White paper: Data-driven process personalizes footwear with silicone benefits

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3D-printable liquid silicone rubber helps advance the future of customized footwear to improve comfort, fit and performance

Introduction

A primary challenge for the footwear industry is the true individuality of shoe wearers; no two feet are alike. Achieving footwear customization using conventional midsole molds and materials is nearly impossible. Yet, in collaboration with Dow, the Innovation Lab of ECCO Shoes (ILE) has launched its QUANT-U technology implemented for footwear customization services. Its intuitive three-step process combines data-driven design with additive manufacturing, resulting in customized 3D-printed silicone rubber midsoles, quantified by the wearer. This offers significant potential to create a new paradigm or model for personalizing shoe fit, comfort and performance.

The result may be an excellent marriage of future material and technology, with a scalable way to produce custom footwear components. Key properties of silicone rubber can enable important features that consumers seek – cushioning, rebound, fit and support, which offer a comfortable shoe for easier walking and better feeling. Applied with additive manufacturing (AM), also known as “3D printing,” liquid silicone rubber (LSR) can be fabricated precisely and made to function according to the specific needs of individual users.

In addition to this footwear application, LSR has a bright future in 3D-printed materials to deliver comfort along with performance. An entire product normally does not need to be customized; we can target the part that functions at the interface with the human body. In the case of personalizing footwear, a connected relationship with consumers, a precise data-driven digital twin and the use of AM enable customization of select components specific to the wearer.

Figure 1. No two feet are alike

Driving factors for additive manufacturing

AM capabilities are growing rapidly, changing the way products are designed and produced. Factors such as ease in development for customized products, reduction in manufacturing cost and process downtime, government investments, and development of new industrial-grade AM materials are driving the growth of the industry. Currently, the usage trend is shifting from prototyping to production-scale manufacturing of functional parts in diverse markets such as automotive, healthcare, aerospace and consumer goods.

The global demand for real-time customization is increasing, with more companies investing in AM capabilities for prototyping and small-scale production.

The key advantages for AM technology are:

- No tooling investment required
- Reduced time to market
- On-demand production
- Part customization without manufacturing penalty
- Fewer design constraints to allow more complex geometries

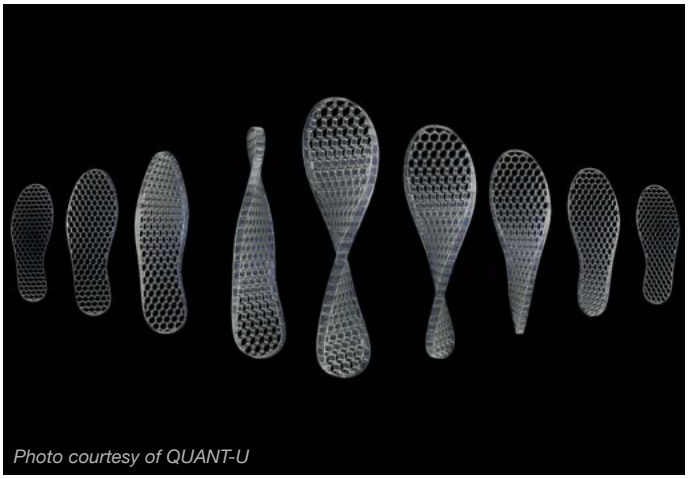

Figure 2. Mass customization potential with 3D printing

As consumers increasingly expect products and services that feel tailored to personal tastes or needs, mass customization will continue growing, and digital manufacturing technologies such as AM will play a crucial role in driving it forward. AM economically can unlock new customization possibilities because it does not require expensive tooling changes based on individual specifications. In AM, the digital design is transferred directly to a 3D printer. This enables agile change exploration, offering a cost-effective way to test the market and to reduce the time to commercialization.

Moreover, AM such as 3D printing is viewed widely as a very relevant factor in relation to sustainability. It tends to reduce waste, using only the material that is needed and producing only on demand. AM also enables more efficient designs that can contribute to lowering manufacturing times and inventory requirements, which can help to reduce labor costs and energy consumption.

AM and the footwear industry

The best shoe is the one made for you – tailored to your foot structure, personal preferences and gait. This is because no two feet are the same. Combining intuitive data-capturing technology and AM, the Innovation Lab of ECCO (ILE) successfully developed a process for the modern equivalent of yesteryear's custom-crafted footwear.

Traditionally, shoes are made using a last – a plastic, metal or wooden foot shape specific to the individual style and size of shoe. The last is developed to reflect the average consumer of the shoe so that the manufacturer can target the mass population in each given size. New lasts are required when changes are made to the sole of the shoe. These can be costly and time-consuming to manufacture.

By focusing AM efforts on customization of functional components such as the midsole, these can be made to according to the wearer's requirements, while the shoe itself can still be made through traditional manufacturing. This allows for a scaled and cost-effective implementation of this technology.

Figure 3. Design freedom for footwear personalization

AM can be a standalone option or can be combined with a brand's traditional supply chain. This offers design freedom to tailor the degree of alteration to the shoe and process, ranging from one or more key components to exploring the potential of making an entire new shoe wholly manufactured using 3D printing in AM processes.

There are some cases of AM being used in today's footwear industry. However, most of these initiatives focus on the whole sole of the shoe, with little to no degree of data-driven design in the process unlike the ILE project strategy. Inevitably, the highly critical element for the success of this new horizon of services is strengthening the link or intimacy between the manufacturer and consumer. The relationship must enable generating sufficient knowledge (data input) for tailoring the AM process and design materials to address the exact needs of the consumer.

Silicone features and benefits

Silicone is the common name for a group of synthetic polymeric materials. A silicone material basically consists of molecules with a silicon-oxygen backbone with two organic groups attached to each silicon atom.

Figure 4. Silicone molecular structure

The most common type of silicone materials are Polydimethylsiloxanes (PDMS) with a molecular structure as shown in Figure 4, where R = CH3. The element silicon (Si), from which silicones are derived, is the second most abundant element on earth (after oxygen), and it occurs naturally as silicon oxide or silica, in sand and quartz and as metal silicates in most rocks.

Although silicone can be engineered to take on an incredible variety of forms and properties, many types of silicone share common features that offer them distinct advantages over other materials. The molecular architecture of these materials offers valuable combinations of performance properties such as excellent elasticity, flexibility, water repellency, durability, colorability and much more.

For footwear applications, some of the key features and user benefits of silicone elastomers (rubber) include:

- **Long-term elasticity, pliability and flexibility**: Stretch them, twist them, drop things on them and compress them, and they quickly will return to their original shape.
- **Stability under challenging conditions**: Silicones are highly resistant to damage and degradation from extreme temperatures, thermal shock, chemicals and oxidation.
- **Resistance to aging**: Silicones do not harden, crack, peel, crumble, dry out, rot or become brittle with age the way carbon-based organic materials do.
- **Inertness**: Silicones don't react with most materials, unless intentionally designed to do so.
- **Water repellency**: Silicone materials are naturally hydrophobic, making them right for all types of waterproofing applications.

This distinctive combination of characteristics enables silicones to outlast and outperform most organic materials. Silicones make existing materials work better – more efficiently, longer and more reliably. They fuel our imaginations and make new products possible. In a society that runs on performance and strives for sustainability, silicones can, for the above-mentioned reasons, be seen as important tools. They enable softness, shape retention and foamable capabilities for athletic footwear that offers shock absorption, comfort and durability.

3D printing of silicone rubber and how it enables AM in footwear

Silicones have many performance attributes that make them the material of choice in liquid additive manufacturing (LAM) for enhancing product customization. Silicone rubber has exceptional elasticity and is transformed into an excellent cushioning medium for midsoles with the 3D printing process.

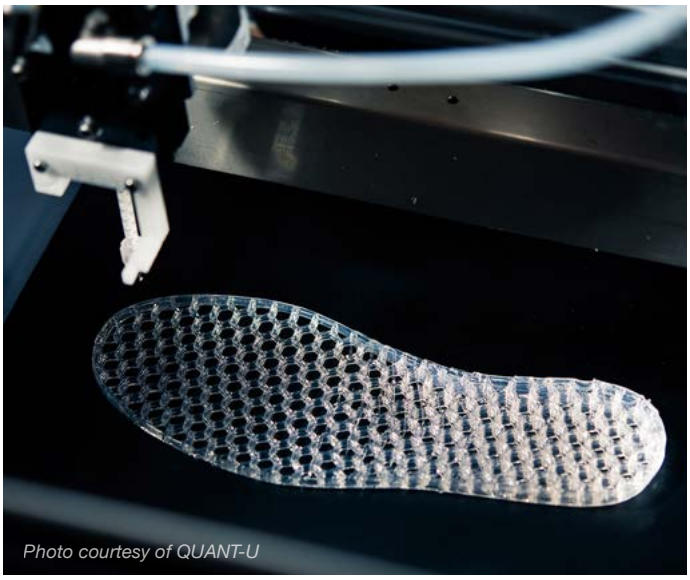

Figure 5. LAM 3D printing of silicone midsole

In combination with an optimized printing design developed by ILE, 3D-printed silicone rubber offers excellent cushioning during impact and excellent rebound resilience during walking. That helps create enhanced ergonomics, contributing to a more even and progressive wear and tear of the shoe. The customized midsole design offers individualized comfort, and that may motivate the user to keep the shoes for a longer time, or to simply replace the interior without replacing the whole shoe.

Silicone rubbers are stable over a wide temperature range and humidity conditions, which are essential performance attributes for footwear component applications. A silicone rubber midsole will offer the same properties whether you are wearing the shoes in winter or summer or in high- or low-temperature regions.

Engineered especially for 3D printing applications such as this, **SILASTIC™ 3D 3335 Liquid Silicone Rubber (LSR)** is a highly transparent material, which is an excellent choice for applications where clarity and transparency are vital attributes. Using compatible color packs and precision-dosing equipment, designers can also 3D-print this high-performing LSR in a range of colors – all with the same base product. This helps to ensure that the final performance will be virtually the same, regardless of which color the designer chooses.

Furthermore, the material's properties closely match those of molded LSR, allowing an easy transfer into injection-molding processes for high-volume manufacturing.

SILASTIC™ 3D 3335 LSR introduces the power and versatility of silicone rubber technology into the realm of LAM. Customers can now combine the distinctively beneficial properties of silicone rubber with faster prototype development and small-series production of highly complex parts.

In shoes, it is important to optimize main parameters, such as energy return, cushioning, stability and fit. Silicone rubber is an excellent choice for such optimizations; however, it is the combination of 3D printing and silicone rubber's inherent properties that allow this, by developing structures unobtainable through molding.

Compared with foam, 3D-printed LSR midsoles offer a more responsive stride, long-term static and dynamic mechanical behavior, and a reduction in overall plantar pressure. The custom midsoles ILE created using **SILASTIC™ 3D 3335 LSR** are a durable option for offering tailored function to each consumer.*

The product's contribution to design freedom has earned it a BIG Innovation Award for 2019. The annual awards program, presented by the Business Intelligence Group, recognizes organizations, products and people that bring new ideas to life.

More information about the advantages and possible uses of this LSR can be found in Dow Product Information for **SILASTIC™ 3D 3335 Liquid Silicone Rubber**.

Take a step into the future of footwear

QUANT-U is a technology suite developed by ILE – the Innovation Lab of ECCO Shoes – that enables customization services. 3D scanning, both online and in-store, is used to capture the contour of each foot of a customer to optimize the fit of the silicone rubber midsoles for them and their chosen shoe.

Wearable sensors (in-store) and an online configurator offer data that is used to customize the cushioning and rebound properties of the midsole, specific to the wearer's gait and their preferences. Gait is the unique locomotive pattern of a person.

The service is an intuitive three-step process based on real-time analysis, data-driven design and localized 3D printing. This specialized customization process includes:

- **3D foot-scanning and walking analysis**: In only 30 seconds, 3D scanners determine the individual orthotic fit. This data tells us the right shoe size and arch height for the midsoles. Wearable sensors build an accurate representation of how one moves in their environment.
- **Digital twin and data-driven design**: The combination of sensor data and the anatomical scan offers a unique digital footprint. This defines the midsoles' footbed shape design.
- **Localized 3D printing**: Using 3D-printable silicone rubber, the customized midsoles can be printed within two hours. With cloud-based services, components can be printed from any location – ready to be picked up in-store or shipped.

The midsoles of upgradeable ECCO shoes are replaced with 3D-printed silicone rubber components. ILE considers the midsoles as the functional heart of the shoe which offer a great deal of the shoe's comfort, fit and performance.

For more information, visit the QUANT-U website at **quant-u.com**. Videos of the process can be found at **vimeo.com/quantu**.

With more than four years of research, ILE has established consumer advantages for 3D-printed silicone rubber in the footwear industry. Initial QUANT-U research focused on establishing tunable benefits to the end-consumer by determining what material and design parameters are best manipulated by algorithms and translated into viable customizing parameters.

This enables a distinctive experience for all types of consumers. The QUANT-U technology, a data-driven process and distinctive customizing service, is expected to expand into more targeted options focused on performance, health and safety.


Photo courtesy of QUANT-U


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Figure 6. Intuitive three-step process

Research findings of 3D-printed silicone rubber midsoles in footwear

The benefits of 3D-printed silicone rubber based on algorithms developed by ILE can fall into two categories: physical and climatic.

Physical: Parameters focused on the cushioning, rebound, stability and fit of the footwear.

- Ranging from a soft memory foam to elastic rubber that offers the highest rebound and elasticity.
- Varying the performance of the midsole, tailored to the needs of the individual customer.

Climatic: Parameters focused on the temperature and humidity regulation within a shoe.

- Reduces the temperature of the internal environment by increasing circulation.
- Reduces humidity of the internal environment.
- Elevating the feet above a porous structure, allowing them to remain drier for longer.

Adjusting each of these parameters according to the wearer's activity, chosen shoe style and typical usage environment can help ensure improved comfort, fit and performance.

Comfort can be evaluated with the following factors:

- Step-in comfort is the initial feeling of the shoe on the foot. This is affected by cushioning of the midsole and the fit of the shoe. A well-fitted shoe allows the foot to move freely, supports the natural stride and allows the foot to breathe.
- Dynamic, long-term comfort is determined by the ability of the shoe to support the feet. This includes giving more rebound in the stride and keeping the shoes cool and dry in most conditions.
- Step-out comfort is a term ILE uses to define the feeling of the feet after wearing shoes.

Fit considers that feet are not just unique to the individual, but rather that any given person may have a difference of anywhere from half a size to more than two sizes between their feet. This difference is not just in terms of length, but also in the volume and mass of the foot.

A shoe that fits too tightly will restrict the foot from moving naturally within the shoe. Discomfort can arise from regions that constrict the foot, and as the day progresses, this tightness can lead to further discomfort or pain as the foot naturally swells. A shoe that is too loose will move independently of the foot, which can lead to instability and rubbing, leading to pain and blistering.

Most aftermarket inserts are made for the wearer but not the shoe. The position and form of these inserts change according to the shoes, affecting the fit.

QUANT-U's 3D-printed silicone rubber midsoles are made for the wearer and shoe, offering improved comfort, fit and performance. In the research, wearers perceived the fit to be better across wearing occasions for silicone rubber midsoles compared to a foam equivalent. The key takeaway from the fit analysis was that QUANT-U allows customization where the shoe can be made tighter or looser depending on the contour of each foot, while standard inserts can only reduce the volume of the shoe by adding an aftermarket component within an already completed product.

The scope of the research included further physical and climatic benefits along with a novel method for testing footwear: The "individual response grid," based on the differences in body mass, foot shape and gait. There were noticeable differences and preferences for each style of footbed, specific to the wearer and not simply at the population level – a truly tailored footwear option.

Research is underway to test the effects specific to the wearer, with indications that customization will offer more granular benefits when tuned to the individual needs and preferences of the wearer.

For more information on the research, visit the QUANT-U research website at **ecco-plus.com/research**.

What's to come?

ILE successfully has established a portfolio of research-backed parameters that support the use of customized 3D-printed silicone rubber midsoles, thereby allowing them to optimize the comfort and fit of casual footwear for consumers. Now, ILE is focusing on bringing this customization to the global consumer while also exploring targeted options ranging from athletic footwear to professional workwear. 3D-printed silicone rubber is a disruptive force, allowing ECCO to usher in a new wave of footwear that offers additional benefits to the wearer.

QUANT-U technology – A commercial customization project

QUANT-U implemented as a customization service offers a seamless omnichannel experience for both in-store and online customization. Initially, the system scans the contours of each foot and captures the wearer's gait. Then the customer indicates their individual preferences, intended uses and typical usage environments for the shoes. This data is used to develop the virtual twin of the customer.

ILE developed a special set of algorithms for the 3D printers that allow liquid silicone rubber to achieve enhanced mechanical properties *only* possible throughout a 3D-printing process. These algorithms interpret data from the virtual twin to design a digital midsole ready to be printed in silicone. Localized 3D printing allows an ability to fulfill a customer's order in as little as two hours, ready to be picked up or shipped globally, to combine with their selected upgradeable shoe.

Because the midsoles are removeable and interchangeable, the same shoe can offer multiple functions depending on daily routine and activities. For example, a wearer could use one silicone rubber version made with increased rebound to offer an extra spring in their step while walking or cycling to work. Once they arrive, they could exchange it with a highly cushioned and supportive silicone rubber version to cradle and comfort each foot during periods of extended sitting and standing.

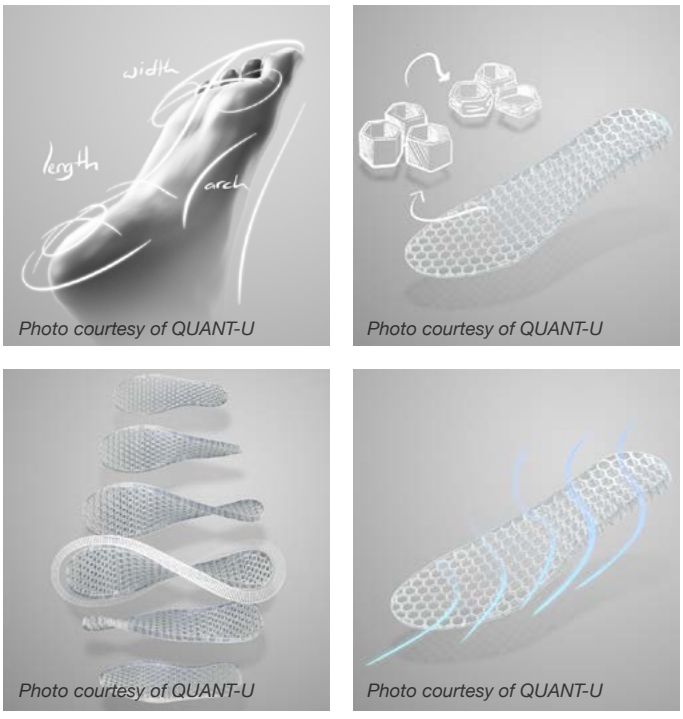

Figure 8. Four pillars of customized comfort

The ultimate goal is to offer consumers control over their shoes. Offering an omnichannel platform allows customers to interact with the brand however they wish, from anywhere in the world, while taking control of how their shoe will function for them. QUANT-U first went live to the public in 2016 and was invited to showcase at prestigious design and technology fairs, including Milan Design Week and CES® 2019 and 2020, the global stage for innovation. It then moved to a global roadshow of limited and exclusive pop-up events in ECCO-owned stores and premium consumer outlets. QUANT-U has established itself as a novel, market-leading customization service that is consumer-centric, using technology to develop a dialogue between consumers and brand.

Through research and testing, ILE has formed a new definition of comfort to elevate an individual's wearing experience, leveraging the benefits of 3D-printed silicone rubber. These can be simplified to the following terms:

- **Continuous cushioning** – Offering shock absorption, all-day comfort and support where you need it with every step
- **Precisely tuned fit** – Customized to help ensure excellent wearability, cradling your foot into the footbed and complementing your natural gait cycle
- **Consistent life-cycle performance** – Supporting your shoes to be dynamic and responsive while offering the necessary strength and durability to keep you moving*
- **Ventilation** – Designed to offer increased airflow with each step to keep your feet fresh and healthy*

QUANT-U is now expanding from an exploratory novel technology into an ECCO staple product, as part of the ECCO PLUS collection. The customization project launched as a commercial ECCO service in 2021 during exclusive global pop-up events in select premium outlets. With the number of available styles of upgradeable footwear expanding from sneakers to men's and women's formal shoes, the horizon of customization services is ever-expanding.

Summary and closing statements

As the number of consumers demanding personalized products such as custom-fit footwear grow, additive manufacturing (AM) and advanced materials will help companies keep up with addressing this demand. AM helps to produce customized products faster and more cost-effectively, enabling companies to offer their customers a greater say in how their products will look and perform. This initiative also could help companies focus strategic attention on making more efficient design and production choices.

The future is customized and connected, and if today's research indicates anything, it is that consumers are ready and willing to adopt these new technologies if they offer added value in the form of health, wellness and performance optimization. With the benefits offered by both the inherent properties of silicone and those derived from 3D-printing the final structure, customization of footwear exemplifies such optimization. This customization can go far beyond consumer comfort, into performance footwear such as running and outdoor shoes, along with targeted fields including health and wellness, medical care, and workwear.

Learn more

To learn more about ECCO's QUANT-U project and technology, visit **quant-u.com**.

For more information about Dow's silicone elastomer innovations for 3D printing, visit **dow.com/consumer3Dprint**.

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Research disclaimer

**Research conducted with the VU biomechanics department. A range of 3D-printed midsoles used in conjunction with leather/foam inlays were tested compared to standard polyurethane components, in ECCO Shoes proprietary design and development footwear, under controlled conditions using gold-standard biomechanics and environmental equipment. Life cycle of footbeds was measured in controlled lab conditions in a simulated environment to replicate 450 km of use.*

Images: Photos courtesy of QUANT-U

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