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IEEE-SA Industry Connections White Paper

IEEE Industry Connections (IEEE-IC) Personalized Digital Last (a Women's Example)—The Tool Required to Enable Mass Customization

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Acknowledgements

Gneiss Concept is an American start-up company based in Washington state and founded in 2016. Since then, the company has been working on developing manufacturing improvements for mass customization. Involvement in IEEE 3D Body Processing Industry Connections Working Group

ELSE Corp is an Italian start-up company based in Milan and founded in 2014. Since then, the company has been working on design and development of a technologically technologically-advanced Cloud SaaS API platform on support of business module “Virtual Retail” (or “no-stock retail”) for the consumer goods—apparel and footwear industry. The platform E.L.S.E. (Exclusive Luxury Shopping Experience) is aimed at providing an extraordinary new Customer Shopping Experience in 3D (applications, web, mobile apps, Virtual Reality, Augmented and Mixed Reality environments), and support in its core the services of Mass Product Customization and cloud based Hybrid Manufacturing, by integrating all their components and processes into brands’ and retailers’ e-Commerce, CRM, ERP, and PLM systems.

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

PDF: ISBN 978-1-5044-4860-4 STDVA23106

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IEEE Industry Connections (IEEE-IC) Personalized Digital Last (a Women's Example)—The Tool Required to Enable Mass Customization

Abstract

This white paper examines the development of a personalized digital last and the impact on the role of footwear technicians. As the personalized digital last becomes the basis of future footwear production, the role of footwear technicians may expand to include a broader definition of fit, maintaining libraries of different lasts, and maintaining quality safeguards for mass customized of footwear. Though this paper focuses on women's footwear, the issue of fit is universal for men, women, and children. The techniques described in this paper, can be utilized for most footwear segments.

1. Introduction

For more than 100 years, shoemakers have worked to provide women stylish shoes, with the premise that average foot parameters could be adequately accommodated with sized lasts regardless of foot size or shape. The well-honed shoe last is a core part of a brand's design and an integral part of the individual brand's success. However, the current purchasing experience for the customer feels equivalent to a "wild goose chase"—an expression meaning "a foolish and hopeless pursuit of something unattainable." The customer may find the stylish shoe that she would like to purchase but is then forced to make a compromise between her individual foot requirements and the shapes provided by the shoe brand. The model of "sell what you've created," based on standard sizes (and standard styles) should become "design what can be sold." The concept of customized footwear, however, is a century-long discussion. In 1902, Gooding was recorded as saying "Every woman has not a size 4B (UK) fitting foot, yet every woman is entitled to the same shoe appearance regardless of the size of her feet." (Golding [5]).[1]

The time is ripe for the footwear industry to provide customers with what they really need—stylish shoes that fit and serve the intended function. Driven by the traditional fashion calendar, the industry places high-volume orders well in advance with supply too often exceeding actual demand. This results in markdowns, which many shoppers expect and anticipate, leading them to over-consume. For those customers who are outside of the size range that the brands purchased from the manufacturers, the choice becomes "none-at-all" and purchases are not made. In the context of mass customization, brands may offer too many choices that do not

[1] Information on citations can be found in Section 6.

appeal to the customers or may lead to a "paradox of choice" overwhelming the customer (Schwartz [15]).

Most shoes are designed for a certain demographic by style. Expanding the definition of fit, the brands can expand who would purchase their products. Anecdotally, customers are self-selecting which brands to purchase based on fit. For example, for the brands that are known to run narrow, people with wide feet tend to avoid those brands and vice versa. Brands are not only educating the consumer on what to purchase but also what not to purchase. Going forward, this will not be the case with mass customization of footwear. Designers and brands are beginning to take notice as illustrated by the following quote by Stella McCartney (2013) for Style with Elana Fishman [16]: "I want the brand to help people, not make people feel more crappy about themselves," she says, later adding, "At the end of the day, I just want to make women feel better about themselves."

Along with the growth of online sales, comes the growth of returns as customers cannot determine their size. In fact, half of online shoppers have returned fashion items that they purchased online (Mintel Press [10]). While the brick-and-mortar return rate is around 9%, online, it is anywhere from 20% to 50% in the footwear industry since the customer often "purchases" two different sizes with the intent of returning the size that does not fit. This makes some sense since the length of shoes varies from brand to brand. For example, Figure 1 shows a comparison in the length of shoes between different brands for the same U.S. size 8 footwear.

Information taken from size information listed on individual websites

Figure 1 Length of size 8 shoe

Receiving customer information before the sale can reduce the number of fit-related returns by comparing the customers' current shoes with ones that they want to purchase (Winkler [19]). 3D models of the human body or body parts have been in use for some time now for various applications and are becoming ubiquitous in industries such as the apparel manufacturing and retail business. A good number of companies are already working on applications that will take advantage of the availability of 3D body models to provide previously infeasible benefits to customers. Specifically, IEEE 3D Body Processing (3DBP) Industry Connections Group sees this taking place in online retail.

The adoption of mass customization techniques for materials and fit will be driven by a cloud-based integration of 3D/2D CAD systems, a new customer experience of product personalization in 3D, and artificial intelligence (learning the customer's preferences for fit). This will encourage a new industrial product design process for companies and independent designers, leading to the accurate prediction of individual customer's style and size needs. The new technologies and alternative approaches to fashion design, retail sales, and manufacturing will support a disruptive transformational change in the industry, moving it towards a direct-to-consumer, customer-pull approach from the current brands' push approach.

The IEEE 3DBP Industry Connections Group is proposing scanning-related standards to help ensure universally consistent quality information that can be used in transforming data into shoe lasts. IEEE 3DBP was launched as a cross-industry effort to collaborate on exploring standardization of interactions across 3DBP technologies such as 3D body models and associated data. Standardization will improve interoperability, which will ease the development of innovative solutions using body models and accelerate the scalability of 3D body-model-based solutions and applications. Any industry standard will not capture every nuance needed for fitting footwear, however, the quality of the customer data will be understood.

Companies involved in the 3DBP initiative include large retailers, scanner providers, virtual fit providers, CAD tool developers, product manufacturers, and start-ups. They impact consumer goods such as apparel, footwear, and wearable accessories, including eyewear and/or gloves. The industry use cases considered thus far range from size recommendation to product personalization, through bi-directional transformations between 2D patterns and 3D models, custom manufacturing, fit predictions, and simulation.

Since the future of manufacturing will certainly entail digitization, shoe technicians should also realize that how they perform their jobs will be affected. Technicians may want to proactively think about personalized digital fit and the impact to their jobs and brands. Their new roles may expand to include maintaining libraries of different lasts and quality safeguards for mass customized of footwear. Understanding digital fit will become an attribute important to customers and will enhance a brand's image.

2. Fit understanding

This evolution of footwear will require adaptation of mass customization strategies and technologies across the value chain at an industrial scale and at a reasonable cost. The industry can achieve this by focusing on tools that are essential for fit. These tools will involve improvements to data processing and digitizing personalized last production. They could be related to using artificial intelligence (AI) for understanding customer data and their definition of fit to interface with last software such as ShoeMaster®, Roman's CAD™, iCad 3D+, and other last modification software.[2]

Currently, customer-related data can be obtained via smart phone apps, biometric scanners, or legacy and expensive scanners, which are subsequently applied to avatars, foot scans, or manually acquired data. Examples of smart phone apps include IBV foot app, FeetIT foot app, RightShoes, Infigic Technologies, and Aetrex Foot.com. Various foot scanners include IBV (see IBV [7]), Aetrex Technology, Vorum 3D scanner, Tom-Cat Solutions, and InFoot scanner (Kimura, et al. [8]). Comparison apps between customer's feet and footwear include ELSE-Corp's ELSE.shoes, vfitshoes, Strutagio [21], MatchMyFoot, and previously Shoefitr (now operated by Amazon, see TechCrunch.com [19]) to name a few.

Today's traditional designs can impact comfort and foot health. If the volume and overall shape of the toe box does not match the customer's, then the only alternative is to go without or choose footwear that is predisposed to causing foot pathologies. Different foot shapes should be incorporated into the latest design "looks" [4]. One proposal is to design an asymmetric shape that curves around the first toe and slopes gradually around the little toe. These style features could reduce the pressure of the shoe on the forefoot. Recommendations for good-fitting dress shoes include: a geometric match, appropriate depth of toe box, and straight-toe joint angles (Nota Bene [12]).

As shoes get wider, the lengths also increase, even if the stated length stays the same. For example, the arch (or heel-to-ball) length of a 7.5 4E shoe is the same as a 9B shoe. Consequently, the shoe clerks will have customers with wide feet try on longer sizes. However, ball joint girth measurement must also be considered when fitting shoes. That is, a large ball girth measurement can put a customer into a longer shoe than what one would naively assume for stated shoe sizes. Thus, a "longer" shoe may still be too small for some customers.

One of the most important ratios in shoe fitting is the width of the foot to the width of the last (Golding [5]). This has been recognized for more than 116 years. "Virtual Shoe Test Bed" [2] lists seven statistics that are important to fitting: total length, ball width, toe width, toe height, and heel width. The height of the ankle bone should be added to this list, since it is important for shoe comfort (Alemany, et al. [2]). *Elements of Comfort* by Manz-Fortuna [9] notes that last designing requires as many as 35 measurements to cover the length and ball girth, heel width and height, arch fit, heel-to-ball, top-line fit, toe box space, total volume space, etc. The best last is the one with a shape that reasonably matches the customer's foot (Manz-Fortuna [9]).

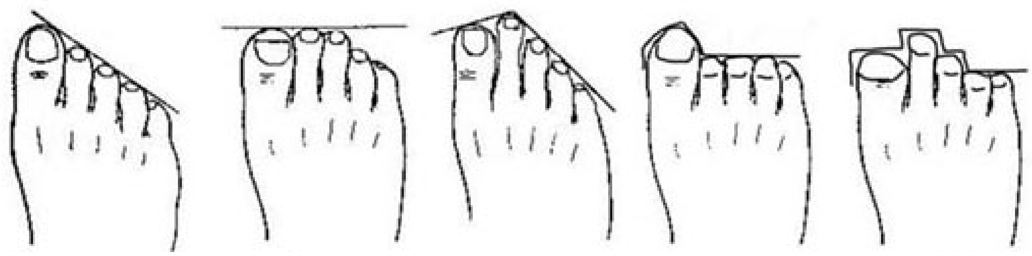
Lasts should be designed for the heel-to-ball length and toe box shape. Note that average ratio of heel-to-ball to foot length is within a narrow percentage of 71% to 73%. The heel-to-ball length is the basis of the Brannock device, which was invented in 1927 to determine shoe size.[3] For shoes to fit properly, it is important for the ball of your foot to rest in the widest part of the forepart of the shoe, which is where the shoe is designed to bend during walking. As most

[2] This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE of these products. Equivalent products may be used if they can be shown to lead to the same results.

[3] Retrieved from http://brannock.com/.

women, (an estimated 90%), wear shoes that are too small, lasts based on the customer's foot allows for proper fit (Munro Shoes [11]).

However, toe box shapes (see Figure 2) usually default to fit an angled foot (Xiong, et al. [21]). With slight modification of the toe box, multiple toe shapes can be comfortably accommodated. Shoe design could be constrained by heel-to-ball length, toe box shape and toe length, not total foot length. Other constraints include characteristics pertaining to: flat feet (lower longitudinal arch), slender feet (small volume or narrow widths), robust feet (large volume, wide and high), short feet (short hindfoot and long forefoot) and long feet (long hindfoot and short forefoot). The type of arch is part of what sets these foot clusters apart (Krauss and Mauch [8]).



angled, squared, rounded, jump, Morton,

Figure 2 Common toe shapes[4]

Not only must the toe box shape and length be considered, but the "bony," "fleshy," or "tenderness" of the customer's foot is a factor to be considered. The "boniness" or slenderness of the foot can dictate the amount of "twist" on the insole shape. Golding also recommends considering the amount of work that someone does while wearing shoes, e.g., with respect to sport shoes, daily wear, or fashion shoes (see Golding [5]).

While designing the production run of various widths to match to stated sizes, the height of the heel should be kept at the proper point for the heel breast, and at the same time keep the toe spring and pitch constant. This allows for one bend in the shank (shank curve) to serve for a whole range of sizes. The upper material and heel height can be made to be the same over all shoes sizes within the style chosen by the customer. See Figure 3 and Figure 4 (Golding [5]).

[4] Image taken from THE ULTIMATE VASS (FOOTWEAR) THREAD (PICTURES, REVIEWS, SIZING, ETC...) after conducting the following YAHOO search: http://us.yhs4.search.yahoo.com/yhs/search =toe+shapes

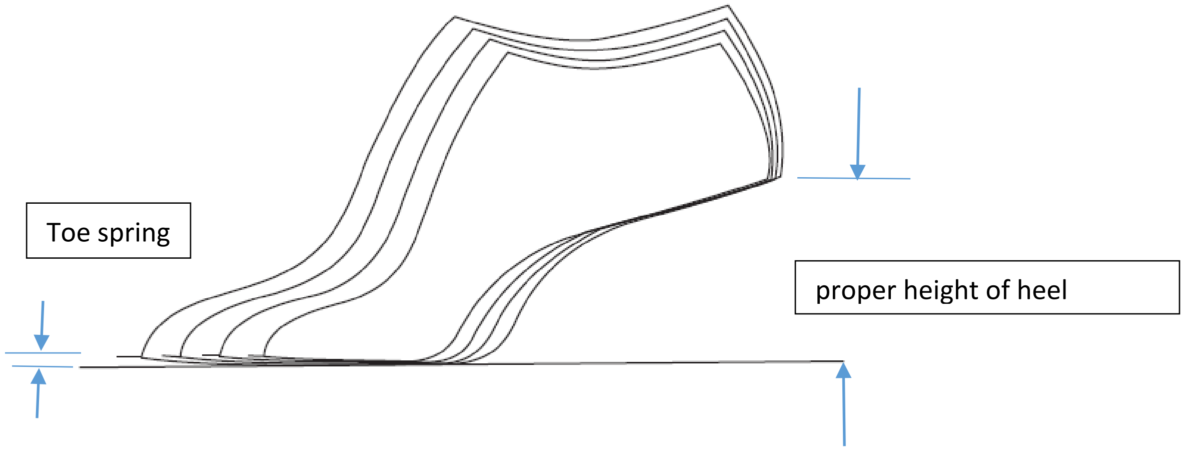


Figure 3 Aligned by toe spring and heel height

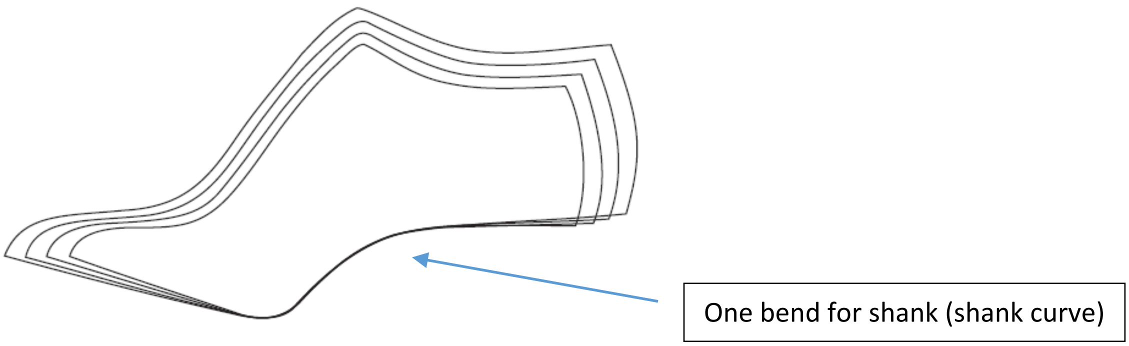


Figure 4 Aligned by shank

3. Customer fit solutions

Simulation of fit between scanned feet (or avatars based on measurements) and footwear last comparison is usually the first step in matching customer data to existing footwear. Fit needs context in terms of movement, function, and compression tolerance of the foot. Consequently, technicians must be trained to implement emerging technologies, especially those related to foot shape and measurement, analysis and design implementation.

At present, the designing and production of personalized shoe lasts is one of the more relevant challenges that mass customization processes are facing—lasts need to be designed and produced in a very short time, a flexible way, and at a very cheap cost because they may only be used once. The present available technologies and solutions do not meet these specific requirements at all; shoe lasts are mostly made of wood, high-density polyethylene (HDPE), or aluminum with the aim of using them several thousand times for standard manufacturing processes and are designed according to standard measures that usually do not fit customer needs.

Currently, lasts are designed with certain sizing (grading and shape) by each brand. As noted previously, each customer must determine if the footwear fabricated from these lasts will work for them, every single time they want to purchase footwear.

Customer fit solutions divide footwear lasts into four different levels: Level 0—Sizing, Level 1—Best fit, Level 2—Temporary modified lasts, and Level 3—True custom/bespoke lasts. Level 0 and Level 1 do not modify how lasts are fabricated and do not change current production methods. Level 2 and Level 3 require a method of temporary lasts.

Level 0—Sizing

Sizing introduces another form of waste in the supply chain and for the retailers. Retailers must purchase several items per size and per style. The factories' efficiency improves, but waste is pushed further along the supply chain to the retailer. Some sizes are sold out too soon and other sizes have leftover inventory.

A major issue with sizing (SterlingLast [17]) is that there are various global sizing systems as wells as brands that have their own lasts and sizing. The most common are identified as U.S. and Canada, Europe, UK and South Africa, Japan, China, Korea, Mondopoint, Australia, Mexico, Brazil, and Russia. The intervals between sizes can range from 5 mm to 7.5 mm depending on the classification of footwear. This does not include the various designations for widths. As stated previously, fit for the customer is determined by trial and error.

Footwear graded with various sizes also requires retailers to optimize stock depending on their customers. Retailers (at least in the U.S. or UK) tend to stock "medium" or "average" over the certain lengths but limit the number of widths available. This may not provide footwear for most of their customers. For example, the SATRA Technology report on foot dimensions statistics [13] finds that offering, "a large range of UK sizes one through 11 in average ('D') fitting accommodates only 24.5% of UK women, and requires 11 items in store. By offering a reduced shoe size range and increased width fitting range, such as UK sizes five to seven in fitting 'C' to 'E', the population coverage rises to 47% with nine items in store." Reviewing various U.S. footwear websites in April 2018, the same pattern is observed. For example, for U.S. sizes 8 and 8.5, Target offers 88.1% of items in medium, 6.6% of items in wide, and none in narrow width; Walmart offers 97.9% of items in medium, 5.8% of items in wide, and 3.2% in narrow; and Zappos offers 98.4% of items in medium, 13.5% of items in wide, 4.2% of items in WW, and 7.6% in narrow.

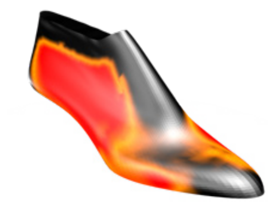
From fashion footwear to running shoes, the recommendation for the fit are similar. Runner's World has a good list to check for fit (Allyn [3]). A personalized digital last would allow most customers to achieve proper fit instead of just a few, as noted by SATRA.

1) Heel should fit snug, but not tight.
2) A shoe's upper should feel snug and secure around the instep.
3) Foot should be able to move side-to-side in the shoe without crossing over the edge of the insole. Should be able to pinch a quarter inch (6 mm) of upper material along the widest part of the foot.
4) A thumb's width of space between the longest toe and the end of the shoe. The toes should also wiggle freely up and down.

5) The shoe should bend and crease along the same line the foot flexes.
6) Pinpoint shoes that match the foot's contours and movements.

Level 1—Best fit

Comparison apps between customer's feet and footwear such as ELSE-Corp's ELSE.shoes can be described by virtual fitting algorithms for best-size and best-style matching. They have collected datasets related to all metrics of all shoe last styles of their brand partners and industrial partners, collection in all sizes available; as well as the 3D models of feet and feet metrics. These customers could still purchase off-the-shelf footwear; virtual fit algorithms help to narrow down the footwear to try on. If the inventory is in stock or in a nearby store, then they could purchase footwear that day or the next. Figure 5 shows an example of fit, with red being too tight a fit for the customer and yellow being only a slightly tight fit for the customer.



Reprinted with permission from ELSE Corp

Figure 5 Example of fit

To increase the number of the best-fit options, brands may want to offer popular styles with various lasts to appeal to a wider range of customers. For example, the same style may use lasts that have higher arch, flatter toe box, or narrower heels; however, to the customer, the style is equivalent, with a fit is close to personalized.

The virtual fit algorithms will need to be easy to use and accurate for both the customer and brands. The brands will need to allow access to the comparison product information to the virtual fit software provider so that their brand is included in the comparisons for the customer.

Level 2—Temporary modified last

Not all customers can fit with current lasts. They may not need orthotics but may have common issues such as bunions, which need a combination last (e.g., very narrow heel, wider toe box), higher arch, or wider area across the ball of the foot. Some of the "best fit" customers may choose to have a modified last for a better fit.

In mass customization processes, shoemakers need shoe lasts designed from specific measures of the customer's feet acquired via 3D scanning systems. A last is modified with 3D printed patches that can withstand the footwear fabrication processes. These patches are on Made-to-Measure zones "MTM zones" (most critical and well-known zones). The patches should be expanded to include combination lasts (start with narrow heel and widen along the foot). If someone has a combination last, then the lateral and medial toe and ball zones will need to run together and along the last. This allows for a temporary modified last to work as a combination last when the foot is merely a “V” shape instead of the “U” shape. (Women tend to have a “V” shape as they age, and the ball of the foot expands.)

Brands need to contract with factories that are set up for mass customization of footwear. The modified lasts can be produced internally at the factory rather than at its supplier. This allows the factories to improve their capabilities and expand their business model. By paying attention to individual consumer needs and providing service rather than simply goods, European producers could win back their market positions and keep their factories in the EU. In this regard, mass customization and product personalization can put European footwear companies in the position of moving the competition onto grounds that are much more favorable to them than the old ones in which production volumes and low costs seem to matter more than anything else.

The temporary modified last breaks with mass and variant production where products are made-to-stock; customized shoes are only produced when an order is placed by an end-consumer. Shoes are then assembled-to-order (made-to-order), based on pre-fabricated materials and components or completely made-to-order for an individual consumer (made-to-measure). Other than the lasts being slightly different, the rest of the footwear is made with current methods.

Expect a decrease in off-the-shelf purchases, even with up to three-week delays in customer fulfillment. However, these customers already anticipate this scenario as other made-to-order and made-to-measure companies have set the stage, including Feetz and Shoes of Prey.

In the U.S., bespoke shoes tend to be made on a standard last that has been temporarily modified. This is usually done by hand and the customer is charged for this service. However, since a “best fit” has to be done first, modifications are dependent on the skill of the shoemaker and customer measurements only.

Level 3—True custom/bespoke last

A small community of bespoke manufacturers still exist to provide expensive shoes to the well-off. In this type of operation, consumers are greeted, inquired, scanned, measured, questioned, supported, and assisted in their purchase experience, transforming a simple necessary act (buying a good pushed by a need) into a ritual that makes the consumer feel that the company is trying to do more than simply sell an item; it is learning more about the customer’s desires and expectations.

In the U.S., the true bespoke last tends to be reserved for orthopedic footwear where the expense may be covered by health insurance.

4. Training and implementation of mass customization for footwear technicians

When personalized digital lasts come to be in common usage, current training courses will become outdated and will need to be enhanced with new topics. Training courses from SATRA and German College of Footwear Design and Technology are general examples of these training courses.

The training from SATRA Accredited Footwear Technologist [14] includes a module on lasts, fitting and comfort; one on testing; and one on lean manufacturing. These modules may need to be expanded to include "best fit" understanding and unique customer specific lasts, but the other modules on materials, constructions, product design, risk assessment and quality assurance, and industrial footwear may not be impacted. The key for the training is that, even though the last is specific to the customer, the footwear style and materials are the same.

The training course from German College of Footwear Design and Technology[5] may need to include "best fit" and unique customer specific lasts in modules 6, 7, and 9. These modules deal with work methodology; project planning with CAD systems; and planning, implementation, and commenting on operation sequences. The other modules may be able to remain the same. The key for this course will be understanding how the CAD systems are utilized not only at the beginning of the project but throughout the product lifecycle. The implementation of operation sequences will need to include tracking the customer's lasts and customer's patterns throughout the fabrication of footwear.

As brands implement unique customer lasts, perhaps starting with "best fit", they may have several lasts for same style. In this case, the footwear technician could be responsible for a library of lasts per style, various foot forms of different shapes (i.e., high arch version, flatter feet, and different toe boxes), and setting up tech pack's work instructions to include travelers (used to track the progress of operations in the fabrication process). Since the footwear produced is equivalent, independent of the last used, tech pack's work instructions, materials specified, and accessories listed would remain the same. The quality of the manufacture/fabrication, ensuring accessories and footwear meets quality standards and safety legislation, working closely with the buying and design team, construction, and safety issues can all be vetted over all standard sizes. Advising on fit may vary depending on the last used.

Since "best fit" or customer-specific lasts are dependent on the function of the footwear, footwear technicians may work with software programmers in determining the starting parameters of fit. The starting point for fit may vary for dress shoe versus a hiking boot or athletic footwear.

5. Summary

As the model of "sell what you've created," based on standard sizes (and standard styles) turns into "design what can be sold" as personalized digital lasts and becomes the basis of footwear production in the future, the role of the footwear technicians may expand to include a broader definition of fit, maintaining libraries of different lasts, and maintaining quality safeguards for mass customized.

[5] Information can be found at http://www.english-dsf.info/.

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