of these options range from $120 to $200. However, because the younger generation has such a large impact on this market, we are starting to see more modern payment methods like subscription based pricing ($30/mo.) and other buy now, pay later apps such as Affirm, Klarna, and Afterpay. These new methods of payment are changing how the industry thinks about price point and are important to consider for the future.

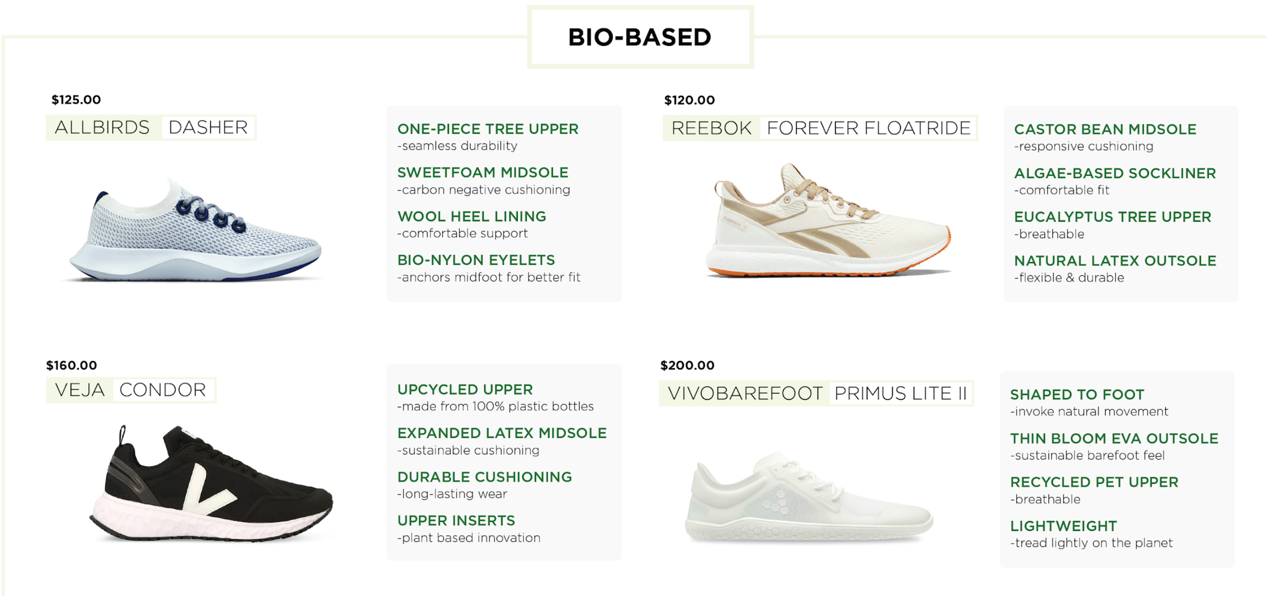


Figure 14. Current bio-based shoes in the sustainable footwear market

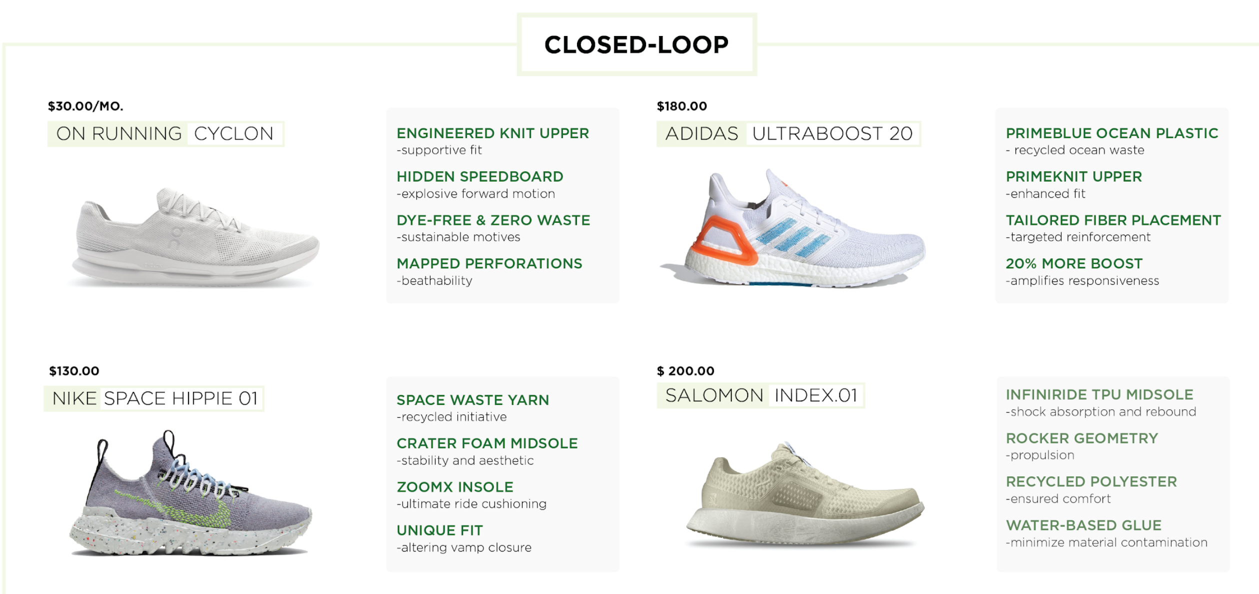


Figure 15. Closed-loop focused shoes in the sustainable footwear market

SWOT Analysis

The current men's sustainable running footwear market can be broken down by strengths, weaknesses, opportunities, and threats via a S.W.O.T. analysis. Below is a S.W.O.T. analysis of the footwear options that specifically feature bio-based solutions within the running footwear market in order to further address the region of focus for this project.

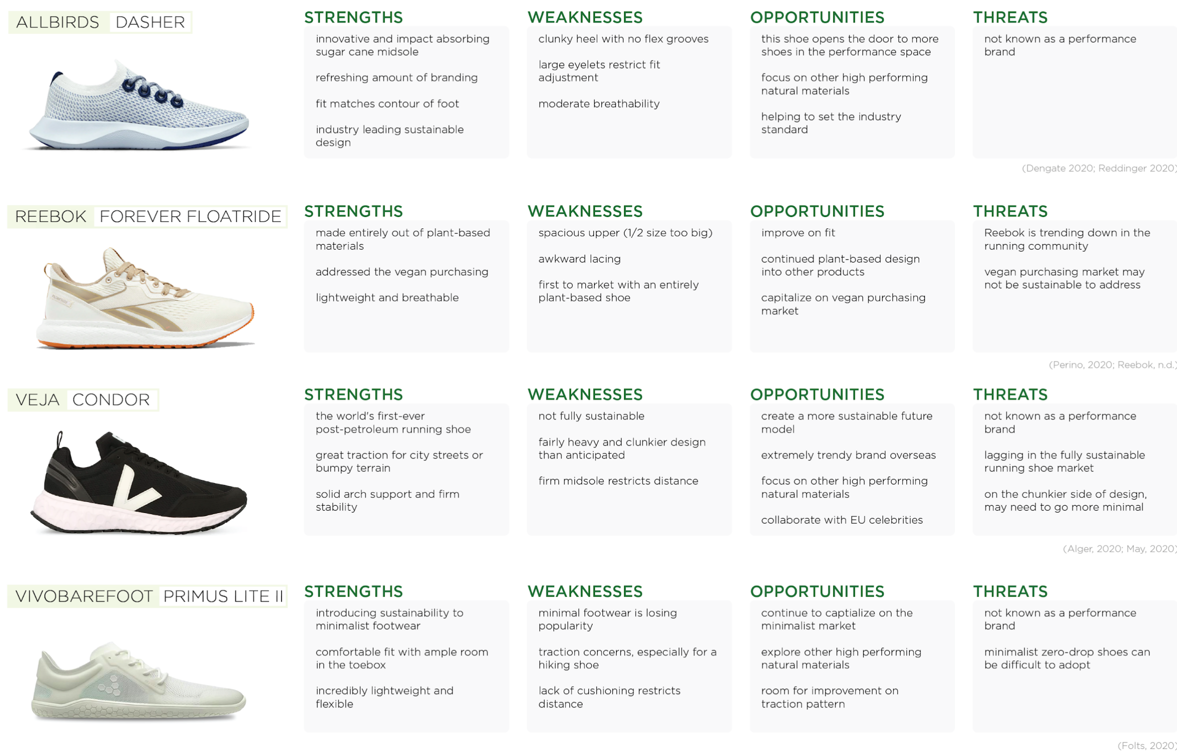


Figure 16. S.W.O.T. analysis of the bio-based competitive products in the sustainable footwear market

To better illustrate the region of focus for this project, products within the sustainable footwear market were then placed on one of two perceptual maps based on their sustainable focus being either bio-based or closed-loop. Products were evaluated on the map based on their performance and sustainability.

Figure 17. Bio-based and closed-loop perceptual maps to visualize targeted market area

Biomechanical Analysis

The biomechanical concerns for a runner center around gait cycle and overall form. The running gait cycle is generally categorized into two phases: the stance phase and the swing phase (Chan & Rudins, 1994). The stance phase takes up about 60% of the gait cycle and can be defined as the amount of time when the runner's foot is in contact with the ground, which typically ends with a toe push off (Chan & Rudins, 1994). The stance phase consists of two periods of double-limb support (each 12%) and one period of single-limb support (35%) (Chan & Rudins, 1994). The swing phase takes up about 40% of the gait cycle and can be defined as the amount of time in which the foot is not in contact with the ground (Chan & Rudins, 1994). However, as the speed of gait increases, a third phase called the “float phase” begins to develop. This is the phase that helps distinguish running from walking. This is because as one increases their speed from a slow jog, to a run, to a sprint, the stance phase time begins to decrease while the swing and float phases increase (Chan & Rudins, 1994).

In terms of injury and performance the stance phase is the phase that is typically focused on since it is the time period when the foot and leg have to bear overall body weight (Runner’s Blueprint, 2017). In order to further analyze this phase from a product improvement perspective, it can be divided into four sub periods: breaking, mid stance, heel off, and propulsion (Casanova, 2018). The breaking period occurs when the foot comes into contact at the ground and your knee and ankle flex to absorb the impact (Casanova, 2018). The mid stance period is when the legs are directly under the hips and the runners weight begins to pass over (Casanova, 2018). The heel-off period occurs when the heel is about to lift off the ground as the hip is hyperextended and the knee is stretched out in preparation to flex (Casanova, 2018). The last of these subphases is the propulsion period where the toe pushes off and the absorbed energy propels the body forward leading into the swing phase (Casanova, 2018). During this time the heel starts to lift from the ground, the hips begin to extend, and the knee will pass under the hips until the leg falls and makes contact with the ground, restarting the cycle (Casanova, 2018).

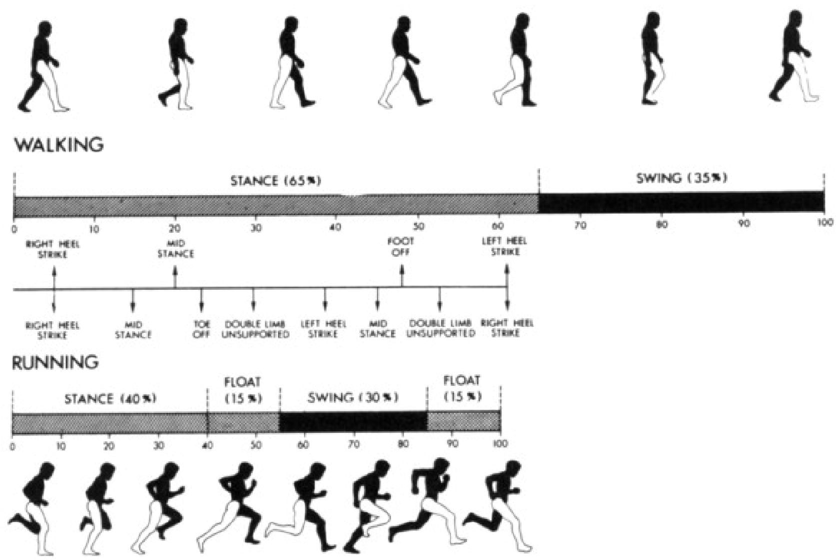


Figure 18. Explanation of the phases that make up the walking vs running cycles (Chan & Rudins, 1994)

Running with the correct form can help a person be more efficient with their movements and prevent injury. Runners should be sure to stretch prior to exercise. This will help avoid injury and added strain on your body. While running form varies from person to person, generally a good running form includes keeping your head straight and upright (Mateo, 2020). Your shoulders pulled back as any form of hunching over is going to affect your speed or endurance (Mateo, 2020). The shoulders should move independently from the torso and opposite of one another (Mateo, 2020). Elbows should be bent at 90 degrees and close to your sides (Mateo, 2020). Your arms should move so that your palms go from chin to hip, while keeping your hands relaxed and open (Mateo, 2020). Keeping a tight core will help you keep the right posture, as less torso rotation will increase your overall speed and allow you to use less energy (Mateo, 2020). Your torso will be slightly forward from your hips in order to lean into the run as opposed to running completely upright (Mateo, 2020). Knees should be kept in line with the middle of the foot, and refrain from bringing your knees too high to save energy (Mateo, 2020). Lastly, after the foot hits the ground, it is important that the runner pushes off with their foot, instead of just lifting them (Mateo, 2020).

One of the most common ways to analyze the biomechanics of running is through ground reaction forces (GRF). GRFs are forces exerted by the ground on the body as a result of the body coming in contact with the ground (Logan et al., 2010). This occurs via Newton’s third law. The direction and magnitude of a GRF is determined by the runner’s center of mass (Novacheck, 1998). GRFs exerted by the foot have been shown to increase to 2.5 times the body weight (D' Ambrosia & Drez, 1989). A common goal of modern running footwear is to reduce the magnitude of GRF through midsole cushioning.

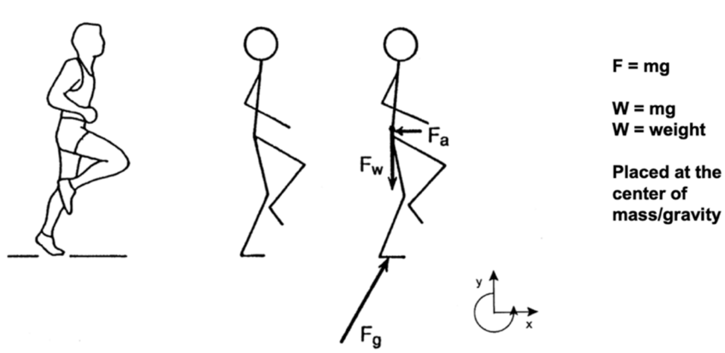


Figure 19. Free body diagram explaining the ground reaction forces (GRF) on the runner (Pomeroy, 2019)

Reducing ground reaction forces can have an overall impact on one's running economy by reducing energy expenditure (Santos-Concejeroa et al., 2016). This is important for improving the physiological demands of running. Running economy can be defined as the steady-state oxygen consumption (VO2) at a given running velocity (Barnes & Kilding, 2015). Shorter ground contact times, lower stride frequencies, longer swing times, greater stride angles and longer strides have all been related to an improved economy, but from a product perspective lowering peak GRFs is one way to improve running economy (Santos-Concejeroa et al., 2016). Another important product correlation to running economy is the weight of the shoe. Oxygen consumption increases by 1 percent for every 100g of added weight (Kirby, 2017). Therefore, footwear cushioning and overall weight are important means to improving overall physiological performance via running economy.

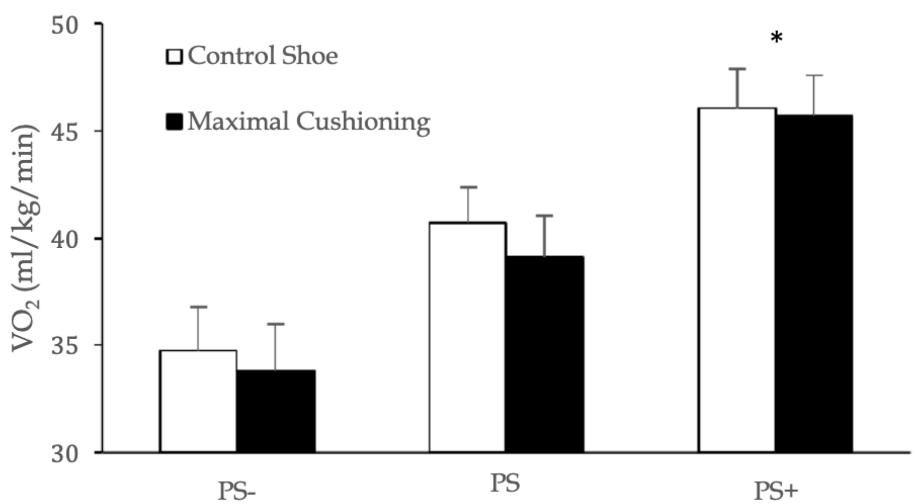


Figure 20. Cushioning lowers GRFs to improve running economy (Mercer et al., 2018)

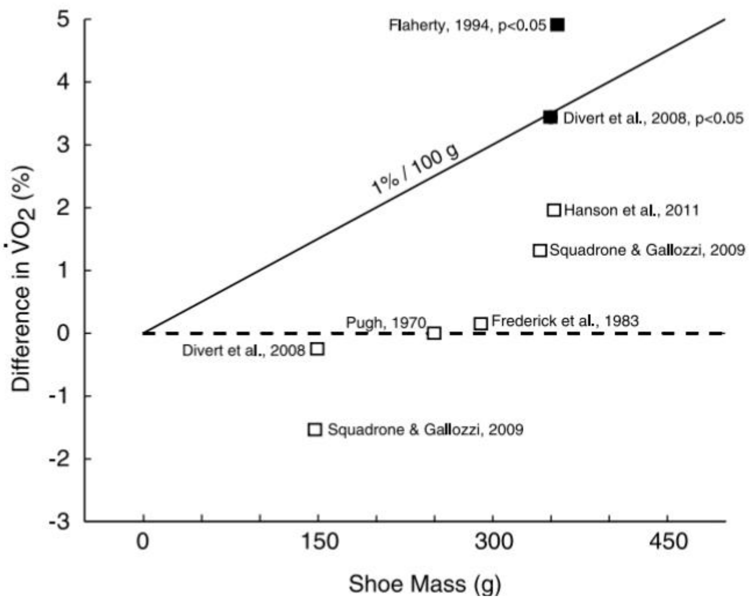


Figure 21. Difference in oxygen uptake reported in literature during shod and barefoot running (Franz & Kram, 2012)

Lastly, anatomical differences between mens and womens footwear can also have physiological impacts on a runner. Traditionally women's running shoes are made by using a scaled down version of a men's last (Wunderlich & Cavanagh, 2001). However, studies have shown that women's feet typically differ in shape from men's feet, meaning that a scaled down men's last is an inappropriate model for a women's shoe last (Wunderlich & Cavanagh, 2001). This could lead to improper fit and a decrease in performance (Wunderlich & Cavanagh, 2001). A women's running shoe last should consider the anatomical differences of a female foot such as a lower ankle and medial malleolus height, a higher arch, a shallower first toe, a shorter ankle length, a shorter length of the outside ball of foot, and a smaller instep circumference than a man's foot (Wunderlich & Cavanagh, 2001). To prevent foot pain and deformity, these anatomical differences should be accounted for when designing men's and women's running footwear.

While there is a great deal of modern research and innovation around improving the biomechanics, running economy, and anatomical fit of running footwear, this project's primary focus will reside more on material and manufacturing innovations to achieve its sustainable goals. However with that being said, much of the research listed above will still be taken into account to help drive materiality selection and the overall design of this project. This project's final design will still look to improve one's overall running economy by selecting lightweight materials and featuring the most responsive cushioning material that the local environment can provide. Anatomical differences between the male and female foot will also be considered to help define the final design.

Materials

As an increased focus on sustainability has developed, more bio-innovative solutions are being created to help lower the impact of the end-use product. Modern sustainable materials and trims used in the upper derive from knitted, woven, or nonwoven textiles. Typical sustainable running footwear mainly features knitted materials for added breathability and comfort. These sustainably knitted materials can be made from spider silk, recycled polyester, organic and recycled cotton, bamboo, wool, or Lyocell (Palmer, 2020). Other woven or nonwoven materials may be used for added support or rigidity. Sustainable wovens can be made from organic and recycled cotton, recycled nylon, hemp, and Lyocell (Palmer, 2020). Nonwovens include recycled leather, fruit and vegetable-based synthetic leathers, cork, wool felt, recycled polyurethane, and EVA bloom foam (Palmer, 2020). Sustainably-based midsole technology consists of solutions derived from natural rubber, cork, coconut husk, algae, caster oil, sugarcane, and recycled PU, TPU, PET, and EVA (Palmer, 2020). Sustainable midsole encapsulated solutions include a speedboard made from castor beans, and added air cushioning made from recycled Nike ZoomX (Palmer, 2020). Sustainable outsole solutions are made from algae-based EVA, natural latex, and recyclable TPU (Palmer, 2020). Lastly, insoles can also be made from a blend of sustainable materials such as recycled PU, EVA, and synthetic rubber, cork, natural rubber, coconut husks, caster bean oil, algae, soy, hemp, organic cotton, Lyocell, and wool (Palmer, 2020).

This project will look to feature more natural and bio-innovative material solutions as opposed to recycled synthetics. This is because recycled synthetics are seen more in the closed-loop footwear market and are not necessarily appropriate for this project. Virgin materials derived from plants and other bio-based methods will be prioritized when selecting materials for the final design of this project. However, current bio-based footwear sources their materials from all over the world. In today's climate this can be challenging with travel restrictions, therefore this project will also prioritize locally sourced materials to cut down on overall emission reduction and to adapt the future trend of consumer awareness and a hyper-localized tomorrow.

Manufacturing

Modern footwear manufacturing process begins with the construction of the upper. The base material is either die-cut by steel dies in a hydraulic press (Motawi, 2016), or digitally engineered on a CNC knitting machine to create a seamless one-piece upper (Motawi, 2017). Once all other details of the upper are assembled, the lining is attached, and foam is inserted into the collar and tongue. The constructed upper is attached to the strobel via a strobel machine. Once the stitching is complete the upper and stroble are ready to be bonded to the outsole. To do this the upper is formed to the shape of a last via heat in a process called "lasting" (Motawi, 2016). The midsole can be molded or printed around an encapsulated technology, or encapsulated technologies can be glued into place after the midsole is molded or printed (Motawi, 2018). Once the outsole is molded, the midsole is glued to the upper, and then the outsole is glued to the midsole. Lastly any finishing touches are added like adding laces and inserting the sockliner.

Modern manufacturing methods are now being analyzed to accurately measure and score a company or product's sustainability performance via the Higg Index or by reporting carbon dioxide equivalent emissions (CO_2e). These new forms of measurements are being implemented across the footwear industry, however, there is still much work to be done as the current manufacturing process of a single pair of running shoes creates about 13kg of CO_2. Modern sustainable manufacturing solutions include optimizing zero waste strategies, lowering energy usage, preserving water, and using less dyes (Palmer, 2020).

This project will prioritize a limited amount of manufacturing steps in order to reduce emissions and energy expenditure. Water based glue or limited to no glue usage will also be considered in the design to reduce toxins and high energy production processes. Similarly, undyed, natural materials will be valued during this project to cut down on water and dye usage. In the end, the sustainability of this project will be analyzed via the Higg Index. Since one of the major goals of this project is localized sourcing, identifying a way to factor in the difference in emissions through said sourcing will be ideal to help showcase this product. This is because other bio-based products source from distant regions, which adds to the overall emissions.

Intellectual Property

Relevant intellectual property within the footwear space include patents on sustainable materials, modern cushioning, and overall fit:

Sustainable Materials:

- Textile Products Produced From Waste Cotton Material (U.S. Patent No. 0,250,425 A1, 2011).
- Textile fibres and textiles from brassica plants (U.S. Patent No. 0,136,412 A1, 2019).
- Individualized bast fibers derived from the flax and hemp plants (U.S. Patent No. 10,519,579 B2, 2019).
- Clothing item comprising spider silk (U.S. Patent No. 0,132,487 A1, 2018).
- Regenerated polyester fabric (Chinese Patent No. 202297997 U, 2012).
- Recyclable shoe midsole cloth and method of making the same (U.S. Patent No. 5,671,495, 1997).
- Sustainable materials for three-dimensional printing (Canadian Patent No. 2,909,849 C, 2019).

Cushioning Technology:

- Chambers filled with ambient or slightly pressurized air (U.S. Patent No. 6,505,420 B1, 2003).
- Integrating particulate matter (U.S. Patent No. 0,223,539 A1, 2019).
- Compressible lattice construction techniques (U.S. Patent No. 10,010,134 B2, 2018).
- Liquid or gel cushioning midsole material (U.S. Patent No. 5,718,063, 1998).
- Cushion wedge for custom control of impact and pronation upon heel-strike in various weights of wearers (U.S. Patent No. 4,882,856, 1989).

- Article of footwear with dynamic edge cavity midsole (U.S. Patent No. 10,111,492 B2, 2018).
- Footwear cushioning spring (U.S. Patent No. 5,279,051, 1994).
- Footwear structure and method of forming the same (U.S. Patent No. 8,381,416 B2, 1997).
- Shoe cushioning system and related method of manufacture (U.S. Patent No. 6,754,982 B2, 2004).
- Sole structure with holes arranged in auxetic configuration (U.S. Patent No. 10,271,615 B2, 2017).
- Articles of footwear and sole structures with pressure-mapped midsole topographies and inlaid outsoles (0,154,819 A1, 2020).

Trends

Overarching footwear trends will drive the design of individual running shoes through silhouettes, colors, graphics, and logo application. Current men's sustainable running footwear trends towards a minimal one-piece, sock-like silhouette with thin collars and limited overlays. External heel counters and integrated loop lacing are commonly used for added stability and comfort. Typical color application derives from earthy and naturally dyed tones such as brown, tan, off-white, variations of green and yellow, grey, and light blue shades to highlight the organic quality of the materials. Sustainable running shoes trend toward minimal to no graphic applications in order to reduce waste or eliminate excessive production steps. Thus graphic details are applied through contrast stitching, blocking, or film overlays. Primary logo application typically occurs on the lateral side of the shoe, however, some models minimize branding and additional logo placement in order to cut down on waste and added manufacturing. These models restrict placement of logos to secondary locations such as the tongue, heel counter, and outsole.

As we continue into a post-pandemic world, there are a handful of future overarching trends that may have an impact on future designs. These include the continued prioritization of sustainability (as noted throughout this paper), the impact of home comforts on workwear as a result of the pandemic, and lastly, the uptick in outdoor activity transforming hiking and running footwear to blur the lines between performance and fashion.

This project will blend the worlds of sustainability, performance, and design to modernize the current bio-based footwear market. Materials and overlays will be limited to reduce waste, weight, and excessive production steps. However, if details of the design are to be added they will be targeted to enhance performance. These design options include a bio-based heel counter, a springboard, and other elements that improve fit or performance. While there has been much progress in the world of bio-based running footwear, this project will introduce more of the modern elements we see running performance shoes that help with overall performance, but in a sustainable manner.

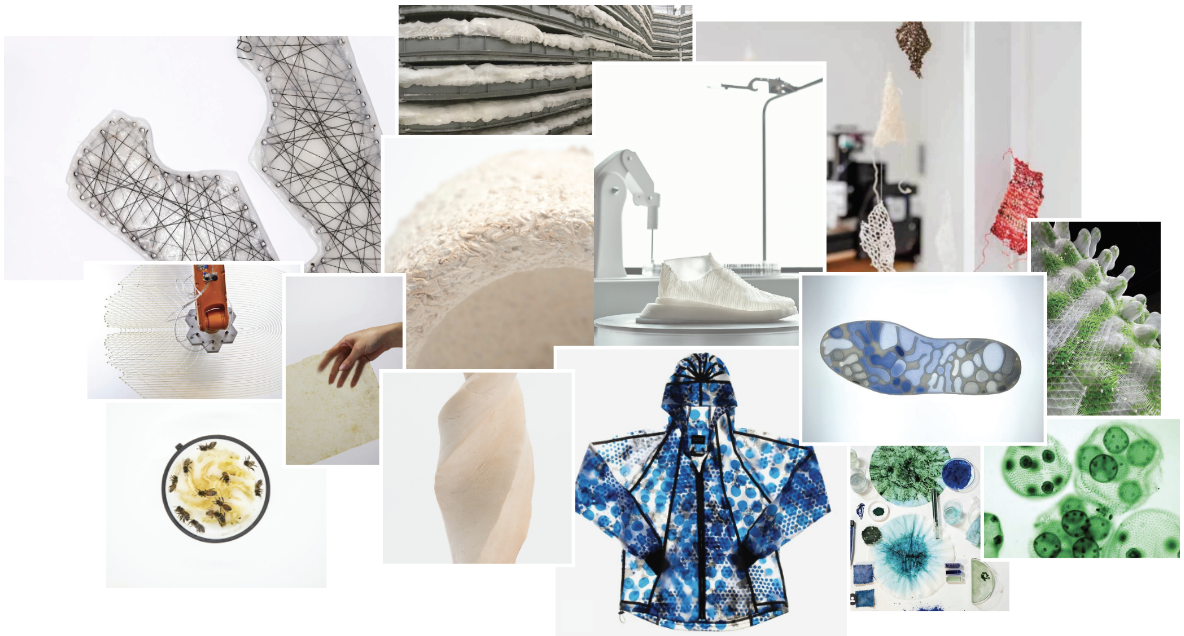


Figure 22. Moodboard resulting in a laboratory and biodesigned aesthetic direction based on bio-based trend research.

Professional Development

My top five strengths determined by the Strengths Finder survey were ideation, futuristic, positivity, achiever, and focus. This project aligns very nicely with those skill sets because it is a futuristic project that will require positivity and focus in order to innovate unique solutions for a better tomorrow. In the end, this project will offer an innovative and positive solution to one of the most serious problems we will face in the upcoming years.

As an innovator, I typically crossover from scientific thinking to design thinking quite often. This allows me to find unique cross sections that I believe are new and innovative areas to approach. Both my scientific and design knowledge will be put at the forefront of this project as I look to create something that highlights my previous education and experiences. Aside from utilizing my scientific knowledge base, I also will lean on my futuristic thinking and intense focus to be able to create meaningful and realistic solutions that also can perform. This will provide many opportunities to immerse myself in the problem at hand and really try to think through a solution, which I very much enjoy. This project will also require a lot of hands-on exploration and discovery, which I will also look forward to. In the end all of these strengths will allow me to achieve a successful capstone project.

This project will be the perfect encapsulation of my education to this point and can show the many hats I could potentially wear within an industry. Overall I am interested in athletic footwear and bioinnovation, with someday hoping to start my own sustainable performance footwear brand. However, for my more immediate career, this project will allow me to apply for both sustainability and footwear positions. Then as I go about completing this project, I will gather insights about the industry that will help me in the long haul.

PART II: INNOVATIVE PROJECT STRATEGY DEVELOPMENT

Term Goals

The goal of this term will be to convert the previous background research into an articulated design direction. At the end of the term, a proof of concept will be presented to show the feasibility of the project as determined from the benchmarking, ideation, and validation research, which were completed throughout the term. Work during the term will be displayed on Instagram to help with personal marketing and brand development. Upon completion of the term, this project will pick back up starting with the proof of concept and progressing towards a final product.

Benchmark Products

To begin, benchmark products were selected in order to learn more about the market and resulting innovation space as well as help with goal setting for this project. As mentioned in the previous consumer analysis section, the sustainable running footwear market can be divided into the closed-loop space and bio-based space. This project focuses on the bio-based sector and it can be determined from the perceptual map (Figure 17) that the Allbirds Dasher and the Reebok Forever Floatride Grow were the most popular footwear models and the most recent innovations within this bio-based space. Thus, these two shoes were selected as the relevant benchmark products for testing and project goal setting.

Benchmark Testing

In order to test the Allbirds Dasher and Reebok Forever Floatride Grow, athletes with an elevated knowledge of running footwear and sustainability were needed in order to provide fruitful feedback. As a result, the athletes selected to test these benchmark products and act as product champions throughout the project were Adam Dalton and Peyton Thomas. Both Adam and Peyton participated in the 2020 Olympic Trials, but outside of running they work within the world of sustainability. Which in turn, checked all the boxes of having a high running IQ, knowledgeable about footwear, and passionate about sustainability.

Once the product champions were identified, they were then asked to participate in benchmark testing. For this, a pair of each benchmark product was sent out to each athlete. The athletes were asked to break in each benchmark product and then run in them for a few miles. The athletes were then asked a series of questions to analyze the performance characteristics of each shoe. This would provide qualitative feedback about the different performance characteristics and identify any areas of improvement to focus on during this project. The feedback was then consolidated and organized into a table based on the benchmark's strengths, weakness, opportunities, and threats. All results helped better define the overall design direction.

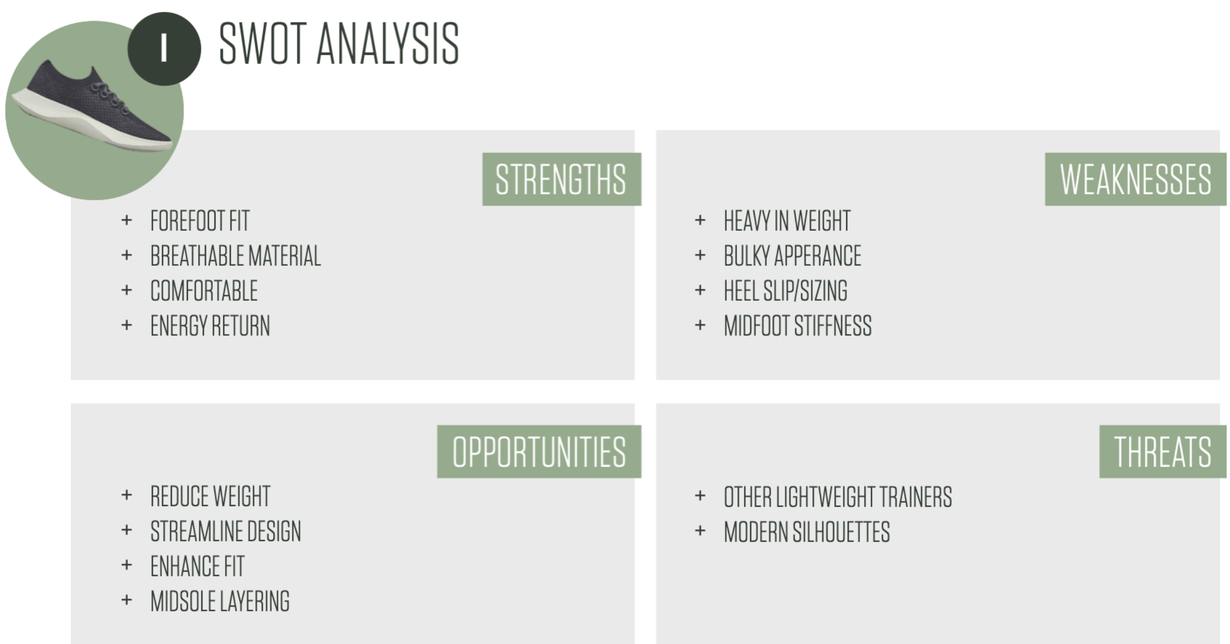


Figure 23. Qualitative feedback regarding the Allbirds Dasher organized in to a SWOT chart.

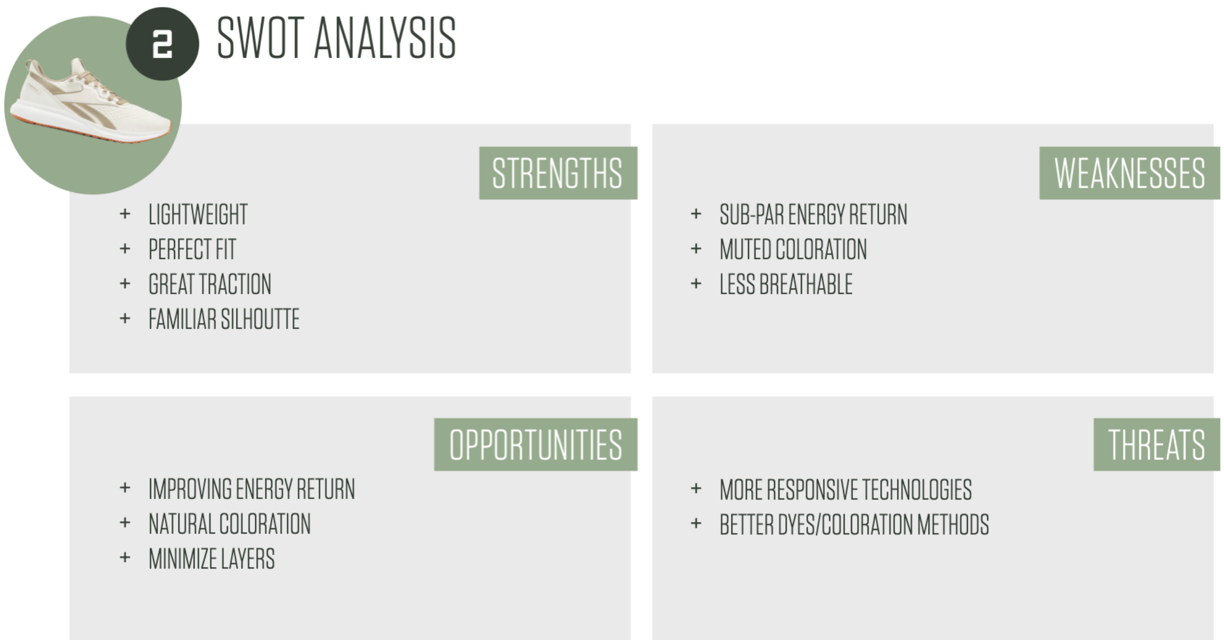


Figure 24. Qualitative feedback regarding the Reebok Forever Floatride Grow organized into a SWOT chart.

Consumer Surveying

After benchmark testing, further research was needed to help articulate the overall design direction of this project. As a result, a survey was created to better determine what members of the targeted demographic were looking for in their running footwear. There were a handful of notable results from the survey, which gave added direction to the project. The first being that the most common shoe worn by participants was the Nike Structure, which is a stability running shoe. Respondents also listed stability as the third more important characteristic the look for in running footwear (behind comfort and fit). Lastly, 100% of respondents said they would buy bio-based running footwear, which is incredibly encouraging for the scope of this project.

A second questionnaire was also created concurrently to a presentation that reviewed all possible natural, bio-based materials featured in footwear. The goal was to gauge what materials excited the targeted demographic the most. It was found that the materials that performed the best had a better overall story of production and an increased regional relevance than the others.

Thus, due to the emphasis on stability within the results of the initial survey, it became evident that stability should become one of the main factors in the ensuing design direction. The enthusiasm behind the regional relevance of materials should also be factored into the final design direction. As a result the final design direction and resulting product line will feature the *first ever bio-based stability running shoe derived from regional in-situ innovation (specifically within the Pacific Northwest) and material exploration.*

Ideation planning

The ideation phase began by using the previous research and testing results to brainstorm various methods of exploration, all of which attempt to improve certain performance characteristics and the overall sustainability of the shoe. The resulting ideation was consolidated into a table format (Table 1).

Table 1. Various ideation pathways to design around in order to improve general performance characteristics and sustainability of the running shoe.

PRODUCT: Men's Bio-Based Running Shoe	
Part: Upper	
Problem Identification from Research	Ideation Path
SWOT Opportunity: Enhanced Fit	_External Heel Counter _Arch Support/Lockdown _Lacing System _Paneling _Slim Toe-Box _Stronger Knit

SWOT Opportunity: More Sustainable	_Localized Sourcing _Material Selection
Benchmark Opportunity: Lighter Weight	_Generative External Structures _Minimal Overlays
Benchmark Opportunity: Better Lockdown	_Tweaked Shell Pattern _Lacing Pattern _Midfoot Strap _Other Strapping
Consumer Opportunity: Foot Splay Ratio	_Anatomical Footscans
Part: Sockliner	
SWOT Opportunity: More Durable	_Material Placement _Material Selection
SWOT Opportunity: More Sustainable	_Localized Sourcing _Material Selection _Generative Design
Benchmark Opportunity: Improve Performance	_Contour to Foot _Softer Foam _Paneled Fabric _Texture Exploration _Perforations
Consumer Opportunity:	_Foot Sweat Map
Part: Midsole	
SWOT Opportunity: Cushioning Stiffness	_Dual Density Exploration _Layered Design _Softer Foam
SWOT Opportunity: Increased Performance	_Carbon Fiber Plate Alternative _Other Encapsulating Technologies
SWOT Opportunity: Weight	_Generative Cut Outs _Auxetic Design _Slimmer Shaping
Benchmark Opportunity: Arch Discomfort	_Contour to Foot
Part: Outsole	
SWOT Opportunity: Reduce Weight	_Generative Design
SWOT Opportunity: Tailored Performance	_Pattern To Needs Of Foot

After the initial ideation period, the focus shifted to identifying sourcing avenues for future materials. During this time general material providers and sourcing methods were researched based on the early ideation and concept pathways. However, the effects of the pandemic still proved to make sourcing methods difficult, pushing this project into more of a self-fabricating and bioinnovation space. The results from the sourcing research were consolidated as a material resourcing plan (Table 2).

Table 2. Material sourcing plan based on the initial ideation and concepting phase.

Product: Bio-Based Running Shoe			
Part	**Performance Goals**	**Materials That Will Solve This**	**Ideas of Where to Source this Material**
Upper	In-Situ Exploration	Algae Knit	Algiknit or self-fabricated
Heel Counter - Arch Caging Structure	In-Situ Exploration	Salmon Skin Leather	Local manufacturer or self-fabricated
Heel Counter - Eyestay	In-Situ Exploration	Chitin Filament	Shellworks or self-fabricated
Fabric Dying	In-Situ Exploration	Spira Algae Extracted Pigments	Spira Inc.
Upper	In-Situ Exploration	Grown Bacteria	Modern Synthesis or self-fabricated
Upper Finishing	In-Situ Exploration	Silk Based Coatings	Self-fabricated
Upper Base	Performance/Breathability	TENCEL Knit	General manufacturers or repurposed textiles with featured content
Upper Base	Performance/Breathability	Cotton Knit	Cotton Works or local fabric stores
Upper Base	Performance/Breathability	Wool Knit	Woolmark, Pendelton, local fabric stores
Upper Base	Performance/Breathability	Bamboo Knit	Tasc Bamboo or local manufacturer
Upper Base	Performance/Breathability	Banana Tree Mesh	Bananatex
Upper Base	Performance/Breathability	Spider Silk	AMSilk, Spiber, Bolt Threads
Upper Base	Performance/Breathability	Hemp Knit	General manufacturers
Upper Base	Performance/Breathability	Soy/Cotton Blend Knit	General manufacturers
Heel Counter - Arch Caging Structure	Performance/Support	Bio-based Leather	Vegea, Desserto, Bolt Threads, Modern Meadow, Ecovative Design, Nova Kaeru,

			Pinatex
Heel Counter - Arch Caging Structure	Performance/Support	Cork	General manufacturers or self-harvested
Heel Counter	Performance/Support	Jute	General manufacturers
Heel Counter - Eyestay	Performance/Support	Algae Filament	Algix
Upper Durability	Performance/Support	Cotton Canvas	Cotton Works or local fabric stores
Heel Counter	Performance/Support	Hemp	General manufacturers
Midsole Material	In-Situ Exploration	Mushroom Foam	Ecovative Design or self-fabricated
Midsole Material	In-Situ Exploration	Soap/Charcoal/Gelatin	Self-fabricated
Midsole Material	Performance/Cushioning	Algae Based EVA	Algix
Midsole Material	Performance/Cushioning	Sugar Cane EVA	Braskem
Midsole Material	Performance/Cushioning	Castor Bean EVA	Pebax or other manufacturers
Midsole Material	Performance/Cushioning	Natural Latex	Yulex
Midsole Material	Performance/Shock Absorption	Coconut Husks	General manufacturers or self-harvested
Midsole Material	Performance/Responsiveness	Cork	General manufacturers or self-harvested
Shank	Performance/Responsiveness	Flax Composite	B-comp
Sockliner Cushion	In-Situ Exploration	Coconut Husks	General manufacturers or self-harvested
Sockliner Cushion	In-Situ Exploration	Cork	General manufacturers or self-harvested
Sockliner Cushion	In-Situ Exploration	Mushroom Foam	Ecovative Designs, other manufacturers, or self-harvested
Sockliner Cushion	Performance	Algae Based EVA	Algix
Sockliner Cushion	Performance	Sugar Cane EVA	Braskem
Sockliner Cushion	Performance	Castor Bean EVA	Pebax and other manufacturers
Sockliner Cushion	Performance	Natural Latex	Yulex
Sockliner Cushion	Performance	Coconut Husks	General manufacturers or self-harvested
Sockliner Cushion	Performance	Cork	General manufacturers or self-harvested

Sockliner Fabric Lining	Performance	TENCEL Knit	General manufacturers or repurposed textiles with featured content
Sockliner Fabric Lining	Performance	Cotton Knit	Cotton Works or local fabric stores
Sockliner Fabric Lining	Performance	Wool Knit	Woolmark, Pendelton, local fabric stores
Sockliner Fabric Lining	Performance	Bamboo Knit	Tasc Bamboo or local fabric stores
Sockliner Fabric Lining	Performance	Hemp Knit	General manufacturers
Sockliner Fabric Lining	Performance	Soy Knit	General manufacturers
Outsole Material	In-Situ Exploration	Algae Runoff	Algix
Outsole Material	In-Situ Exploration	Tree Based Material	TENCEL
Outsole Material	Performance	Natural Latex	Yulex
Outsole Material	Performance	Algae Based	Algix

Once the initial ideation and material sourcing plans were completed, the next objective was focusing on all the different ways stability can be achieved in running footwear. It was found that stability running shoes feature supportive elements that can be found in the upper (e.g. arch band, heel counter, forefoot room, and supportive lacing), midsole (e.g. medial post, guide rails, shanks, and utilizing geometry), and the outsole (e.g. full-length, medial reinforcement, and pronation resistant structures) of the shoe.

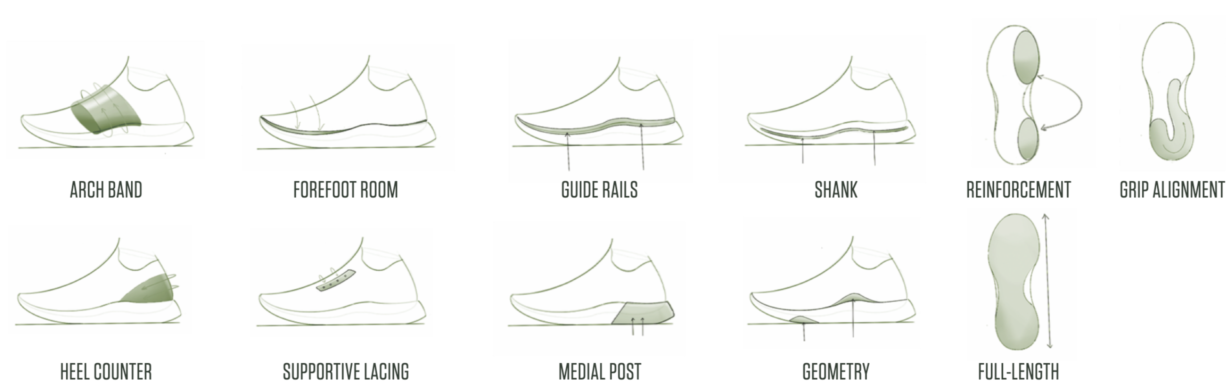


Figure 25. The different ways to increase stability within running footwear.

With more of a functional direction and an increased interest in self-fabrication due to the continued effects of the pandemic on material sourcing, a handful of natural materials were identified by their proximity (to the PNW) and potential to be manipulated into elements of footwear. These materials included shellfish bioplastic, seaweed bio-yarn, mushroom aerial mycelium foam, algae-based foams, and bio-based leathers.

In the end, a finalized ideation plan calendar was proposed that divided the ideation phase into two segments: a footwear design segment and a material exploration segment. The footwear design segment focuses on traditional design practices such as sketching, prototyping, and CAD in order to create stability solutions for running footwear. The material exploration segment centers around exploring regional materials for biofabrication means, which can then be used in the final design to help lower emissions and increase regional relevance of the product.

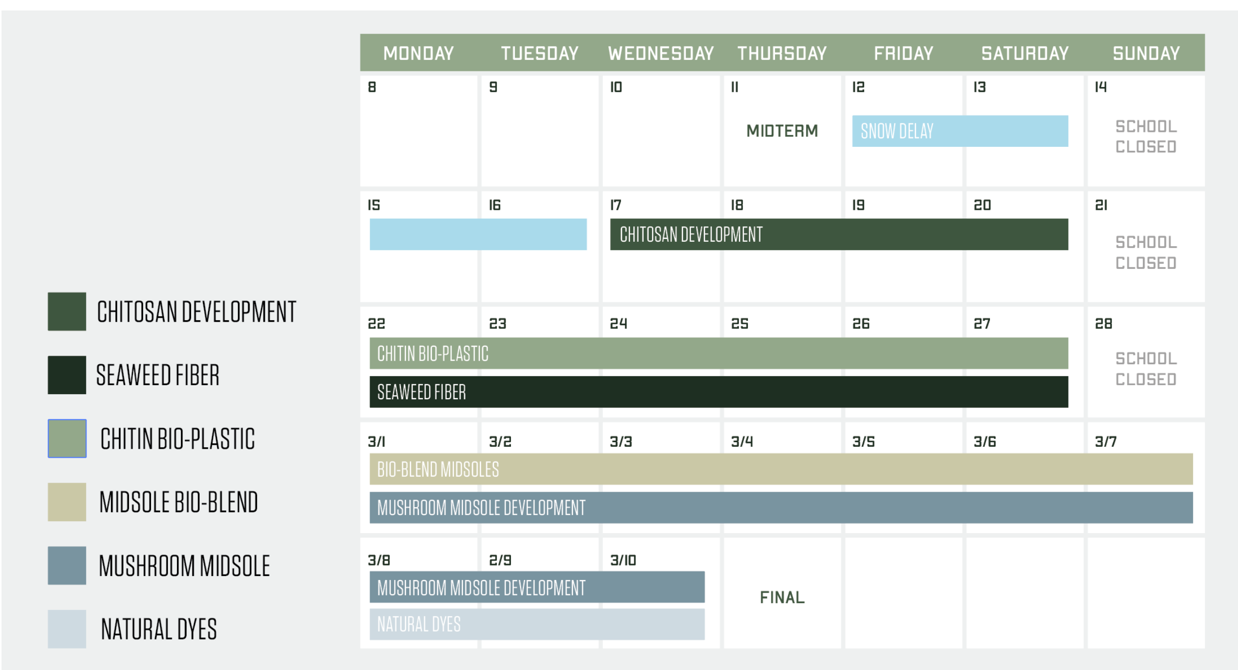


Figure 26. The ideation plan for the material exploration portion of this project.

Figure 27. The ideation plan for the footwear design portion of this project.

Ideation and Prototyping

The true ideation phase began with exploration of stability footwear concepts. Different elements of stability were explored including internal arch bands, external heel counters, supportive lacing systems, guide rails, integrating a medial post, and articulated outsole development. All while keeping the overall aesthetic focus as something that is organic yet sporty. Eventually a final design was determined and the respective linework was created.

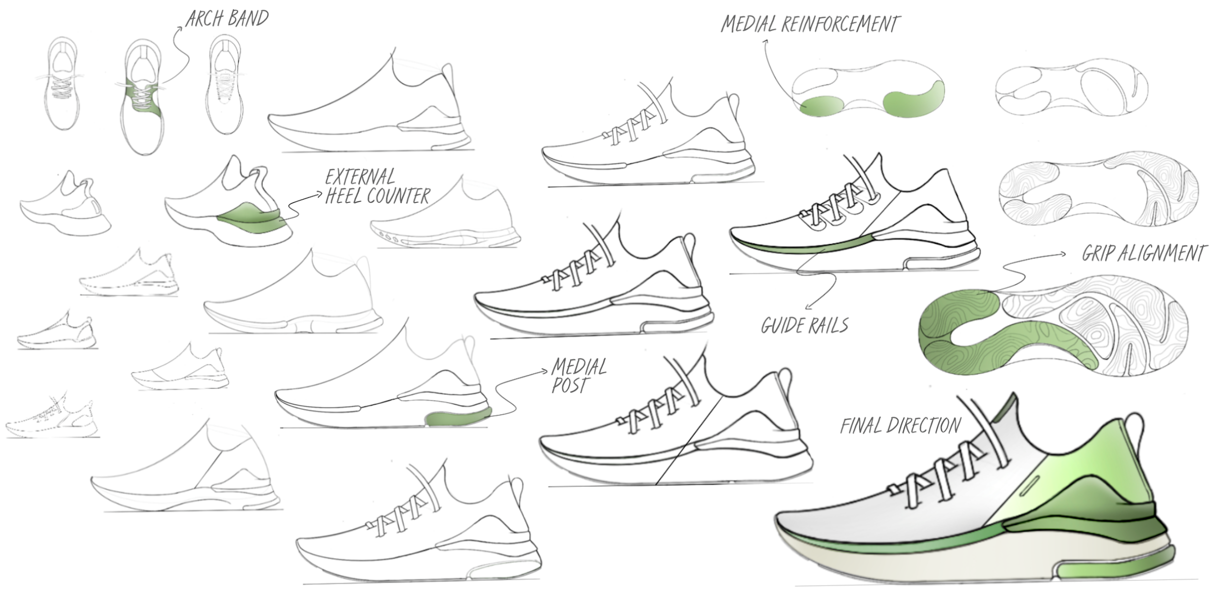


Figure 28. Summation of the ideation process through sketch development.

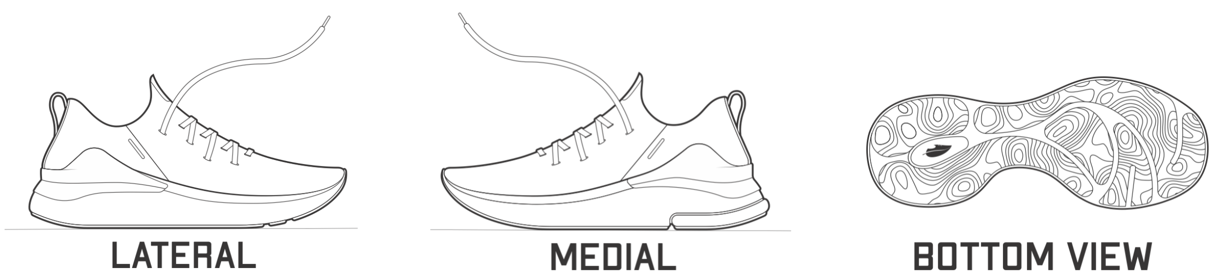


Figure 29. The resulting linework based on the final sketch direction.

From the design direction, certain elements were identified as having the potential to be composed of self-fabricated material, which crossed over into the material exploration phase as indicated above. The first material that was explored was the rigid material needed for the external heel counter. The proposed material for this was to use shellfish-based bioplastic, which can be created in four steps - the first three involve reducing shellfish waste down to chitosan powder and the last step being to add white vinegar. Chitosan is the second most abandoned bio-polymer in the world and it can be derived from shellfish or purchased in powder form as a dietary supplement. The goal of this exploration was to test this process for feasibility and functionality. In the end a petri dish sized sample was created by combining 30g of chitin powder in 1L of distilled white vinegar. This indicated that shellfish bioplastic is a feasible alternative for this project for any sort of rigid material. The next steps will be pouring the material into molds and testing performance.

Figure 30. Development process of chitin bioplastic from shell to plastic mold.

Next was the exploration of seaweed based bio-yarns for potential upper material. The bio-yarns are developed by reducing seaweed down to sodium alginate. Once that is complete, 15g of the alginate powder can be blended with 3g of chitosan and 250 mL of water. The resulting slurry is then extruded into a 10% Calcium Carbonate solution via a 100 mL syringe with a blunt tip. This cures the yarn filament resulting in a stretchy yet durable material that is translucent and heat resistant. This material can then be knitted and potentially used as an upper. In the end, I was able to create a 4” x 3” swatch of the yarn to show the materials feasibility as an upper. The next steps will be to continue working on the knitting pattern and working with natural dyeing methods to color the yarn.

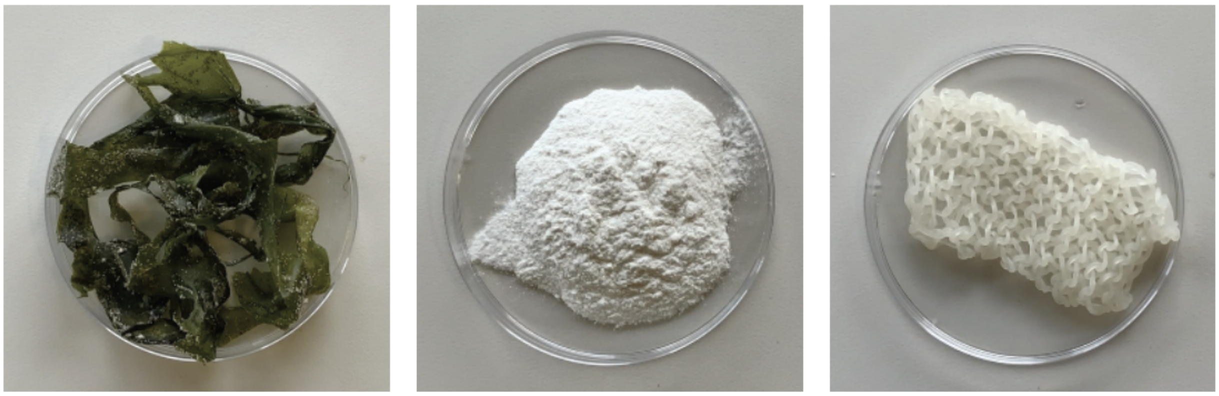


Figure 31. Development of the knitted bio-yarn from seaweed to sodium alginate to bio-yarn.

Once these two materials were complete, more detailed ideation was achieved through 3D modeling programs such as Blender and Gravity Sketch and upper making. The resulting 3D model helped finalize the potential list of materials that will be assembled together at the start of next term based on the patterns determined from the upper making prototyping.

Figure 32. Exploded view of the 3D model made in Gravity Sketch & Blender.

Figure 33. One of the more finalized upper prototypes made in tandem with the 3D model.

Other ensuing steps will be to continue working with Ecovative Designs to produce the mushroom foam midsole material, and intertwine the more dense algae-based foam from Algix to achieve stability characteristics. Another area of stability to address will be to source a bio-based alternative to the carbon fiber shank. Specifically, Bcomp's AmpliTex which is a flax based carbon fiber alternative. The remaining steps will revolve around continuing along towards a final design from this "proof of concept."

Validation planning

The validation plan for this project resides mainly in the overall feasibility of the project, the regionality of sourcing, and the project's ability to be reciprocated. The project will be validated through three metrics. The first being that the final product is created using materials found in the Pacific Northwest. The second validation metric is similar to any other scientific experiment in that the materials created should be able to be easily reciprocated at a local level.

Lastly, the project will require general positive feedback regarding the final model from past product champions and general demographic.

PART III: COLLABORATIVE CREATION & LAUNCH

Project Planning

This term began by revisiting feedback from the critique of the proof of concept pitches. That feedback will help drive the prototyping process and user performance testing in order to refine the concept and come to a final design. General feedback centered around streamlining the bio-materials and exploring more technologies to add stability into the shoe.

Another goal of the term was to establish a relationship with an outside partner. After the review of the proof of concept pitch, I was notified that a Portland State graduate student in the area was studying similar materials named David Crinnon. After initial contact and review of our projects, we decided it would be best to collaborate on our projects moving forward.

Design Iteration

Design iteration began with sketching on the feedback given from the review. A key area of focus during was on the midsole technology. With the shoe being a stability shoe, many people liked the idea of using a shank to stiffen the midsole but its performance benefits. Through prior research I had found a bio-based carbon fiber alternative made from flax, and shortly after the review I was able to source some of this material. Initial sketches were made on how this technology could be implemented, and the changes were then reworked into the CAD model of the midsole. Once the design was finalized the flax fiber was ordered from a distributor and then layed-up using a 3D printed platform that matched the topography of the plate. The flax fiber was hardened using a bio-based resin and then cut and sanded to fit within the midsole.

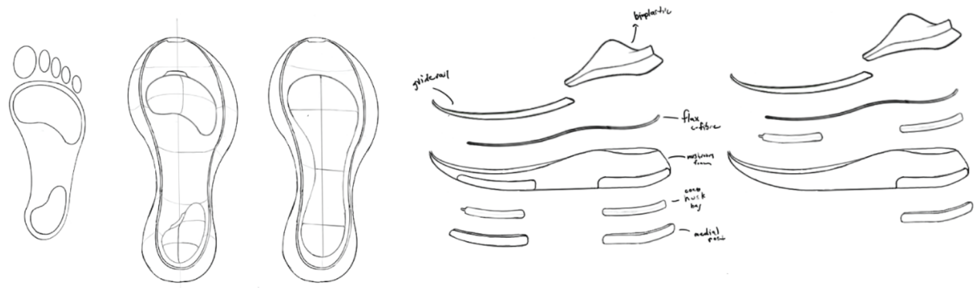


Figure 34. Encapsulated midsole exploration centered around the flax fiber speed plate.

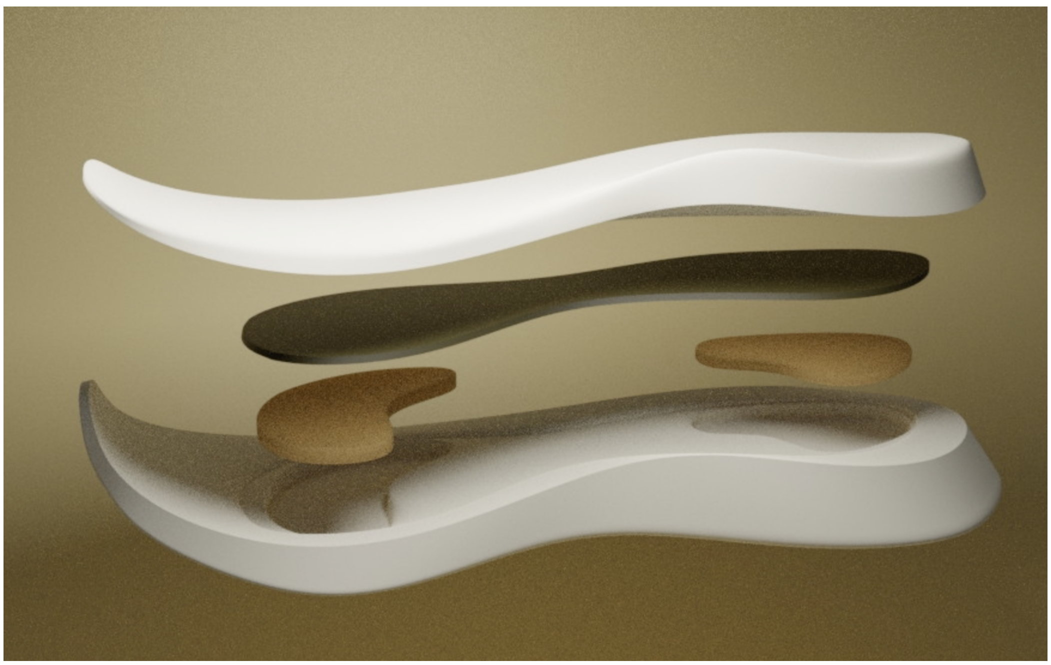


Figure 35. Proposed layering of the flax shank displayed in CAD.

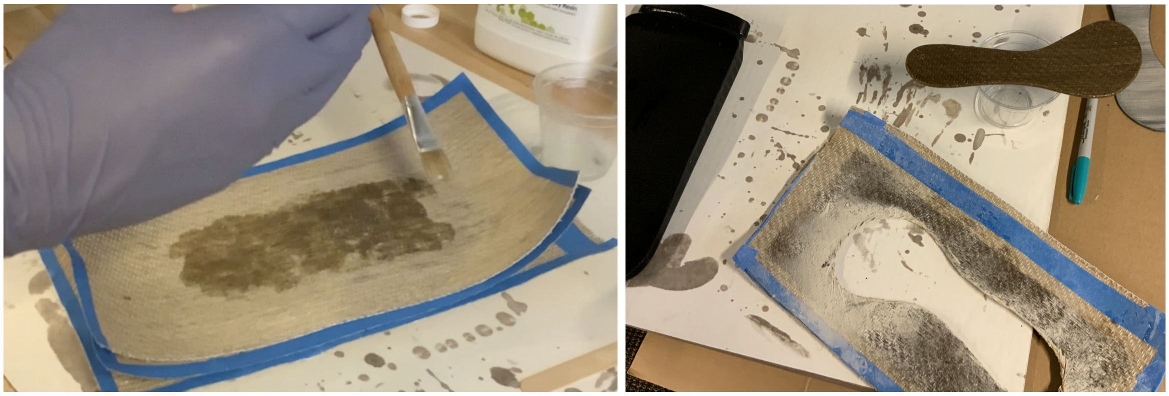


Figure 36. Custom flax fiber lay up process, material cutting, and finishing.

Another initial focus was dying the bio-yarn that was previously created. Natural dyes felt the most fitting for this project, and through research I found that boiling spinach and artichoke for an hour releases greenish-yellow and forest green-brown tannins respectively into the water, which can be used for dying. After the first few tests I began to test other dying methods that made green such as mixing boiled turmeric and red cabbage (with a dash of baking soda). I found that a 49:1 ratio of the turmeric yellow dye to the red cabbage blue dye produced the best green coloration. Other retail natural dyes were also tested deriving from sephora flowers were also experimented with.

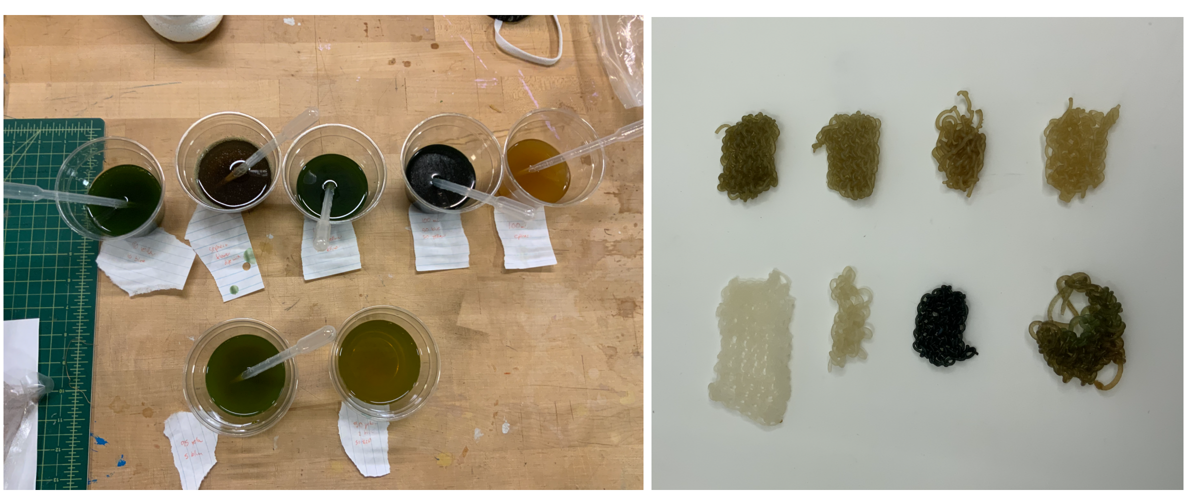


Figure 37. Bio-yarn natural dye exploration.

As for the extrusion process, the same 15g of the alginate powder blended with 3g of chitosan and dissolved in 250 mL of water was kept, however, the material was extruded using a Filastruder filament extruder. This was to create a stronger, more consistent yarn to make the knitting process easier. Enough yarn was extruded using this equipment to hand knit a large swatch capable of covering the forefoot toe-box pattern. It was during the time where it quickly became evident that material exploration was going to consume most of my ideation methods moving forward.

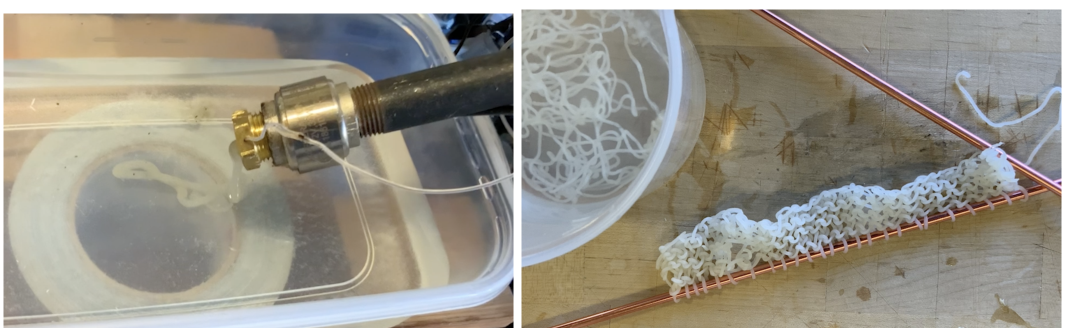


Figure 38. Bio-yarn extrusion via a Filastruder and knitting process.

As for the heel counter, prototypes were printed with a algae-based 3D printer filament in order to create the molds to make for the shellfish bioplastic. However, it quickly became clear that hardening of the bioplastic was uncontrollable and the only other way was to heat set the material to a custom metal mold, which was too expensive and time consuming for this project. Therefore, the heel counter material was changed to the algae-based filament allowing for more branding moments and design details.

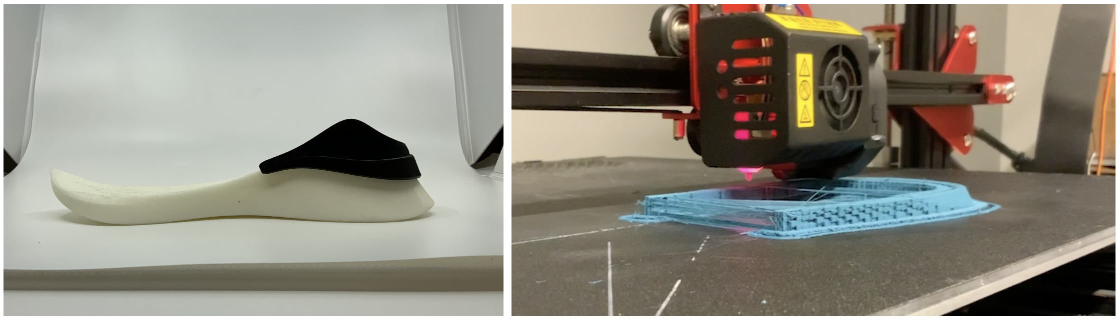


Figure 39. Heel counter exploration and algae-based 3D print.

The last phase of material development was ideating on the midsole material. From initial conversations with David it was clear he had created a new material (similar to the bio-yarn but with a glycerin base) that created a foam like material. The material was made from a mixture of sodium alginate and vegetable-based glycerin. It was also found that dunking this material in a Calcium Chloride bath also cures the material making it stiffer and translucent to an extent. This material was perfect to create a medial post but far too heavy to be used as a midsole at first until I began experimenting with algae-based foams as a possible midsole material.

By exploring the idea of adding ground up bits of algae foam into Smooth-On Flex Foam 17. It was discovered that by adding a more rigid foam (algae foam) to a softer pour-in expanding foam (Smooth-On), one can harden up the original material. So I figured this probably works in reverse in that if you take a heavy foam (like the sodium alginate and glycerin material) and mix in a softer foam that is ground up, the resulting mixture will be lighter and more flexible. Through material testing this held true as as adding in the lighter foam reduced a third of the overall weight. Due to this, a 100% pure mycelium mushroom foam was selected to serve as the midsole material that would be mixed in for the final design based on its weight and flexability.

Figure 40. Midsole exploration and foam integration to influence material hardness.

Design Refinement

As the materials became more finalized the final overall design became more clear. One last design direction was presented to faculty members at the University of Oregon Sports Product Design program and industry professionals. Reviewers suggested morphing the midsole and the guide rails to just a midsole that has built in guide rails. It was also suggested to reorganize the midsole hierarchy in terms of the flax plate and where to place it for best performance.

Figure 41. Design refinement and identification of materiality.

The last part of the shoe that still needed to be finalized was the outsole pattern. A green natural rubber derived from sunflowers was chosen over traditional natural rubber to cut down on transportation emissions and the reliance on the Hevea brasiliensis, which become susceptible to disease during the latex harvesting process which requires stripping away the tree's bark daily. Once the material was selected, a common critique was to sketch more to find a design that was more biophilic than a simple topographic map, and so a new design was created to be featured on the bioengineered latex.

Figure 42. Biophilic outsole sketch ideation.

Usability Testing

To test the stability mechanism of the midsole design and the overall performance of the flax fiber plate in comparison to a carbon fiber plate a testing shoe was created in order to compare to some of the most common shoes on the market. The shoes selected to compare the proposed midsole system to were the Nike Zoom Fly 3 and Hoka Rocket X based on the fact that they both feature a carbon fiber plate. While the Nike Speed Plate is for propulsion, the Hoka Rocket X plate is more intended to assist with added stability by stiffening up the midsole.

The testing shoe featured all of the elements of the proposed midsole technology, but an upper from the Nike Zoom Fly 3 was used on this shoe to act as a control and help the wear tester focus solely on the midsole technology. The user was asked to try both sets of shoes, and run around for 5 minutes to compare the performance benefits. The tester was instructed to focus on the stability and speed plate aspects of the midsole unit, and then was asked to rate each shoe on aspects of the plate, the stability, and the overall feel of the shoes.

Based on proprioception, the tester rated the feeling of each shoe’s speed plate on a scale from 1-5 (1 being no feeling and 5 begging springy). The test shoe scored a 3 meaning the flax fiber was moderately noticeable. In comparison the Nike Zoom Fly 3 also scored a 3 and the

Hoka Carbon X scored a 2. The same situation was used to analyze the stability of each shoe by rating them on a scale from 1-5 (1 being unstable and 5 being stable). The test shoe scored a 4 whereas the Nike Zoom Fly 3 scored a 2 and the Hoka Carbon X scored a 3. Lastly the shoe was rated on the overall feeling of the shoe from 1 to 5 (1 being poor and 5 being great). The test shoe scored a 4, the Nike Zoom Fly 3 scored a 2, and the Hoka Rocket X scored a 3. The results of this testing prove that performance does not have to be sacrificed when you are designing for sustainability, and that bio-based shoes can perform just as well as any shoe on the market for those willing to invest.

Figure 43. Testing process between the proposed design and shoes in the current marketplace.

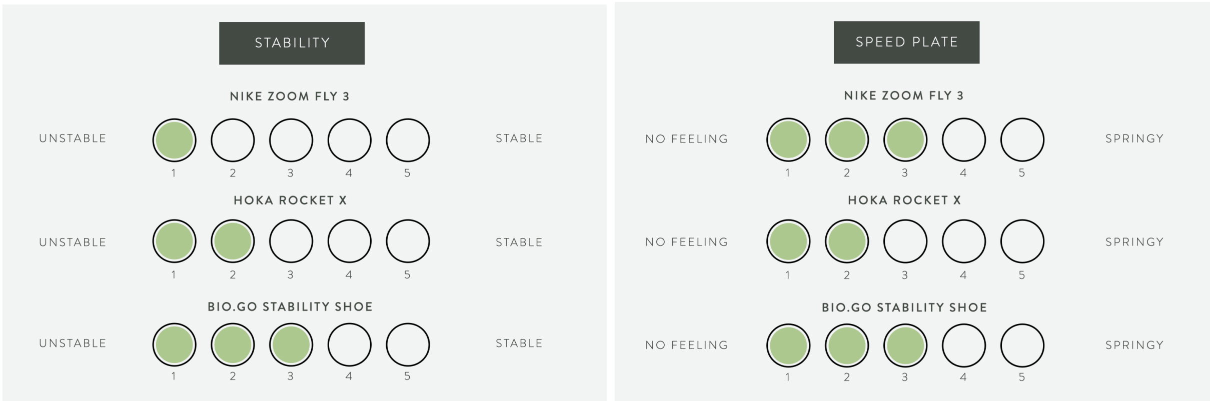


Figure 44. Testing results analyzing the test shoes effectiveness in terms of the speed plate and the overall stability.

Final Product

After a successful testing, the final product including the upper was assembled. The resulting product featured a sunflower latex full length outsole for extra grip. The medial post was created using a custom mixture of sodium alginate and vegetable based glycerin to act as a dual density foam in comparison to the midsole material and assist the runner in refraining from overpronation and remaining in a neutral position. The two part midsole featured the same mixture of sodium alginate and vegetable based glycerin, however, ground up bits of 100% mycelium were added into the material to cut weight and improve flexibility. In between the two part midsole was a flax fiber plate for added stability and propulsion. The insole was composed of cork recycled from the wine industry, which allowed for user comfort and natural responsiveness. The heel counter consisted of an algae based 3D filament that was 3D printed to allow for added additional branded moments. The upper was primarily composed of the seaweed-based bio-yarn in the forefoot to allow for breathability and lined with bamboo silk. The rear part of the upper featured a seaweed and eucalyptus based knit and a mushroom foam and bamboo silk lining for added comfort. The laces were made from 100% hemp and the tongue tab made from Kombucha leather.

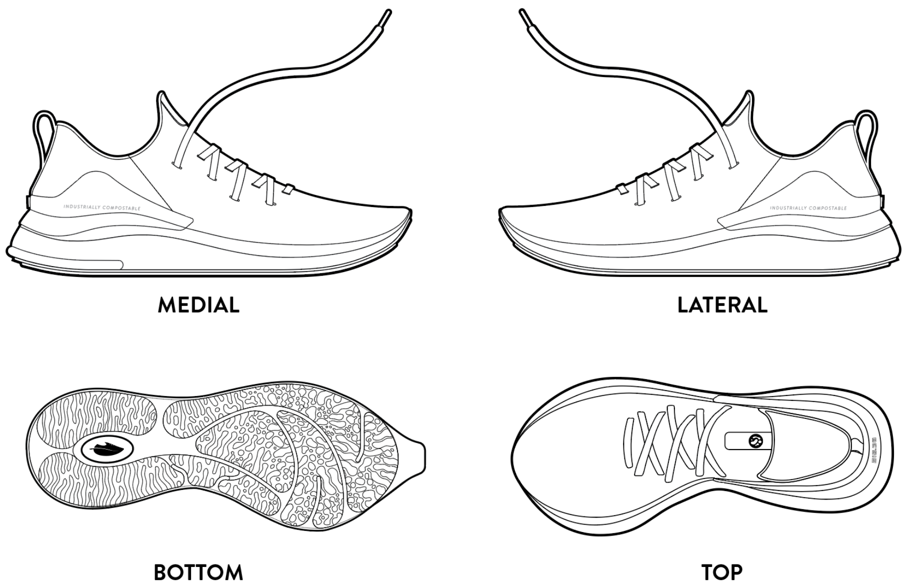


Figure 45. Final linework of the overall design.

Figure 46. Medial view of the final model.

Packaging and Branding

To reduce waste this product will be sold primarily through online retail. The online retail environment will resemble that of the sustainable footwear market and provide the appropriate information for the user including features, benefits, and composting instructions. To continue pushing materials as the focus of the overall brand much of the same materials will be used to create the specific packaging. Once purchased, users will be sent the shoes in a shoe box made from mushrooms and encased in a shellfish-based bioplastic bag. All of this will continue to push the sustainable aspect of the brand and tie together material focus of the project and brand.

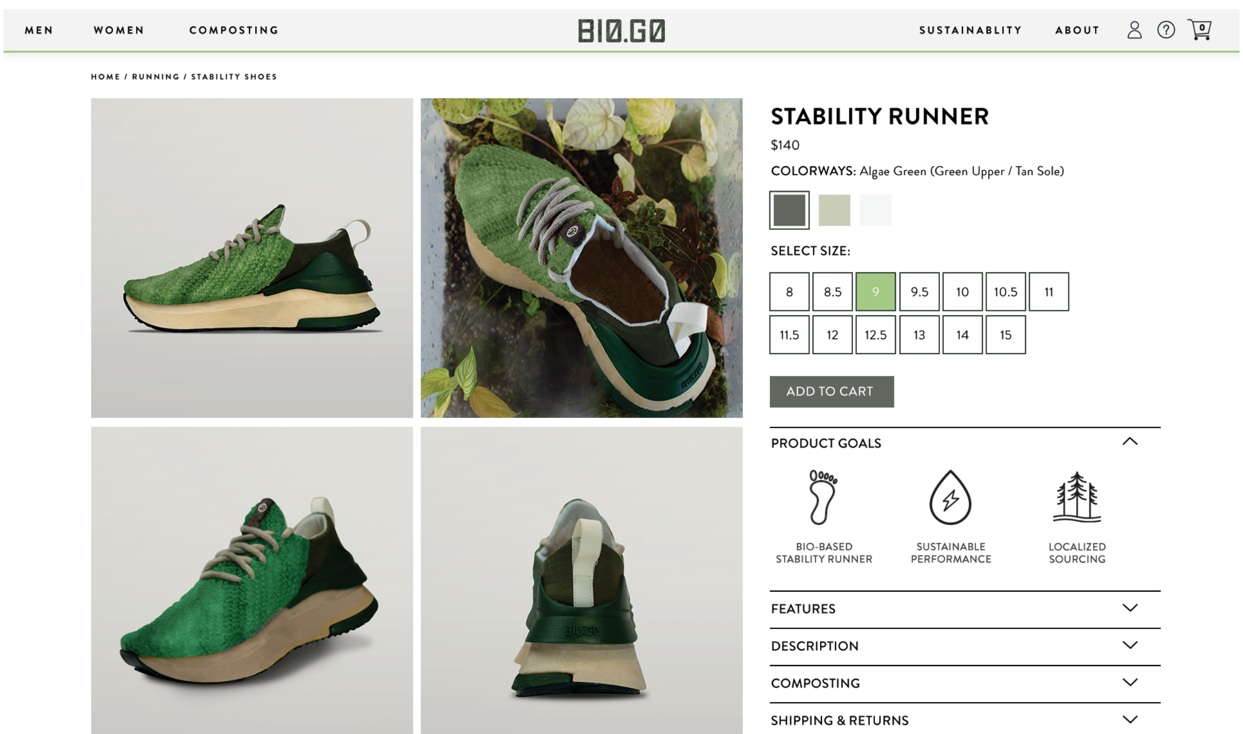


Figure 47. Proposed retail environment mock-up.

PART III: FINAL PRESENTATION


BIO.GO
RUN FOR TOMORROW

HOW DO YOU CONVINCE SOMEONE A PROBLEM IS WORTH SOLVING?

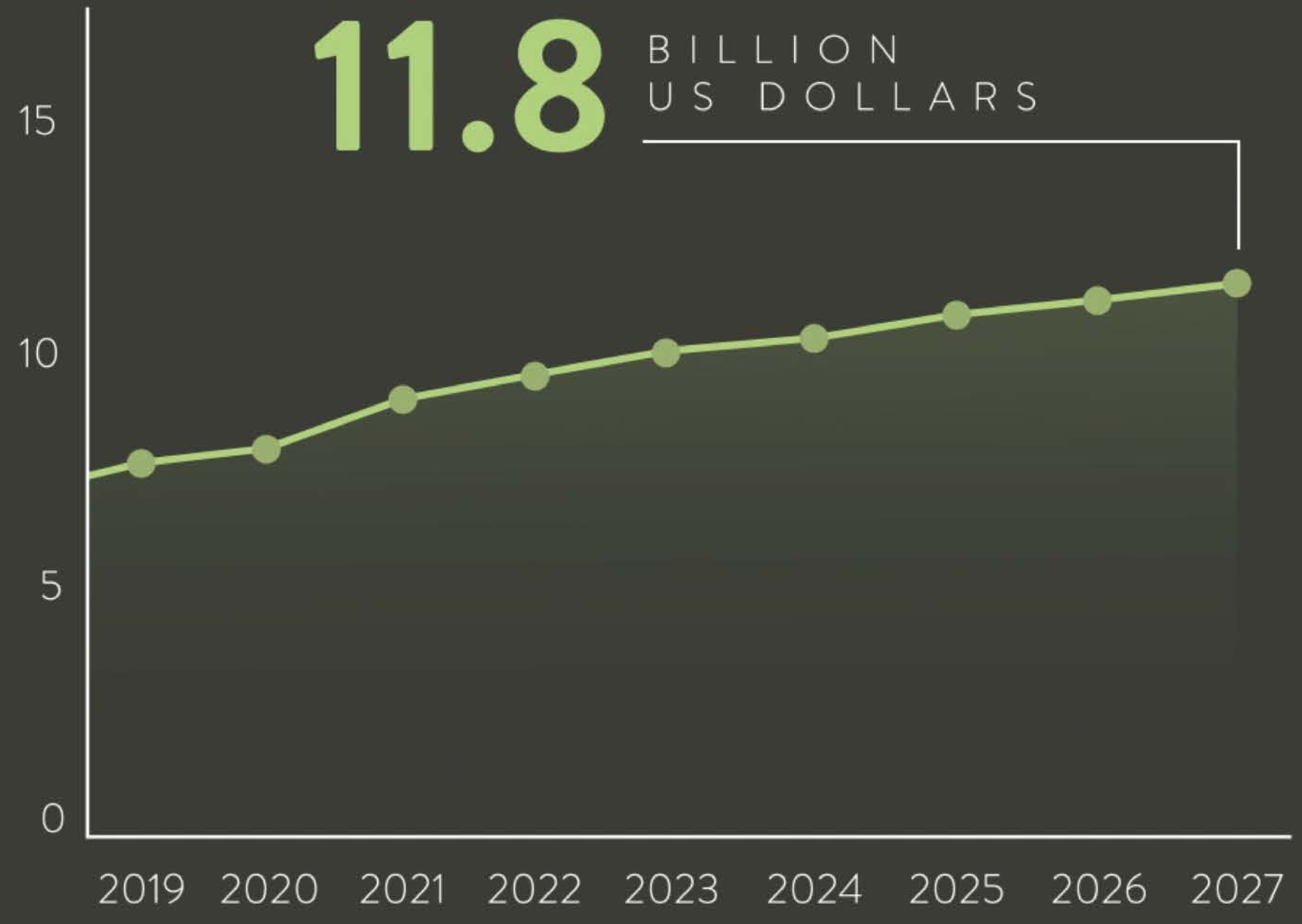
THE PROBLEM

THE WORLD HAS CHANGED...

110+ COUNTRIES

HAVE PLEDGED TO GO CARBON NEUTRAL BY 2050

THE
SUSTAINABLE FOOTWEAR MARKET



AN EVER-CHANGING WORLD

THE FOOTWEAR INDUSTRY IS LAGGING...

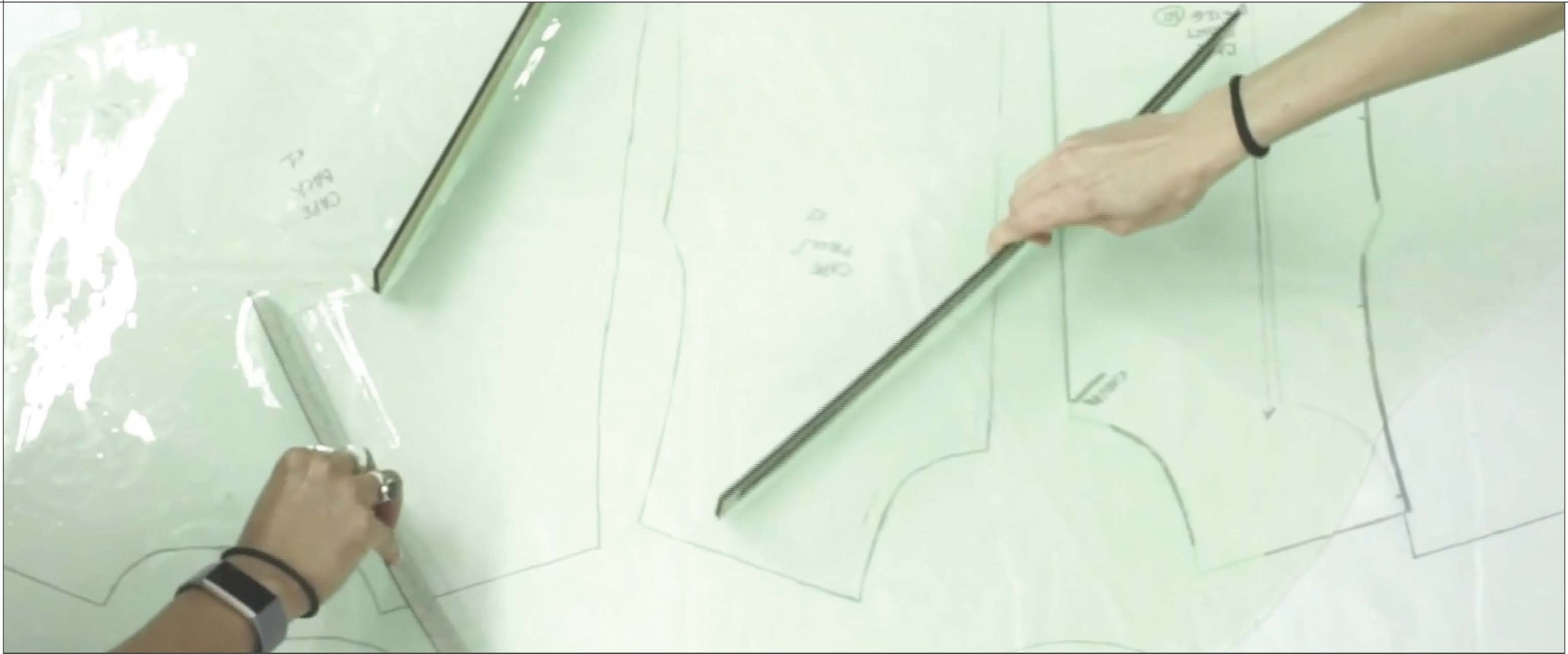
300 MILLION PAIRS OF SHOES THROWN AWAY ANNUALLY

700 MILLION METRIC TONS OF CARBON EMISSIONS

TODAYS FOOTWEAR

8 MILLION METRIC TONS OF PLASTIC ARE DUMPED INTO OUR OCEANS EVERY YEAR.

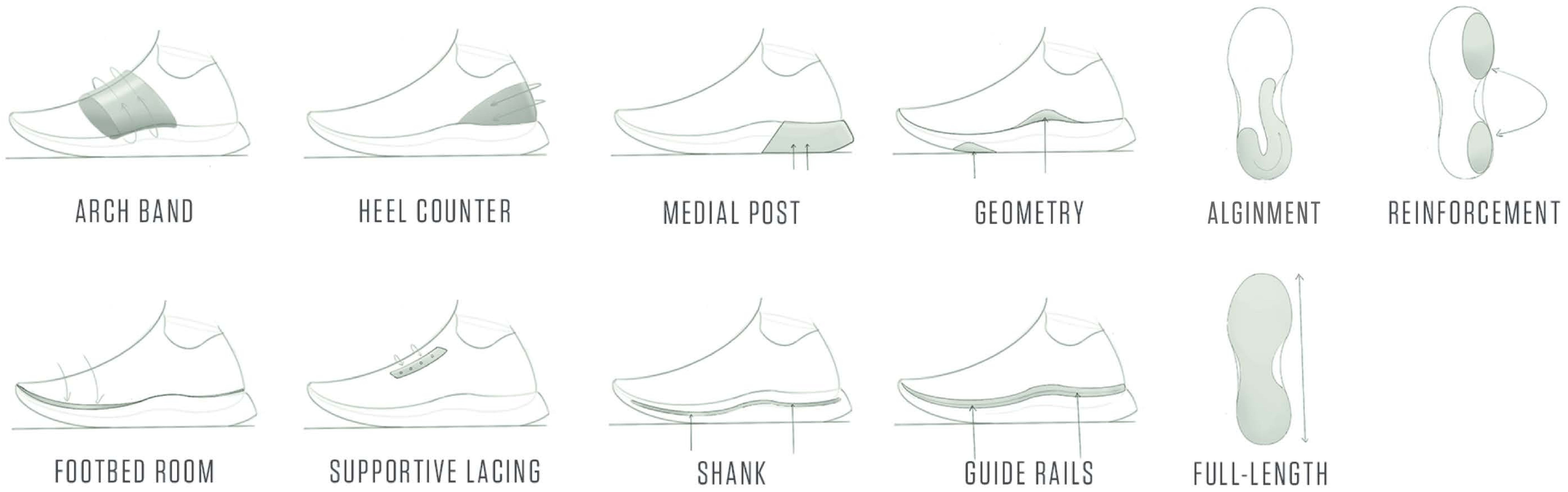
EVEN THE MORE SUSTAINABLE FOOTWEAR OPTIONS CONTAIN HYBRID BIO-MATERIALS WHICH CAN CONTRIBUTE TO MICROPLASTICS THAT POISON OUR ENVIRONMENT.



HOW MIGHT WE CREATE BETTER SUSTAINABLE RUNNING FOOTWEAR THROUGH REGIONAL IN-SITU EXPLORATION AND BIOFABRICATION FOR A ZERO WASTE AND ZERO CARBON FUTURE.

DESIGN PROCESS

SOLVING FOR STABILITY



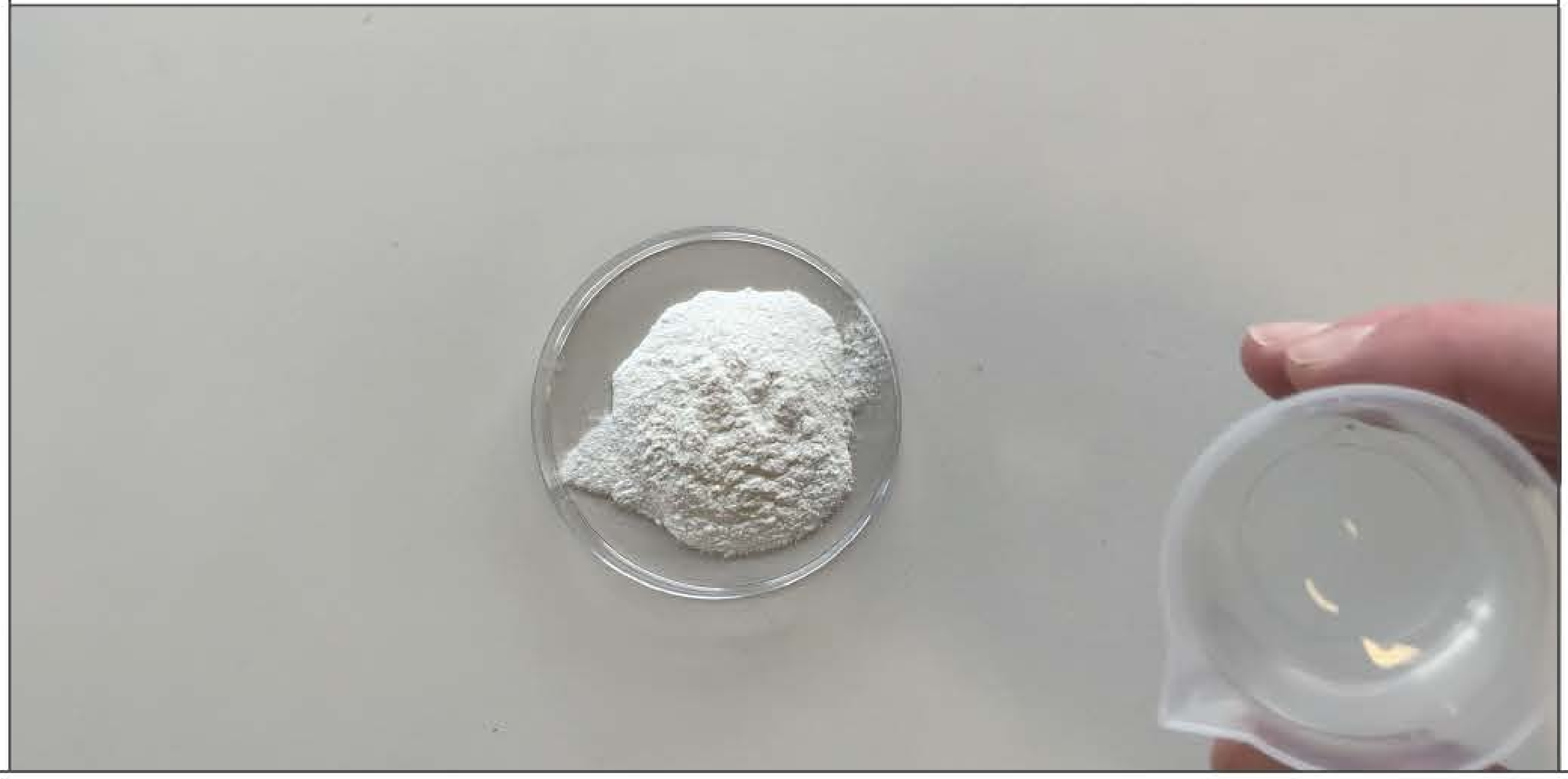
DESIGN
PROCESS

DESIGNING THE FIRST BIO-BASED STABILITY SHOE

MATERIAL EXPLORATION

SHELLFISH BIO-PLASTIC

SEAWEED BIO-YARN



SEAWEED YARN

BIOPLASTICS

MUSHROOM FOAM

FLAX FIBER

ALGINATE GLYCERIN

ALGAE FOAM

BIO-LEATHER

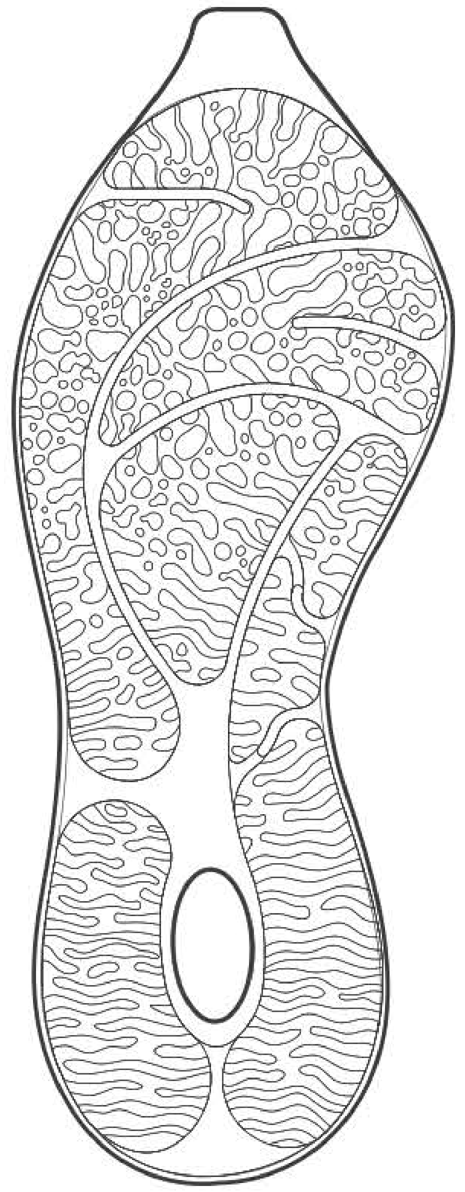
NATURAL LATEX

COCONUT COIR

FINAL SOLUTION

MEDIAL

LATERAL



TRACTION


HEMP LACES
MUSHROOM LINING
BIO-LEATHER BRANDING
SEAWEED X EUCALYPTUS KNIT
ALGAE-BASED BIO-PLATSTIC
HEEL COUNUTER
INDUSTRIALLY COMPOSTABLE
SEAWEED- BASED BIO-YARN
CORK INSOLE
FLAX FIBER SPEED PLATE
ALGINATE / GLYCERIN / MUSHROOM
FOAM MIDSOLE
ALGINATE X VEGETABLE GLYCERIN
MEDIAL POST
SUNFLOWER LATEX OUTSOLE

PROTOTYPING

ATHLETE TESTING

PERFORMANCE TEST >>>

STABILITY

NIKE ZOOM FLY 3

UNSTABLE ● ○ ○ ○ ○ STABLE
1 2 3 4 5

HOKA ROCKET X

UNSTABLE ● ● ○ ○ ○ STABLE
1 2 3 4 5

BIO.GO STABILITY SHOE

UNSTABLE ● ● ● ○ ○ STABLE
1 2 3 4 5

ATHLETE TESTING

PERFORMANCE TEST >>>

SPEED PLATE

NIKE ZOOM FLY 3

NO FEELING 1 2 3 4 5 SPRINGY

HOKA ROCKET X

NO FEELING 1 2 3 4 5 SPRINGY

BIO.GO STABILITY SHOE

NO FEELING 1 2 3 4 5 SPRINGY

THIS SHOE IS INDUSTRIALLY COMPOSTABLE AND HAS A SEED EMBEDDED WITHIN IT SO ENCOURAGING USERS TO BURY THE SHOES ONCE THEY ARE DONE WITH THEM.

COMPOSTING

PRODUCT

AFTERLIFE


BIO.GO
BIOPHILIC. LOCALIZED. MORAL IMPERATIVE.

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