Universität Bremen

Innovative Skills for an Old Vocation

Innovative Skills for Design

WP 04

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Content

1 Introduction

This manual is a joint product of all partners from the Erasmus+ project ”Innovative Skills for an Old Vocation” (ISOV, 2024-1-DE02-KA220-VET-000254492, https://isov-project.eu/). As all sectors, the sector of industrial footwear production faces the mega-trends of globalisation, digitalisation and sustainability. Main aims of the project are the development, pedagogical structuring and piloting of courses for apprentices, students and/or employees in industrial footwear production in Germany, Portugal and Romania, based on scientifically developed impact analyses on which of the dimensions of the trends influence which of the 18 Spheres of Activity (SoA) of the sector. The courses and the manuals refer to 12 chosen concrete SoA in which the participants are working, are supposed to work, or want to work.

Basic materials for the courses are the manuals. As the estimated impact of the dimensions respective sub-dimensions of the trends differ between partner countries and as the equipment of training providers with modern technology is differing, as well, the manuals follow a modular structure:

Chapter 2 documents the, partly shortened or updated, “state of the art” manual from previous projects “Integrating Companies in a Sustainable Apprenticeship System” (ICSAS, http://icsas-project.eu/) respective “Developing Innovative and Attractive Continuous Vocational Education and Training (DIA-CVET, https://dia-cvet.eu/).

Chapters 3-5 illustrate the expected impact of the various (sub-)dimensions of the 3 trends in the near future (up to 5 years) on the work-processes of the chosen SoA.

This approach has the huge advantage that, for example, if the sub-dimension “additive manufacturing” is estimated to have high impact on a certain SoA and a training provider has no 3-d printer, he can, with respect to this sub-dimension, rely on the “old” manual referring to subtractive manufacturing – but still impart the impact of other subdimensions, where the equipment is available.

Finally, chapter 6 offers a case study of apparent good practice, demonstrating not only what to teach but also, exemplarily, how to teach.

Or, to put it different, this manual should not be read as a “receipt”, where all condiments should be added or imparted in a fixed row and a defined quantity – but as a “toolbox”, aiming at inspiring trainers to impart not only “state of the art” knowledge, skills and competences (KSC) – but to prepare their apprentices, students or participants in continuous vocational education and training (CVET) for upcoming work-processes.

2 Footwear Design

This manual was updated based on the training material titled Design developed in the framework of the project "Developing Innovative and Attractive Continuous Vocational Education and Training (DIA-CVET, https://dia-cvet.eu/)

Footwear design is a complex process that involves a variety of individuals, including consumers, retailers, marketing, designers, product developers, engineers, technicians and even scientists and doctors.

Footwear design stages:

- Research – brand identity, consumer requirements, current trends, materials, technologies, innovations, competitors, etc.
- Design brief – establishing parameters like features, characteristics, construction, technical solutions, materials, design constraints, target group, target price;
- Design conceptualisation – inspiration, concept, sketches, virtual modelling, renderings;
- Product development – patternmaking, technical sheets;
- Prototyping – rapid prototyping, samples, testing, modifications;
- Testing – final products approval by company management, marketing team, and customers.

2.1 Overview of the design process

Footwear design is a multidisciplinary and collaborative process that brings together a wide range of professionals, each contributing essential knowledge, skills, and perspectives. Successful footwear development does not depend solely on the designer's creativity. It involves **consumers**, **retailers**, **marketing experts**, **product developers**, **engineers**, **technicians**, **materials specialists**, and sometimes even **scientists and healthcare professionals**. This diversity reflects the complexity of modern footwear, which must meet aesthetic, functional, ergonomic, technological, and sustainability requirements simultaneously (Vieira, 2023[1]).

To manage this complexity, the footwear creation process is typically divided into a series of stages that guide a product from the **initial idea** to the **final approved model**. Each stage has a specific purpose and involves different types of expertise (Curteza et al., 2005[2]; Mihai et al., 2009[3]; Chen et al., 2017[4]). Together, they form a structured workflow that helps companies deliver innovative, comfortable, and commercially successful footwear. Footwear design stages are presented in Fig. 1.

[1] Vieira, J. (2023). Shoe Design: From Concept to Creation. LinkedIn. Retrieved from: https://www.linkedin.com/pulse/shoe-design-from-concept-creation-jean-vieira/
[2] Curteza, A., Mihai, A. (2005). Design- elemente, principii, aplicatii, Performantica Publishing House, Romania. ISBN 973-730-149-8
[3] Mihai, A., Pastina, M., Harnagea, M., Rusu B., Volocariu, R., Dragomir, A., Ichim, M. (2009). Metode utilizate pentru conceptualizarea si dezvoltarea produselor de incaltaminte, Performantica Publishing House, Romania. ISBN 987-973-730-648-7
[4] Chen, X., & Crawford, R. H. (2017). A Review of the Design Process: How Methods Impact Design Creativity. In Proceedings of the ASME Design Engineering Technical Conferences (pp. V003T04A009). American Society of Mechanical Engineers.

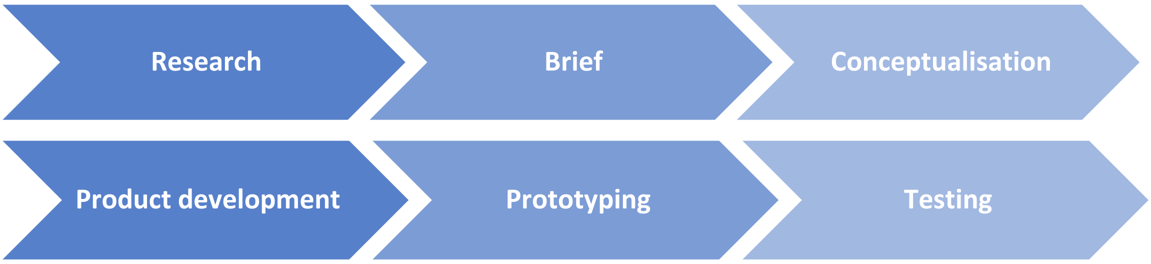

Fig. 1: Footwear design stages

2.1.1 Research

Prior to drawing any sketches or selecting any materials, designers (along with their marketing team) must collaborate to define a company's brand identity, values, and future direction. Research involves gathering information about **customer behaviour and lifestyle choices**, and examining customer needs. For instance, a brand marketing to urban commuters would likely notice growing interest in lightweight footwear that offers both comfort and waterproofing.

Trend forecasting is equally important. Designers look at fashion trends, forecasted colour palettes, cultural movements, and market trends to identify opportunities for the next season's collection.

Additionally, analysing **competitors** allows a brand to better understand how competitors use materials to position themselves in the market or how they price their offerings.

Researching **materials and technology** is essential as well. For example, new foams, textiles, eco-friendly materials, and manufacturing processes (including 3D knitting and additive manufacturing) create new design possibilities.

At times, research may involve working with scientists and/or medical staff who can provide insight into biomechanics and/or foot health to help develop more ergonomic and functional products for consumers.

Through research, designers build a clear understanding of the context in which their new product must exist, namely the consumer, the market, the brand, and the technical and environmental constraints (Qubstudio, 2023[5]).

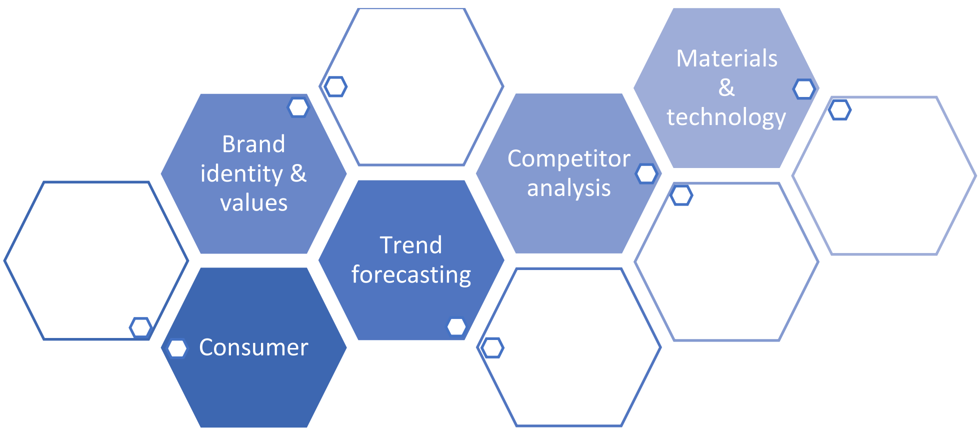

Fig. 2: Footwear design research framework

[5] Qubstudio. (2023). Product design process: 10 steps. Retrieved from: https://qubstudio.com/blog/ten-steps-of-the-product-design-process/

2.1.2 Design brief

After conducting market research, the design team prepares a **design brief** outlining the parameters of the new product. The brief should provide a common understanding of what is expected of the new product by defining the main components of the design process, including the **market** for the product, the **purpose** of the product, the product **features**, the price range for the product, and how the product will be positioned in relation to its competitors (Mihai et al., 2025[6]).

For example, if the new running shoe is to weigh less than 250 grams, to provide the maximum amount of energy (the higher the percentage of returned energy equals higher energy return) back to the runner when he/she runs in them, to contain at least 30% recycled material, and to be priced within a specific range, the design brief will outline these specifications.

The design brief will provide guidelines for the **aesthetic direction** of the new footwear product, as well as **technical information** for engineers and product developers on the specifications required.

The design brief will also define any **limitations and constraints** for the new product. Cost restrictions, available factory capabilities, sustainability restrictions or permitted materials will all be defined in the design brief. By defining the limitations and constraints in advance of the design process, the design brief will help minimise redesign costs and ensure that each decision supports the overall strategy.

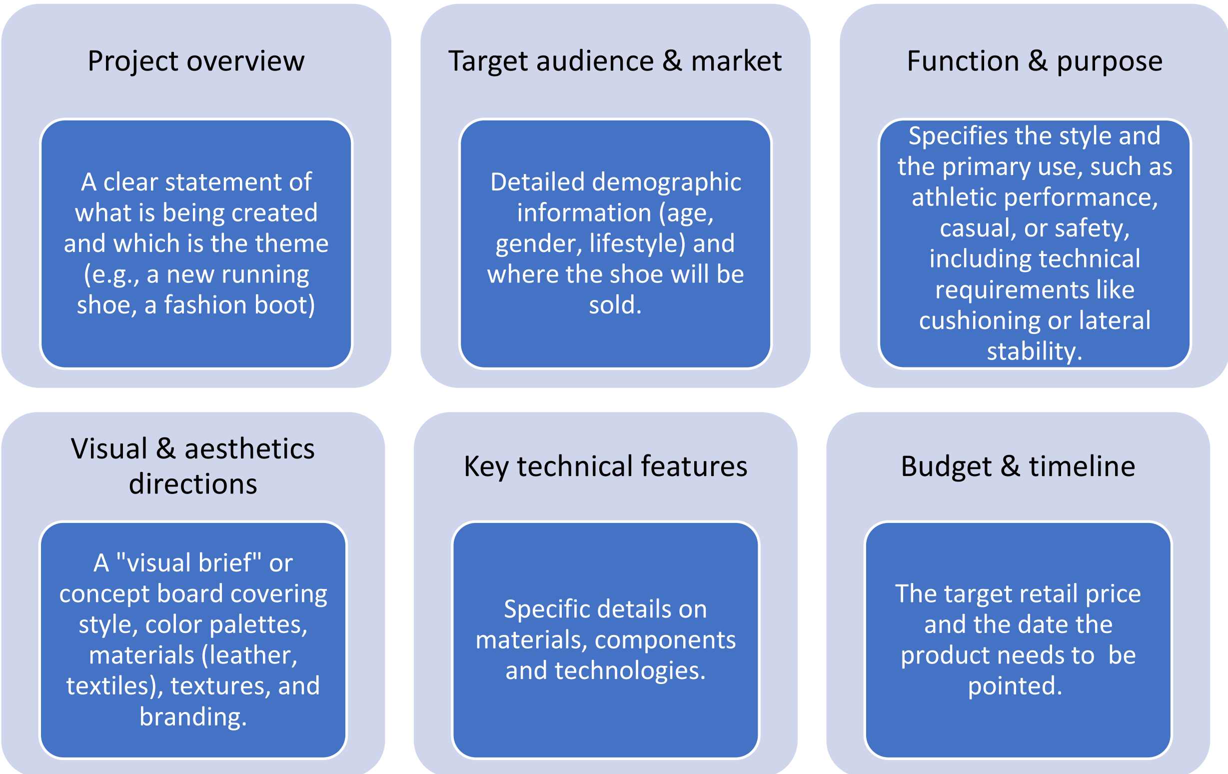

Fig. 3: Components of a design brief

[6] Mihai, A., Seul, A., Costea, M., Chirilă, A., & Lupu, R. (2025). Footwear design engineering. Performantica. ISBN 978-630-328-172-8. Retrieved from: https://e-learning.digi4wearables.eu/#/modules/student-details/3

2.1.3 Design conceptualisation

The **product concept** is established through design based on research insights and brief requirements. Designers will reference **multiple sources of inspiration** (e.g. art forms, architecture, natural phenomena, cultural activities, sports performance, and brand heritage) when conceptualising.

As designers develop concepts, they begin visualising the creative direction of products through multiple forms, such as **sketches**, **moodboards**, **concept boards**, and **colour studies** (Mihai et al., 2025[7]). In Fig. 4, the concept sketches, moodboard, and concept board for the *Bonmanship Dandy* student's collection are presented.

Fig. 4: Sketches, moodboard, and concept board for Bonmanship Dandy collection. Source: TUIASI- Diana Boncan

Additionally, **virtual modelling** and digital creation (3D rendering) increase design visualisation capabilities, enable designers to test complex forms, utilise diverse material types, and assist in the communication of **product ideation** across teams (Kotelskaia, 2023[8]).

Design is an iterative process, and as such, designers will always reevaluate and modify assignment constraints, shapes and proportions. The iterative design process ensures that collaboration with engineers, developers, and marketing confirms that the design's **creative and functional objectives** are met. The primary goal is to deliver a creative, appealing and well-designed product that meets the original brief, creates excitement and provides ultimate value to consumers.

Once the core footwear model is complete, the **footwear collection development** can start. A footwear collection consists of an organised group of models that share commonalities, whether in their design or fit, and are offered together for a specific season, market segment, or brand strategy.

[7] Mihai, A., Costea, M., Seul, A., & Chirilă, A. (2025). ShoeDES – Footwear design for the circular economy: Module 3. Footwear product design for circular economy. Performantica. ISBN 978-630-328-141-4. Retrieved from: https://shoedes.eu/Library/Uploads/R4-EN.pdf#page=127&zoom=100,68,212
[8] Kotelskaia, A. (2023). Digital tools in the footwear design process: From traditional practices to artificial intelligence. Retrieved from: https://www.theseus.fi/handle/10024/792430

When developing footwear collections, several strategies are used to achieve both continuity and variety among the styles. The design process begins with an analysis of the core product and determination of its **modular parts**, which are designed so the designer has the flexibility to vary them individually (e.g., upper pieces, sole units, closure systems, etc.), which will create the overall look of the footwear collection, while still creating designs that are similar yet different from each other. **Signature elements** from the core model, such as a **texture**, a **stitch pattern**, **or geometric shapes, can be adapted across** the entire collection to reinforce its identity.

Continuity is further achieved through other methodologies such as **proportion**, **pattern-engineering techniques**, and **product adaptation/versatility** for various performance-oriented/dress, seasonal-life, or performance-focused purposes.

In addition, the **material and colour choices** used to create the collection are integral to the development process. These allow the designer to continue expanding on the core model and to provide options for the end-user through seasonal fabrics, sustainable alternatives, premium finishes, and/or curated colour palettes that work together to create a visually cohesive collection.

Another way to enhance the market relevance of the footwear collection is to create “core-level,” “premium,” and “simplified” versions of each style.

In addition to these strategies, the creation of **limited editions** and **story-driven capsules** based on the core model provides dynamic opportunities to tradition and to create cultural depth, with the core model serving as the basis for both unique finishes and thematic interpretations.

2.1.4 Product development

The **development process** focuses on turning creative thinking into technical detail. While an initial design may have been created by the designer's artistic vision and/or 3D modelling, the final output is produced through the pattern maker's technical skills. The patternmaker will use the designer's drawings to produce a set of **patterns**. The pattern determines how the upper will be made and assembled, and therefore represents the most crucial step in ensuring that a shoe has the correct fit, comfort, and is producible.

In this stage, **technical sheets** (Fig. 5) are created that contain all information on the **materials** to be used, **colours, threads, reinforcements, components**, and **construction methods**. Technical notes sent via a technical sheet to the manufacturing department will outline all requirements for product consistency and quality.

The development phase converts the designer's concept into a technical instruction document that details every aspect of the artistic vision and the final shoe product.

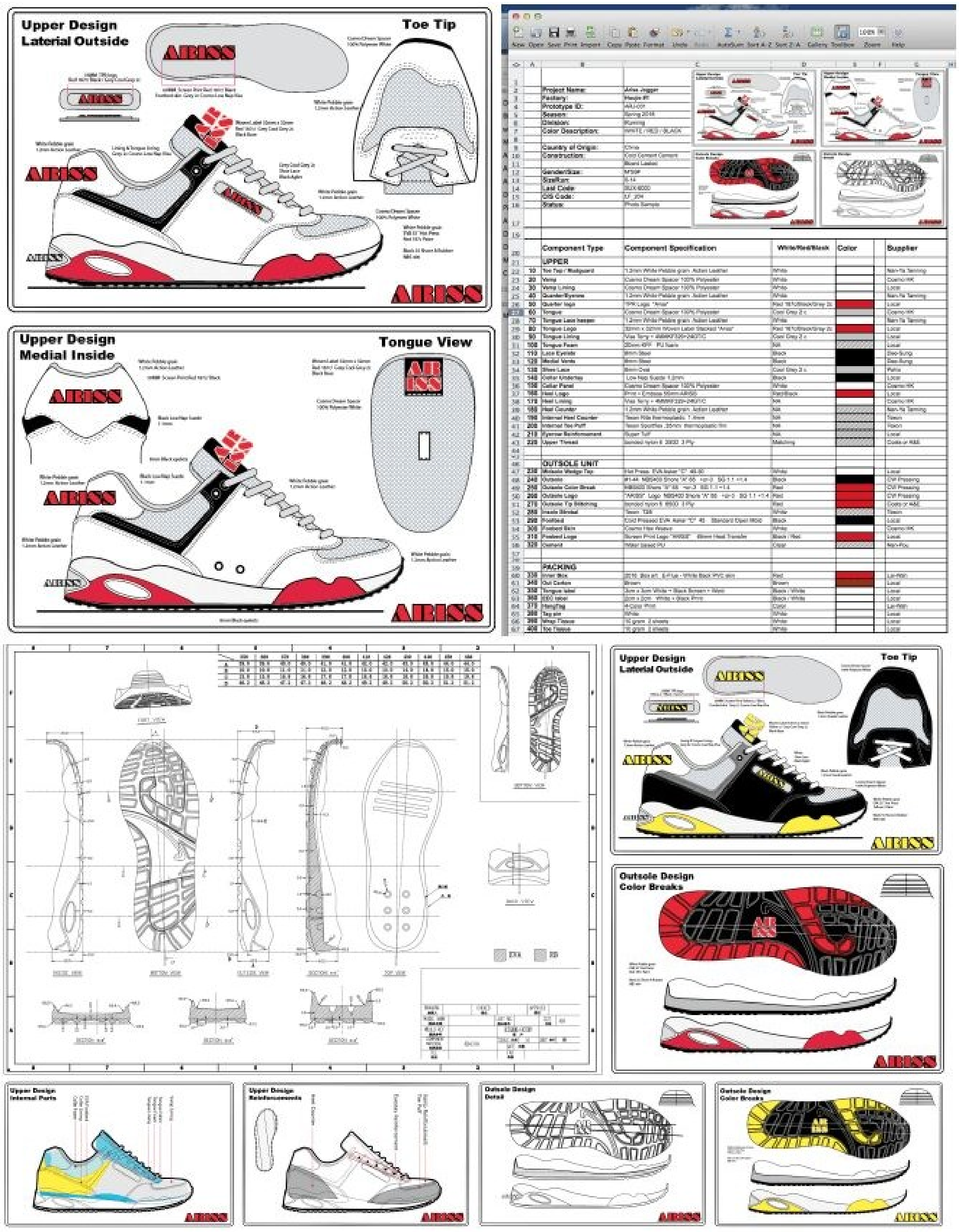

Fig. 5: Technical sheet. Source: https://shoemakersacademy.com/shoe_development_specification_pack/

2.1.5 Prototyping

The **prototyping stage** is the first opportunity for teams to evaluate their designs in a **virtual** or **physical** form. Factories producing initial samples can use **digital tools**, **rapid prototyping** technologies, **traditional manufacturing**, or a combination of the two.

The **virtual prototype** (Fig. 6) is created using advanced computer programs that apply specific parameters to generate a **3D visual representation,** which could give preliminary information on **appearance, colours, texture and shapes**. Additionally, this virtual prototype is used to perform functional simulations, such as Finite Element Analysis, which allows the evaluation of mechanical behaviour under simulated use conditions.

Physical prototypes (Fig. 7) include all the styles that will eventually be used in the shoe's production, including functional, mock-up, and 3D-printed prototypes. A **functional prototype** is usually made from the same materials as the final product and enables us to evaluate the shoe's overall cushioning, support, and performance. A **mock-up** is made of inexpensive materials to give designers a basic idea of how the footgear will feel and look (Lauff, 2018[9]).

Fig. 6: Virtual prototype. Source: TUIASI- Alexandru Urmă, Marin Cojocari and Diana Misiru

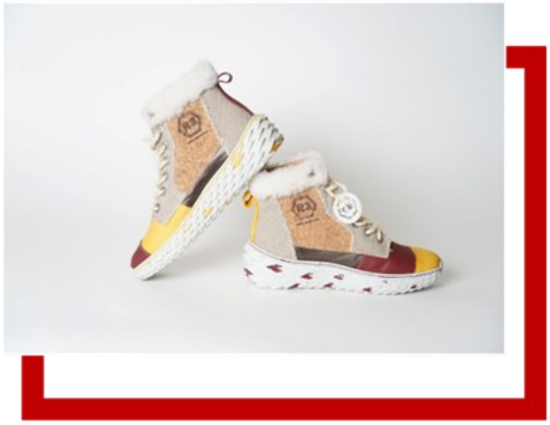

Fig. 7: Physical prototype. Source: TUIASI- Alexandru Urmă, Marin Cojocari and Diana Misiru

Upon receipt of the samples, designers and developers conduct **fit testing**, **wear testing**, and **visual inspections**. These involve checking for pressure points, unstable heel cups, material wrinkles, colour discrepancies, etc.

Also, prototypes are used to evaluate the sample's performance and to conduct preliminary testing of flexibility, slip resistance, and cushioning.

The prototyping stage often involves multiple iterations. It is often necessary to create multiple samples before achieving the perfect fit, comfort, shape, and/or material selection (TCLF, 2021[10]).

2.1.6 Testing

The **testing stage** validates that the footwear's design is ready for both production and market launch. Validation requires approval from the organisation's management and marketing department, as well as pre-marketing testing with some consumer groups.

During the validation phase, the following aspects are assessed:

- Design brief compliance;
- Compatibility with brand identity and collection;
- Cost-effectiveness;
- Final quality assurance and durability test results, if applicable;
- Consumer opinions on the product's design and performance, if available.

[9] Lauff, C. A., Kotys-Schwartz, D., & Rentschler, M. E. (2018). What is a Prototype? What are the Roles of Prototypes in Companies?. Journal of Mechanical Design, 140(6), 061102. Retrieved from: https://www.researchgate.net/publication/323198004_What_is_a_Prototype_What_are_the_Roles_of_Prototypes_in_Companies

[10] Skills4Smart TCLF project. (2021). Skills for Smart Textile, Clothing, Leather and Footwear Industries, 591986-EPP-1-2017-1-BE-EPPKA2-SSA-B. Retrieved from: http://www.s4tclfblueprint.eu/

Through marketing studies and character development, the company will determine how to promote this product, what story to tell to convey its value to the intended audience, and whether it meets the needs of the intended audience as consumers. The product design team will compare the final version with the proposed product concept to ensure it remains true to the vision intended. The engineering department will ensure that the validated version can be manufactured without compromising performance.

After all interested parties approve the design, the footwear will proceed to mass production. The validated footwear will be added to the brand's catalogue and be available to both retailers and consumers.

2.2 Emergent trends in footwear design

Footwear must be both functional and aesthetically appealing, and offer consumers a way to express themselves.

Trends that are shaping the footwear industry:

- **Sustainability** - consumers are growing more aware of global and ecological issues and start to prioritise brands that make a positive impact by recycling, using eco-friendly materials, adopting sustainable manufacturing technologies and promoting durability and quality over fast-fashion.
- **Comfort** - manufacturers should focus on comfort and health features, for footwear categories, occasion and formal, by adopting innovative materials and constructions.
- **Multifunctional and smart -** consumers want more from their products, to cover both leisure and outdoor activities by merging style and performance and also by incorporating smart wearable technologies.
- **Personalisation** - customers are willing to pay for the possibility to express themselves and to have something specifically designed by them and for them.

2.2.1 Virtual Prototyping

Virtual Prototyping (VP) is a computer-aided design process that involves the construction of digital product models and realistic graphical simulations to address the broad issues of physical layout, operational concept, functional specifications, and dynamic analysis across various operating environments.

Virtual prototyping offers several benefits, including flexible design, shorter development time, reduced time-to-market, easier error detection, realistic simulation, reduced costs, fewer physical prototypes, and increased productivity.

Fig. 8: Footwear virtual prototype. Source: www.compasslist.com/insights/4d-shoetech-digital-design-platform-helps-shoemakers-to-slash-production-time-by-over-60

2.2.2 Digital materials and rendering

True realism in virtual design and prototyping can be achieved by using rendering software and digital materials that reproduce the appearance (brightness, roughness, transparency) and textures of real materials (e.g., textiles and leather).

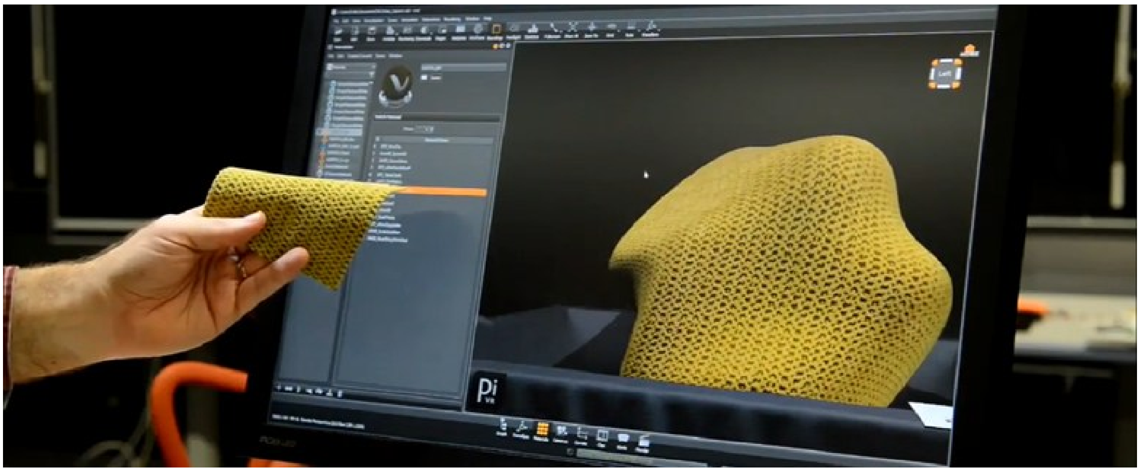

Fig. 9: Digital material. Source: https://blog.ranchcomputing.com/capture-of-real-materials-next-step-of-photorealism

2.2.3 Rapid Prototyping

Rapid Prototyping (RP) is the fast fabrication of physical components and models by using virtual tools and additive manufacturing. The use of additive manufacturing shortens the development process and represents a more viable solution than traditional manufacturing techniques by enabling complex parts to be manufactured directly from digital models without specialised tooling.

An example of using rapid prototyping for 3D printing of footwear components (sole, heel and counter) is given in the following figure:

Fig. 10: 3D printed prototypes of footwear components. Source: TUIASI

2.2.4 Virtual Reality and Augmented Reality

Virtual Reality (VR) and Augmented Reality (AR) are technologies that enhance and simulate physical environments using computer-generated virtual information. AR enhances/augments the environment by adding digital elements to a live view. VR is a completely immersive experience that replaces and simulates a real-life environment.

Virtual prototyping applications can incorporate VR, AR, or mixed-reality technologies.

Fig. 11: Augmented reality application. Source: https://scanblue.com/augmented-reality-and-shoes/

Fig. 12: Virtual reality technology in footwear design. Source: https://www.worldviz.com/post/footwear-company-deckers-uses-vr-to-reduce-travel-and-drive-collaboration

2.2.5 Virtual testing

Testing footwear is an expensive and time-consuming process. Each concept has to be manufactured and tested; if it does not meet the desired performance requirements, it is sent back to the drawing board, and the entire development process is started over. One solution is to use virtual testing.

For example, Finite Element Analysis (FEA) software can be used to test the performance of different footwear geometries and footwear materials.

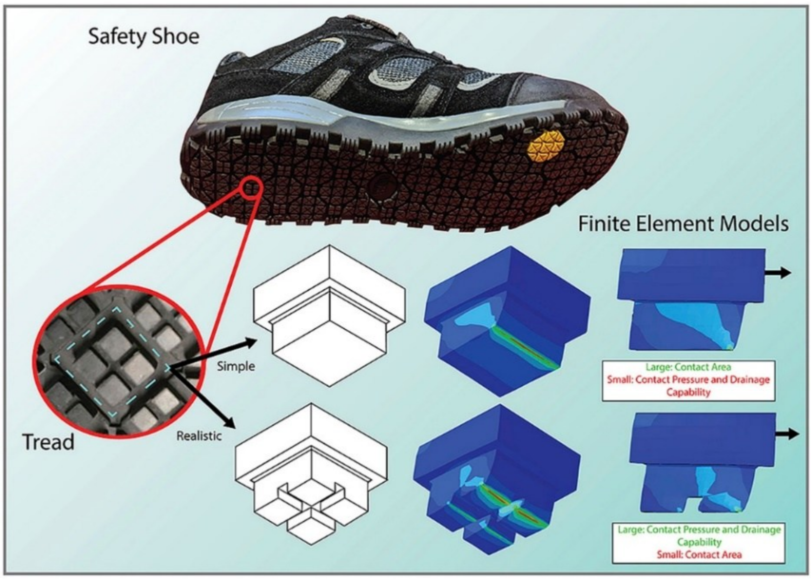

Fig. 13: Virtual testing of footwear outsole. Source: J. Hale, A. O'Connell, R. Lewis, M.J. Carré, J.A. Rongong, An Evaluation of Shoe Tread Parameters using FEM, Tribology International, Volume 153, 2021, 106570, ISSN 0301-679X, https://doi.org/10.1016/j.triboint.2020.106570.

3 Globalisation in Footwear Design

Globalisation has transformed the footwear industry into an interconnected global network of designers, consumers and manufacturers (Cietta, 2026[11]). Therefore, design teams now face the challenge of creating designs that meet the diverse needs of different cultures, respond to rapidly evolving markets, and compete with an increasing number of companies offering similar products across several regions and manufacturing environments.

3.1 Markets and consumers

As **consumer diversity increases**, footwear designers must develop products that reflect diverse fit preferences, cultural perspectives, and functional requirements. For example, in both Northern and Central Europe, consumers tend to prefer shoes with higher instep volume and wider forefoot shapes and construct them for outdoor-like uses or 'all-weather' shoes, i.e. those that meet their needs regardless of the type of weather.

Conversely, Southern European consumers typically prefer shoe lasts with a narrower width (or 'fit'), as well as 'low-volume' lasts with a more refined silhouette and a lighter-weight, more flexible construction, which reflect their local fashion culture and the warmer climate.

Likewise, **climate conditions** also heavily influence the designer's decision on a particular shoe design. For instance, shoes designed for consumers in tropical regions will need to use breathable mesh materials. Conversely, waterproof boot styles are required by Northern European consumers.

The need for greater product diversity has led to shorter product development cycles, making products more technically complex. As a result, footwear designers develop **modular designs** that enable multiple footwear variations to be derived from a single **base concept**.

Evolution of consumption standards has taken place over the years (McKinsey & Company, 2025[12]). Consumers expect high levels of comfort, lightweight materials, ergonomic design, and visually interesting designs across all price points. This consumer need has enabled designers to develop footwear that blends fashion with functionality. Many brands have created product lines of city sneakers that feature running-inspired cushioning and high-quality materials for everyday wear.

As trends in **personalisation** evolve (colour choices, printed graphics, etc.), designers must develop **modular designs** that enable **mass-customisation processes.**

Emerging markets (such as parts of Eastern Europe) are shaping global footwear design by influencing **local cultural aesthetics**, **climate**, and **lifestyle preferences**, which require adaptations in product design (APICCAPS, 2024[13]).

[11] Cietta, E. (2026). Globalisation, spheres of influence and the new geographies of fashion: The outlook for footwear and bags. Expo Riva Schuh and Gardabags. Retrieved from: https://exporivaschuh.it/en/news/detail/globalisation-spheres-of-influence-and-the-new-geographies-of-fashion-the-outlook-for-footwear-and-bags

[12] McKinsey & Company. (2025). The state of fashion 2025. McKinsey Global Fashion Index. Retrieved from: https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion

[13] APICCAPS. (2014). Footwear consumer 2030: A background study incorporating global trends to foresight footwear market (World Footwear report). World Footwear. Retrieved from: https://www.worldfootwear.com/media/wf_uploads/wf20191132716572.pdf

Comfort | Ergonomics | Fashion +Functionality

Customisation | Aesthetics

Sustainability

Fig. 14: Footwear consumer expectations

Additionally, technology is emerging in how we conduct commerce through Direct-To-Consumer (D2C), **subscription business models**, and **On-Demand Manufacturing (ODM)**. Therefore, product timelines have decreased, and digital samples have increased. Designers are creating **3D representations** that accurately reflect the final product and are using **faster consumer feedback loops** to **refine** their **designs**.

3.2 Economic and social factors

Effective global footwear design requires an understanding of the many cultures around the world and the utilisation of those cultural differences in **colour choices**, **pattern motifs**, and **material choices**. What may be considered bold by one country or region could easily be seen as minimalist by another. For instance, in Scandinavian markets, the majority of consumers prefer a minimalist design approach that emphasises subtlety. A key factor in the success of any product is the designer's ability to fully understand and **anticipate** cultural **expectations;** therefore, the ability to create **interculturally sensitive, globally appealing footwear** is becoming an increasingly important core design competency (The Textile Quality Assurance Experts Group, 2022[14]).

The footwear labour market is becoming increasingly diverse, as a result of **shifting production centres** and the rapid emergence of new supplier regions. As such, footwear designers are required to consider each **factory's production capabilities**, including the types of equipment available, and to adapt their designs accordingly. For example, if a design uses the latest advancements in knitting technology, the factory that manufactures it must have access to state-of-the-art knitting machines; otherwise, producing the item will be impossible.

Additionally, due to disruptive geopolitical events and supply chain vulnerabilities, footwear designers may develop products with flexible bills of materials that can be produced by multiple suppliers while maintaining the same level of performance and aesthetic.

3.3 Demographic trends

Changes in demographics directly affect the way footwear is designed. An **ageing population** is creating a greater demand for footwear that provides the right **support, comfort, stability, cushioning**, and **easy access** (Jellema et al.[15]). Designers are utilising **ergonomic design principles** in their footwear, including contoured footbeds, adjustable closures, and designs that are typically orthotic-friendly. Many designers are currently using adjustable Velcro strap closures and elasticated knitted uppers to provide ease of entry.

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[14] The Textile Quality Assurance Experts Group. (2022). Every step counts: Four key challenges facing footwear today. SgT Group. Retrieved from: https://www.sgtgroup.net/four-key-challenges-facing-footwear-today/

[15] Jellema, A. H., Huysmans, T., Hartholt, K., & Van Der Cammen, T. J. (2019). Shoe design for older adults: evidence from a systematic review on the elements of optimal footwear. Maturitas, 127, 64-81. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0378512219301318

For example, cultural and value shifts driven by **younger generations**, particularly Gen Z, have created a need for products that embody **authenticity, inclusivity**, and **sustainability** (Allodi, 2022[16]). The majority of Gen Z consumers prefer to buy gender-neutral footwear and fashion products, including designs with non-standard silhouettes and Eco-Friendly materials. To meet the needs of Gen Z consumers, designers must adapt their designs to create unisex last shapes and modular collections, and clearly communicate the design's sustainability through visible structural elements and material choices.

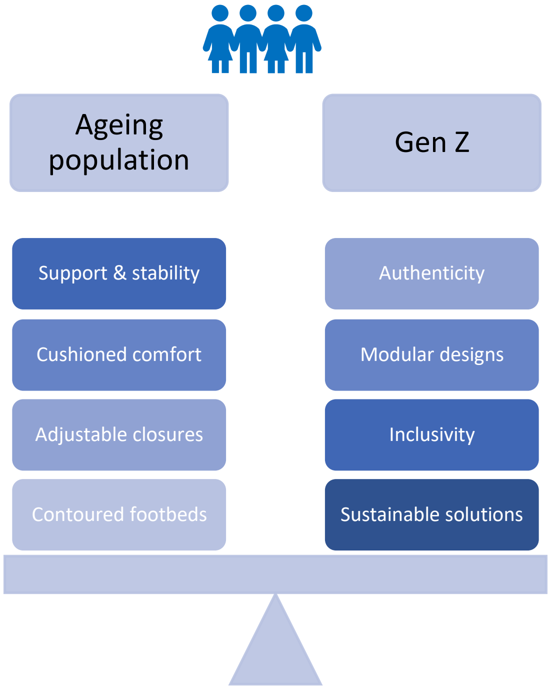

Fig. 15: Demographic impact on footwear design

3.4 Training, skills, and knowledge requirements

Today, footwear designers must develop skills beyond just a creative mindset. Education must now include the following:

- 3D Computer-Aided Design (CAD) Software (MindCAD, ICAD, CLO, Romans CAD, Rhino, Blender);
- Fundamentals of Material Science;
- Biomechanics and Ergonomics;
- Sustainability Frameworks;
- Basic Data Analysis;
- Cross-Cultural Communication.

For instance, when designing performance footwear, it is important that the designer has a basic understanding of how **gait analysis** can be used to determine the optimal midsole geometry. When designing for environmental sustainability, it is vital that the designer understands the **Life Cycle Assessment** (LCA) process.

[16] Allodi, P. M. (2022). Analysis of the Key Drivers and Sustainability Impact on Sneaker Purchase Decisions Among Italian Gen Z (Master's thesis, Universidade Catolica Portuguesa (Portugal)). Retrieved from: https://www.proquest.com/openview/f37404dfeb15e3afa62ecc6816687683/1?pq-origsite=gscholar&cbl=2026366&diss=y

4 Sustainability in Footwear Design

The growing trend toward sustainability is shaping how shoes are designed. Because most of a shoe's environmental impact is determined by the decisions designers make when they first conceptualise the product, it is increasingly important for designers to consider sustainable design principles from the earliest stages of product development (Andrade et al., 2023[17]).

4.1 Green awareness and consumer expectations

Shoe consumers expect more than just a product; they expect full transparency into the materials and chemicals used to manufacture footwear, as well as the materials' carbon footprint and recyclability. Designers are responsible for demonstrating compliance with **eco-labelling** and **digital transparency standards** for their products.

Eco-labelling is a voluntary, third-party certification process identifying products or services with lower overall environmental impacts based on life-cycle considerations. These labels help consumers and buyers identify environmentally preferable options in terms of toxicity, energy use, and sustainability, while also serving as marketing tools.

In this context, the European Union (EU) is currently developing a **Digital Product Passport- DPP** (European Union, 2024[18]) will require brands to provide detailed, transparent information about each product (Fig. 16), including its material composition and the origin of all key components, as well as verified data on environmental footprint indicators such as carbon emissions and resource use. It will also include information on the product's durability and repairability, outlining expected lifespan and available repair options, together with clear end-of-life instructions describing how the product or its materials can be reused or recycled. In addition, the DPP will document all relevant regulatory compliance aspects and certifications, ensuring that the product meets chemical, environmental, and safety requirements across global markets. The next page presents a **conceptual template** that contains the main information required for the **Digital Product Passport**. This template is a conceptual proposal intended for illustrative purposes.

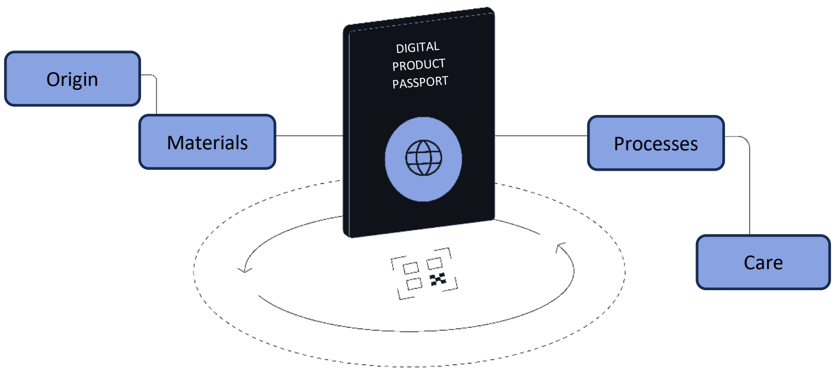

Fig. 16: Digital Product Passport- DPP. Source: https://www.vaayu.tech/insights/the-ultimate-guide-to-digital-product-passports-dpps

[17] Andrade, B., dos Santos, A., & Broega, A. C. (2023). Design for sustainability in the footwear sector: Survey on strategies and impacts mitigation. In International Fashion and Design Congress (pp. 472-482). Cham: Springer Nature Switzerland. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-031-43937-7_42

[18] European Union. (2024). EU's Digital Product Passport: Advancing transparency and sustainability. data.europa.eu. Retrieved from: https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability

The design team works together with marketing to **help consumers understand the sustainability of footwear products** through effective communication. For example, a design that provides an **attractive visual** representation of recycled content (e.g., speckled EVA, undyed textiles, or modular construction) may help build consumer confidence and strengthen the story for each product. Ensuring that consumers have access to clear, accurate, and meaningful information about the environmental, social, and ethical aspects of footwear products is essential. It will allow consumers to **make informed purchasing decisions** that align with their values and sustainability goals, namely sustainable consumption (European Commission, 2022[19]).

Additionally, to promote sustainable innovation, it is critical to establish and maintain **partnerships throughout the footwear industry's value chain** (METASKILLS4TCLF, 2024[20]). In many instances, designers collaborate with their suppliers to develop new materials (e.g., bio-based foams, recycled rubbers, and plant-based materials), resulting in shorter development cycles and a higher likelihood of successful performance while also meeting sustainability goals.

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[19] European Commission. (2022). Empowering consumers for the green transition. Proposal for a directive. Retrieved from: https://ec.europa.eu/environment/

[20] METASKILLS4TCLF. (2024). Skills intelligence for forecasting and monitoring TCLF emerging skills needs. Retrieved from: https://www.metaskills4tclf.eu/Library/Uploads/WP3_Final_Report.pdf

Product name

Product picture

General information

Code:

Category:

Style:

Designed by: ***brand / designer, country, city***

Manufactured: ***brand / designer, country, city***

Materials & components Traceability

Upper: ***type of materials and origin***

Linings: ***type of materials and origin***

Bottom: ***type of materials and origin***

Accessories: ***type of materials and origin***

Auxiliary materials: ***type of materials and origin***

Environmental footprint

Product carbon footprint: ..

Energy efficiency: ....

Water consumption in production: ....

Environmental product declarations: ......

Durability & repairability

Care guidelines: .....

Product guarantee: .....

Possibilities for reuse or reconditioning: .....

End of life & recycling

Recycling instructions: ....

Recovery of valuable materials: ....

Regulatory compliance certifications

Safety certifications: .....

Ecolabels: .....

Compliance with specific EU requirements: ......

4.2 Sustainable design and circular economy principles

Sustainability and **circularity** are the biggest trends in footwear design. The designers must change their traditional approach to incorporate circular-economy principles into footwear design and create footwear that considers its entire **life cycle** (Andrade et al., 2023[21]).

The most effective ways to **design sustainably** within a circular economy framework for shoes include **Design for Recycling, Repair and Reuse, Design for Waste Minimisation, and Design for Disassembly** (Ghimouz et al., 2023[22]).

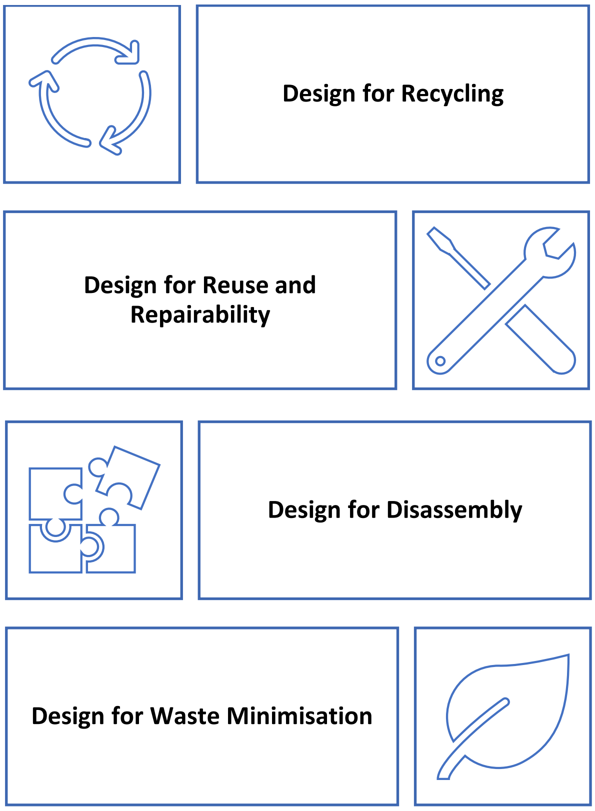


Fig. 17: Main direction in sustainable design

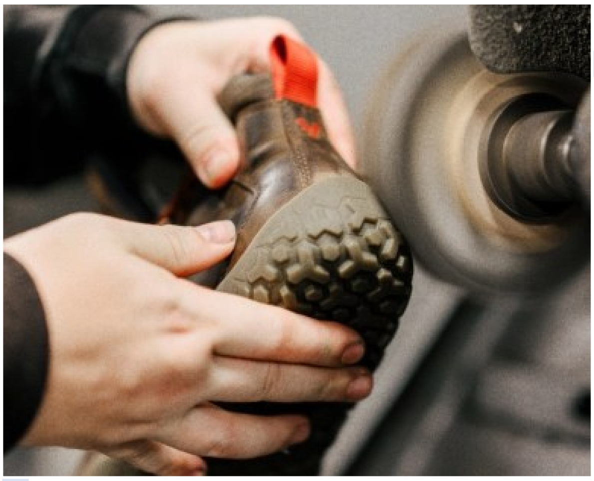
Design for Recycling is an engineering practice that involves creating products with features/characteristics that make recovering materials for recycling (high quality/cost-effective) easier at some future point in time, as part of a circular economy. Engineering techniques to produce products based on Design for Recycling include using **mono-materials** instead of **composites** to facilitate easy separation of components and eliminating contaminants when designing to improve recycling efficiency.

[21] Andrade, B., dos Santos, A., & Broega, A. C. (2023). Design for sustainability in the footwear sector: Survey on strategies and impacts mitigation. In International Fashion and Design Congress (pp. 472-482). Cham: Springer Nature Switzerland. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-031-43937-7_42
[22] Ghimouz, C., Kenne, J. P., & Hof, L. A. (2023). On sustainable design and manufacturing for the footwear industry– Towards circular manufacturing. Materials & Design, 233, 112224. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0264127523006391

Futurecraft.Loop by Adidas is a shoe made entirely from a single material (a modified TPU) that can be ground down and melted to create a new shoe, using no glue.

Fig. 18: Adidas Futurecraft.Loop- a footwear concept based on Design for Recycling. Source: https://news.adidas.com/running/futurecraft.loop-phase-2--how-we-re-finding-away/s/43c42bf2-73ca-4ccb-930b-5ac5b6637a76

Design for Reuse and Repairability. As footwear brands work to extend a shoe's lifespan, they have begun creating footwear with removable insoles, replaceable outsoles (e.g., high-end hiking boots), and uppers made from durable materials that resist tearing and wear.



Revivo by Vivobarefoot

is a recommerce platform buys, refurbishes, and resells pre-loved shoes, promoting a circular economy by supporting a take-back program for repair and recycling.

Fig. 19: Revivo by Vivobarefoot- a concept that allows users to repair their shoes ot to return them for resale. Source: https://www.vivobarefoot.com/rw/about-revivo

Design for Disassembly. This includes reducing the use of permanent adhesives and enabling **easy separation** of a shoe's components at the end of its life. For example, using stitching rather than cementing materials together or designing soles that can be removed during recycling creates opportunities for circularity in the footwear industry.

Roku by Camper is a shoe made of six interchangeable parts that can be sold as an assembled pair or as parts in four different packs, allowing you to build a customised shoe shoe.

Fig. 20: Camper Roku- footwear concept based on Design for Disassembly. Source: https://www.camper.com/en_RO/women/shoes/rku/camper-roku-K201630-007

Design for Waste Minimisation involves designing products to reduce, reuse, or recycle materials from the start of the project until waste is eliminated. Engineering methods to achieve waste minimisation in design include using **simple designs** with **modular components** and **sustainable materials**. Estimates indicate that 30% of all manufacturing waste could be prevented by using this design approach.

In addition to the above, 3D printing enables the production of specific types of footwear components in the precise volumes and sizes (geometries) needed by consumers. The way these parts are produced using additive technology reduces material waste by eliminating cutting operations. Minimising waste is an important benefit of footwear production via additive manufacturing, ultimately leading to a more cost-effective, eco-friendly method of producing shoes.

Halo by Zellerfeld shoe is a fused 3D lattice construction, breathable, washable, odour-resistant, 100% recyclable and sweatshop-free.

Fig. 21: Zellerfeld Halo- 3D printed footwear. Source: https://www.zellerfeld.com/products/halo-1

Design for Manufacturing is another method for developing a collection line to reduce production costs. Also, this method offers a solution for creating footwear models from a core design concept by applying a logical framework to the relationships among the models.

In the example below, the first model is the core product concept, and the other models have been developed by varying the upper constructive lines.

A footwear collection developed based on Design for Manufacturing principles starts with a core model and expands into new models by varying the upper lines while keeping the main structure, components, and materials consistent to ensure efficient production.

Fig. 22: Collection line obtained by varying the model lines of uppers. *Source: TUIASI*

As noted, selecting **materials** is a key area of sustainable design. Designers should choose **recyclable**, **biodegradable**, or **bio-based** materials. Examples of these materials include: Algae-based EVA for midsoles, pineapple fibre for uppers, low-impact, chrome-free leather, and knitted fabrics produced from recycled polyester or organic materials. Designers, therefore, need to make their material selections not only on traditional aesthetic and comfort factors but also on environmental performance and sustainability.

In this context, the importance of **recycling programs** (INESCOP, 2024[23]) should be highlighted as an important element of the design process. These programs are intended to collect products at the end of their useful life and reintroduce their materials into new production cycles, thereby reducing waste and reliance on virgin resources. Examples of modern programs include brand-driven take-back programs, networks of third-party collection systems, and pilots to test new technologies for recovering materials. Such programs rely on consumers returning their used footwear to designated collection points, where it is processed by sorting/shredding, and separation to extract usable materials, including rubber granulate, EVA foam, thermoplastics, and textile fibres. The success of these programmes is highly influenced by the design of the footwear, as products constructed from complex, multi-material systems bonded with strong adhesives are significantly more difficult to recycle, underscoring the need for **Design for Disassembly**, **simplified constructions**, and **compatible materials**. In the design stage, it should be considered that materials will tend to exhibit colour, texture, and mechanical properties different from those of the corresponding virgin material, leading to different design decisions regarding component thickness, reinforcement, and colour strategies, and the aesthetic expression of the products.

[23] INESCOP. (2024). DIS4REC: Footwear disassembling technology for the optimisation of the recycling process. INESCOP – Centre for Technology and Innovation. Retrieved from: https://www.inescop.es/en/inescop/activities/proyectos-i-d-i/proyectos-i-d-i-regionales/ivace/60-2024/780-dis4rec

4.3 Energy, process, and resource efficiency

Although the design department is not specifically responsible for factory energy consumption, its **design decisions** do affect **production efficiency**. By designing products that are easier to produce, both in terms of the number of machines used and the time required to manufacture, designers can reduce the energy required to produce a pair of shoes.

For example, midsole designs that are free of the many complex multi-density layers will likely require less time and fewer moulds to manufacture. Water-based adhesives and textiles that require fewer finishing processes will also reduce resource consumption.

Design for Automation is becoming more important in this context (Firtikiadis et al., 2024[24]). The continued advancement of automated cutting, stitching, and injection processes will lead to greater production efficiency and higher product quality for shoe manufacturers and footwear retailers. Examples include designs with uniform stitch and seam lines, as well as automated knit or 3D-printed patterns.

4.4 Social responsibility in footwear design

Footwear design also extends into **ethical dimensions**. This means ensuring that fair labour, safe working conditions, and transparency in supply chains are paramount when selecting materials and establishing manufacturing partnerships.

Designers have an important influence on advancing social responsibility by selecting **responsible suppliers**, **avoiding overly complicated designs** that promote low-cost/high-risk labour, and **incorporating human-centred design principles** such as improving comfort, increasing access for all, and enhancing user well-being (European Parliament and Council, 2024[25]).

In addition to its role in production, the concept of social responsibility also considers the impact of footwear on society as a whole. When designing shoes, designers should create **shoes** that are **safe and durable**, **free of harmful chemicals**, and that also consider **accessibility and cultural sensitivity**. Designers can further contribute to social responsibility through **community engagement** and by being honest when communicating with customers about how to use their footwear after purchase. Additionally, engaging customers through **circular repairability and take-back models will help reinforce the footwear industry's social responsibility efforts, creating a positive impact** on the environment and the people and communities tied to the product's life cycle.

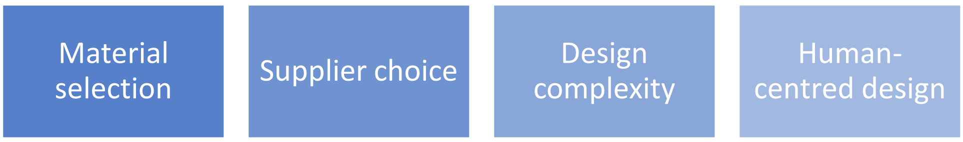


Fig. 23: Social Responsibility in footwear design - designer's sphere of influence

[24] Firtikiadis, L., Manavis, A., Kyratsis, P., & Efkolidis, N. (2024). Product design trends within the footwear industry: A review. Designs, 8(3), 49. Retrieved from: https://www.mdpi.com/2411-9660/8/3/49

[25] European Parliament and Council. (2024). Regulation (EU) 2024/1781 establishing a framework for the setting of ecodesign requirements for sustainable products, Official Journal of the European Union. Retrieved from: http://data.europa.eu/eli/reg/2024/1781/oj

5 Digitalisation in Footwear Design

The advancement of digital technology has changed how footwear is designed, visualised, tested, and presented. Digital technology will begin to dominate the shoe market in the next few years, resulting in shorter production times and greater accuracy, and enabling more creative exploration of ideas by leveraging increased data support. Digital trends are changing design workflows and driving unprecedented product design that continues to emerge beyond the established Virtual Prototyping (VP) process, which provides designers with detailed digital models and realistic simulations of footwear products (Kotelskaia, 2023[26]).

5.1 Artificial Intelligence in footwear design

The increasing use of Artificial Intelligence (AI) has an important impact on the design process and the development of footwear collections.

AI accelerates the creative process by allowing designers to **explore new shapes**, **surfaces**, and **colour concepts**. For example, AI tools can generate variations of a running shoe concept, ranging from organic shapes inspired by nature to futuristic patterns derived from algorithmic designs (Cheng, 2023[27]).

AI applications such as **generative design tools**, **sketch-to-image converters**, and **virtual try-on platforms** can support and enhance the creative process in product design and footwear collection development. For instance, Midjourney[28] is used for **visual concept generation** (Fig. 24), while NewArc.ai[29] is used to **transform sketches into realistic images**.

Designers must evaluate the results for feasibility and refine them to align with the collection and brand identity.

[26] Kotelskaia, A. (2023). Digital tools in the footwear design process: From traditional practices to artificial intelligence. Retrieved from: https://www.theseus.fi/handle/10024/792430
[27] Cheng, S. H. (2023). Impact of generative artificial intelligence on footwear design concept and ideation. Engineering Proceedings, 55(1), 32. Retrieved from: https://www.mdpi.com/2673-4591/55/1/32
[28] Midjourney. (n.d.). Midjourney. Retrieved from: https://www.midjourney.com/
[29] NewArc.ai. (n.d.). NewArc.ai. Retrieved from: https://www.newarc.ai/

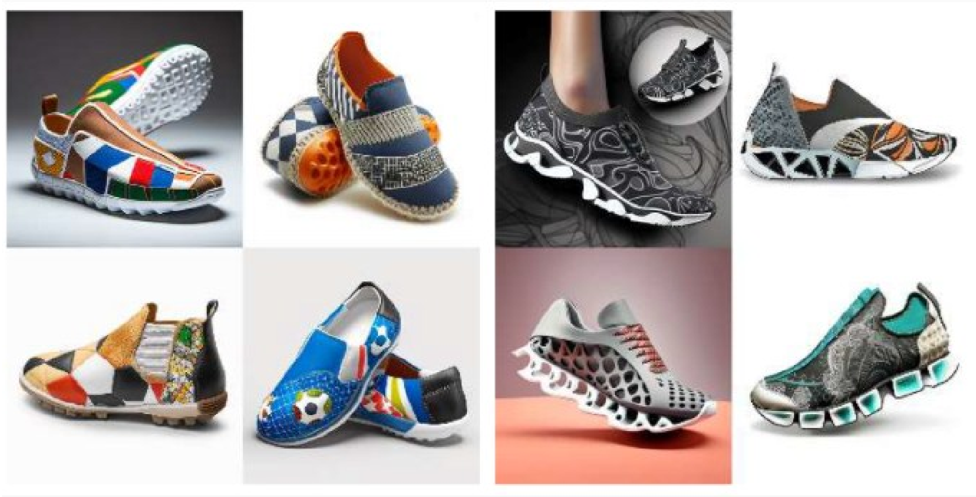


Fig. 24: Models generated using the Midjourney app. Source: Cheng, S. H. (2023). Impact of generative artificial intelligence on footwear design concept and ideation. Engineering Proceedings, 55(1), 32. https://doi.org/10.3390/engproc2023055032 Retrieved from: https://www.mdpi.com/2673-4591/55/1/32

Text-based AI tools assist with writing **design briefs**, **trend summaries**, and **collection concepts**. They are also used for **market research** by translating consumer reviews across different languages, making global sentiment analysis more accessible.

Additionally, by using AI to **mine** previously accumulated **data**, it will be possible to generate reports on **trend-based insights**, **competitor strategies**, and customer preferences. During the design phase of footwear lines, designers will be provided with real-time data to help them make decisions on colour, silhouette, and functional features.

5.2 Big Data and design decisions

The use of Big Data in design has shifted from creative choices based on intuition and experience to **data-driven decisions**. Examples of Big Data are Trend Forecasting Agencies (WGSN[30]) and Social Media Analytics. All of these provide large amounts of Big Data that identify essential information for the design process (Fig. 25).

- Most searched colours
- Most popular shoe category
- Emerging lifestyle patterns
- Fit feedback and sizing issues

Fig. 25: Information identified using Big Data Analysis

For instance, Big Data analytics can be used by organisations within the footwear industry to examine how **consumers perceive sustainability** and provide insights that facilitate better decision-making (Polese et al., 2019[31]). Through these analyses, organisations locate potential

[30] WGSN. (n.d.). WGSN – Trend forecasting & analytics. Retrieved from: https://www.wgsn.com/en
[31] Polese, F., Ciasullo, M. V., Troisi, O., & Maione, G. (2019). Sustainability in footwear industry: a big data analysis. Sinergie Italian Journal of Management, 37(1), 149-170. DOI: 10.7433/s108.2019.09. Retrieved from: https://www.researchgate.net/publication/337736234_Sustainability_in_footwear_industry_a_big_data_analysis

areas where they can align their product design with their business strategies to meet consumer expectations for sustainability. These analyses provide organisations with the opportunity to maximise their advantages while minimising their risks when designing and implementing sustainable business initiatives.

Another example is when data indicate a significant increase in demand for trail-running shoes in urban areas, designers may include more rugged outsoles in their lifestyle sneaker lines, thereby merging fashion with functionality.

Additionally, Big Data has made mass customisation of footwear a reality. By collecting customer foot scans and developing a database of shoe sizes, companies are refining their last shapes worldwide to create better-fitting footwear for their customers (Nuswantoro et al., 2025[32]). By changing the shape of the last or upper materials, designers can create silhouettes that accommodate a range of fits.

Traceability is important in shoe design because it allows the designer to track each material back to its source and provides access to **environmental impact data** for all materials used in the footwear production (Luca et al., 2018[33]). Traceability must be documented and included in material specifications.

5.3 3D Printing in footwear design

Footwear design is increasingly influenced by 3D printing technologies for **customising** new products, **rapid prototyping**, and **reducing material use** in manufacturing.

Additive manufacturing technology enables designers to create highly complex geometries, lattice structures, and performance-oriented components that are difficult to produce using traditional manufacturing methods or too expensive (time/money).

For example, Adidas (Fig. 26) and New Balance (among others) have been developing advanced, customised **3D-printed midsoles** with complex lattice structures to provide improved cushioning and maximise performance. The lightweight construction of these new midsole designs, coupled with their mechanical properties, makes them very difficult (or even impossible) to produce using traditional injection-moulding methods.

[32] Nuswantoro, W. B., Frannita, E. L., & Hidayahtullah, M. C. (2025). Toward customizable footwear: A systematic review on digital transformation in the footwear industry. Jurnal Teknologi Technoscientia, 18(1), 16–26. https://doi.org/10.34151/technoscientia.v18i1.5325. Retrieved from: https://ejournal.akprind.ac.id/index.php/technoscientia/article/view/5325

[33] Luca, A., & Iovan-Dragomir, A. (2018). Software Application for Footwear Traceability. In The International Scientific Conference eLearning and Software for Education (Vol. 3, pp. 188-193). " Carol I" National Defence University. Retrieved from: https://www.researchgate.net/publication/325569646_Software_application_for_footwear_traceability

Fig. 26: Adidas 3D-printed running shoe midsole. Source: https://news.adidas.com/futurecraft/adidas-breaks-the-mold-with-3d-printed-performance-footwear/s/8099a318-f9e7-45d8-9887-42c3dde5e6fd

The creation of **custom orthotics and insoles** is another key application of 3D printing for footwear design (Fig. 27). By pairing digital scanning technologies of an individual's foot with 3D printing, designers can produce customised insoles that fit an individual's foot shape, pressure distributions and support requirements. As well as enhancing comfort through improved fit, customised insoles demonstrate how the use of digital processes for user-centred design has expanded the range of product development possibilities available to footwear designers (Anggoro et al., 2019[34]).

Fig. 27: 3D printed custom insoles. Source: https://www.illinoisfoot.com/blog/the-power-of-custom-orthotics

In addition to the above, a growing range of 3D-printed footwear products is being developed for **experimental** and **forward-thinking fashion** designers who require complex heel styles and

[34] Anggoro, P. W., Bawono, B., Jamari, J., Tauviqirrahman, M., & Bayuseno, A. P. (2021). Advanced design and manufacturing of custom orthotics insoles based on hybrid Taguchi-response surface method. Heliyon, 7(3). 10.1016/j.heliyon.2021.e06481 Retrieved from: https://www.cell.com/heliyon/fulltext/S2405-8440(21)00586-7

structural components that showcase the artistic potential of 3D printing (Lin et al., 2015[35]; Armillotta et al., 2014[36]).

Furthermore, 3D printing enhances footwear designers' ability to produce rapid-prototyping footwear by enabling them to experiment not only with the bottom but also with the upper and accessories, without incurring the long lead time normally associated with conventional tools. This enables faster product development and a flexible, iterative approach to designing new products.

The **Easter Egg Collection** (Mihai et al., 2025[37]) used 3D printing technology to create elements inspired by traditional Romanian decorated Easter eggs, aiming to both preserve cultural heritage and explore new ways of interpreting this art form. Designers developed digitally crafted patterns with rich ornamental details and printed them using additive manufacturing technologies. These elements were also used for footwear customisation (Fig. 28).

Fig. 28: CONDUR by alexandru footwear customised with 3D-printed elements inspired from traditional motifs. Source: TUIASI

Finally, new concepts for footwear produced entirely through 3D printing are emerging as a potential solution for on-demand and as part of a circular, sustainable production model. Companies such as Zellerfeld (n.d)[38] have begun developing shoes made from a single material (mono-material) that can be produced as a single continuous piece and easily recycled into more printing material, thereby eliminating waste and streamlining the supply chain (Fig. 29).

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[35] Lin, L. Y., & Chen, C. H. (2015). Innovation and ergonomics consideration for female footwear design. Procedia Manufacturing, 3, 5867-5873. https://doi.org/10.1016/j.promfg.2015.07.891. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2351978915008926

[36] Armillotta, A., Cavallaro, M., & Minnella, S. (2014). Direct digital manufacturing of shoe heels through Fused Deposition Modeling. In Proceedings of the Digital Design Manufacturing Conference (pp. 1-6). Fraunhofer Verlag. Retrieved from: https://re.public.polimi.it/handle/11311/978204

[37] Mihai, A., Curteza, A., Firicel, R., Streba, I., & Ionesi, D. (2025, June 9). Can we train future artisans to bring sustainable solutions to creative communities? CRAFT-IT4SD. Retrieved from: https://craft-it4sd.eu/can-we-train-future-artisans-to-bring-sustainable-solutions-to-creative-communities/

[38] Zellerfeld. (n.d.). Zellerfeld – Printed shoes on every foot. Retrieved from: https://www.zellerfeld.com

Fig. 29: Lotus 2 mid by Zellerfeld - 3D printed footwear. Source: https://www.zellerfeld.com/products/lotus-2-mid

These examples show how 3D printing is transforming both functional and creative aspects of today's and future footwear design.

5.4 Integration of digital science

The integration of modern design and science continues to increase exponentially.

Digital twins enable designers to understand material properties before physically constructing a prototype. A digital twin of a material provides designers with an understanding of the material's elastic limit, stretch, abrasion resistance, and breathability (Kalidindi et al., 2022[39]).

Sensors are a transformative element that reshape both the shoe's physical characteristics and the overall development process**.** While developing shoes with **embedded pressure, motion**, **temperature, and humidity sensors,** designers will have access to **real-time biomechanical** and environmental data to understand how the foot interacts with a shoe during different physical activities (Firtikiadis et al., 2024[40]). This understanding provides data-driven insights that assist designers in making **evidence-based decisions** throughout the research and concept phases; establishes a functional architecture for the concept; and helps designers select materials and ergonomically shape the shoe in the detail design phase. Lastly, shoe prototypes incorporating built-in sensors allow designers to quickly **validate performance and comfort**, enabling data to be utilised as quantitative metrics rather than qualitative (subjective) assessments. In addition to assisting with the physical design of the shoe, sensor data supports services, predictive maintenance, and **iterative improvement** of future designs. Therefore, sensor-equipped shoes create a connection between the engineered physical product (shoes) and the engineered digital product (information), enabling a smarter, adaptive, customer-focused product while providing a feedback loop for continued innovation throughout the shoe's entire lifecycle.

By using **simulation tools** such as Finite Element Analysis (FEA), designers could generate insights into the durability, comfort, and service life of footwear components. Through these simulations, designers can evaluate the structural behaviour and performance of different shoe elements under a range of loading and use conditions (Fig. 30). Designers can also study the distribution of

[39] Kalidindi, S. R., Buzzy, M., Boyce, B. L., & Dingreville, R. (2022). Digital twins for materials. Frontiers in Materials, 9, 818535. https://doi.org/10.3389/fmats.2022.818535 Retrieved from: https://www.frontiersin.org/journals/materials/articles/10.3389/fmats.2022.818535/full

[40] Firtikiadis, L., Manavis, A., Kyratsis, P., & Efkolidis, N. (2024). Product design trends within the footwear industry: A review. Designs, 8(3), 49. Retrieved from: https://www.mdpi.com/2411-9660/8/3/49

pressure and flexion when a simulated foot strikes the ground and use this information to develop optimal geometric designs for midsoles and outsoles (Spahiu et al., 2021[41]). Also, the impact of materials on footwear behaviour could be evaluated (Seul et al., 2023[42]).

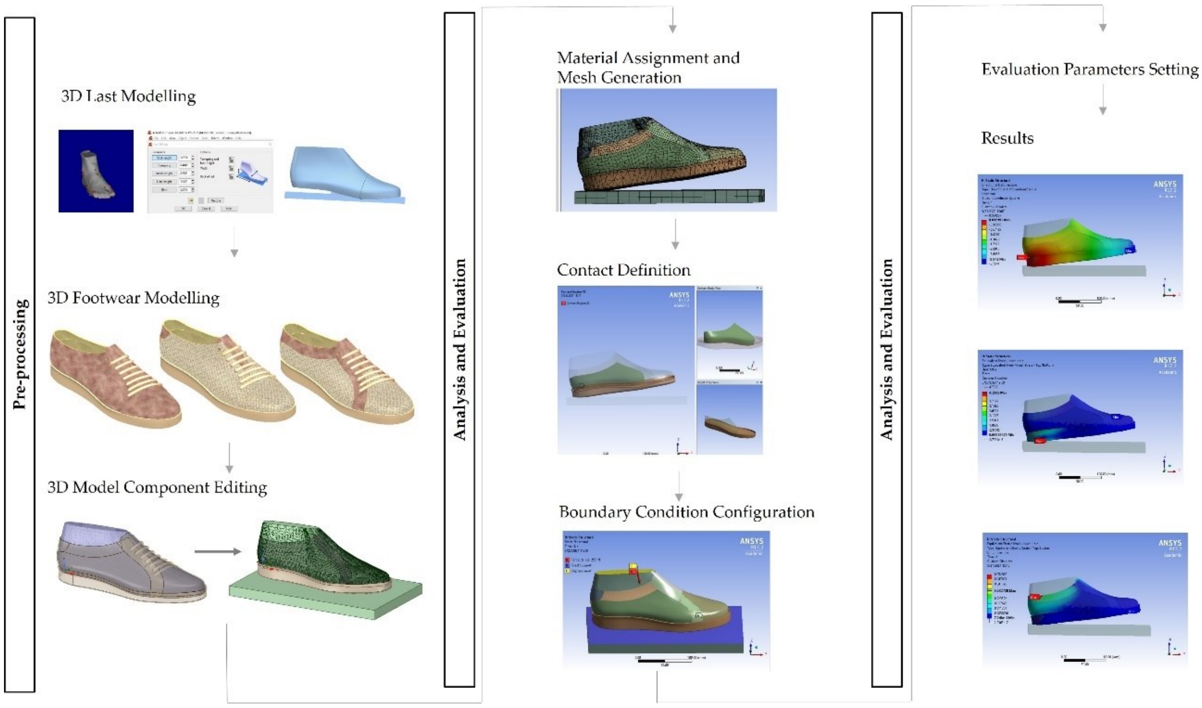

Fig. 30: Footwear behaviour simulation using Finite Element Analysis. Source: Seul, A., Mihai, A., Costea, M., Bodoga, A., & Curteza, A. (2023). The influence of materials on footwear behaviour: A finite element simulation study. Materials, 16(22), 7203. https://doi.org/10.3390/ma16227203. Retrieved from: https://www.mdpi.com/1996-1944/16/22/7203

These tools enable adaptive designs that fit the size and shape of the user's foot. The workflow for producing these designs requires an understanding of the footwear's various functions, as well as technical knowledge of how to produce them.

5.5 Virtual and Augmented Reality in footwear design

Virtual Reality (VR) refers to computer-generated, immersive environments that create a simulated experience for users to interact with, as if they were physically present. VR uses devices (VR headsets, controllers, or motion sensors) to place users in a three-dimensional (3D) space, both visually and, in some cases, physically. Within this 3D virtual environment, users can look around, physically move, and manipulate virtual objects. VR's primary purpose is to create a feeling of "presence" by making a user feel as if they are situated within the virtual environment; this feeling may be used for entertainment, training and learning, design, or the simulation of real-world situations.

[41] Spahiu, T., Almeida, H., Ascenso, R. M., Vitorino, L., & Marto, A. (2021). Optimization of shoe sole design according to individual feet pressure maps. Computers in Industry, 125, 103375. https://doi.org/10.1016/j.compind.2020.103375 Retrieved from: https://www.sciencedirect.com/science/article/pii/S0166361520306096

[42] Seul, A., Mihai, A., Costea, M., Bodoga, A., & Curteza, A. (2023). The influence of materials on footwear behaviour: A finite element simulation study. Materials, 16(22), 7203. https://doi.org/10.3390/ma16227203 Retrieved from: https://www.mdpi.com/1996-1944/16/22/7203

VR provides footwear designers with an **immersive digital environment** in which they can experience their footwear concepts as life-sized visual representations (or virtual images) and quickly change them (Fig. 31).

In addition, VR enables footwear design teams to analyse, manipulate, and evaluate the **shape, proportions**, and **colour** of their designs using a visual, spatially-based method without the need to create a physical prototype. Thus, the use of VR will reduce the product development cycle and minimise the amount of physical material required to create prototypes.

Fig. 31: Footwear concept modelled in Virtual Reality using Gravity Sketch. Source: https://gravitysketch.com/

Furthermore, footwear designers can **replicate real environments**, including, but not limited to, shoe movement on the wearer's foot and ambient light at different times of day, enabling them to make aesthetic assessments of their designs much earlier in the design development process. As a result, increased collaboration among team members in remote locations via VR will enhance the efficiency of the design development process for each participant.

Augmented Reality (AR) refers to the addition of digitally created content—such as photos of products, three-dimensional (3D) models, animated GIFs, written text, etc.—to real-world surroundings in real time. While it does not replace the actual environment as many VRs do, it provides more information about an environment by including interactive elements that can be overlaid onto the physical space using various devices, such as smartphones, tablets, AR eyewear, or smart mirrors. Users can see the actual physical space and view or interact with the added digital content simultaneously. A blended experience created by this allows for a wide variety of use cases: virtual try-on, navigation, training, design visualisation, and many forms of interactive advertising.

AR enables footwear designers to create visual representations of actual footwear digital models, overlaying them onto the buyer's/person's foot (Fig. 32). AR provides footwear designers with potential insight into a footwear prototype's fit, style, and scale in the digital design environment (Luh et al., 2013[43]).

[43] Luh, Y. P., Wang, J. B., Chang, J. W., Chang, S. Y., & Chu, C. H. (2013). Augmented reality-based design customization of footwear for children. Journal of Intelligent Manufacturing, 24(5), 905-917. Retrieved from: https://link.springer.com/article/10.1007/s10845-012-0642-9

Fig. 32: Virtual try-on experience using AR. Source: https://www.perfectcorp.com/business/products/augmented-reality-shoes

As AR and VR continue to evolve, these technologies enhance innovation in footwear design by promoting a data-driven approach, reducing reliance on physical prototypes, and increasing creativity and personalisation.

In the context of this topic, the Volumental Technology[44] system scans feet three-dimensionally and digitally visualises footwear fit to help consumers determine their proper size and model (Fig. 33). Digital displays and smart mirrors are often seen as complementary to the Volumental Technology system. For instance, New Balance partners with Volumental for 3D foot scanning in stores, improving fit recommendations and helping customers select the most suitable models.

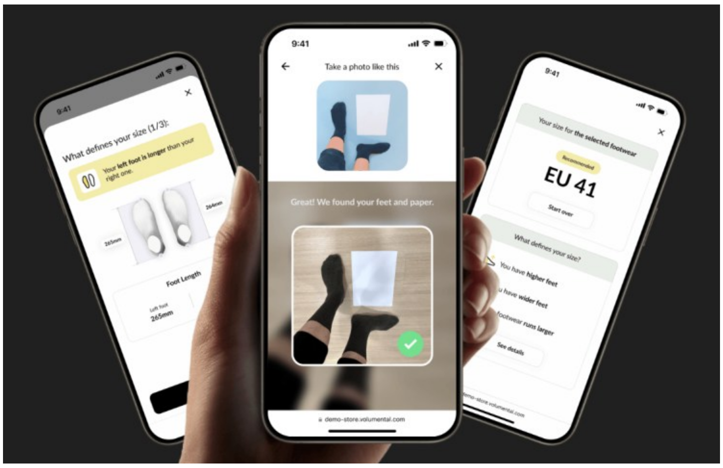

Fig. 33: Volumental scanning system. Source: https://demo-store.volumental.com/pages/how-to-scan

[44] Volumental. (n.d.). Volumental. Retrieved from: https://volumental.com/

6 Case Study and Project Work

6.1 Case study – CONDUR by alexandru

The Romanian shoe brand **CONDUR by alexandru** is a high-end luxury brand known for its **distinctive design** and **materials**.

The shoes are **handcrafted** by Romanian artisans from the highest-quality materials, with meticulous attention to detail and finishing. It adds a luxurious feel to the shoe while also increasing its **longevity**, which is very important given the **sustainability trend**.

The brand uses **ethically sourced materials**, **ethical labour practices**, and **small-batch production**. Additionally, the brand encourages consumers to buy a product they can be assured will not go out of style and will therefore yield long-term returns on investment.

The following pages present the conceptual Digital Product Passport (DPP) template proposed in this manual, completed with relevant information for two footwear models developed by the CONDUR by alexandru brand, namely **BLACK-GOLD ARCHITECTURAL SANDAL** and **MAGIC BLUE ART LACE BOOT**.

Within the context of footwear design, the DPP will be not only a documentation tool but an integral component of the design process itself. It includes essential information on each product's identity, regulatory compliance, and sustainability performance. It supports transparency across the product lifecycle and facilitates informed decision-making for both producers and consumers.

Fig. 34: Black-gold architectural sandal. Source: CONDUR by alexandru

Fig. 35: Magic Blue Art lace boot. Source: CONDUR by alexandru

BLACK-GOLD ARCHITECTURAL SANDAL (Diana Black)

condurbyalexandru.com

Code: 1212 – black
Category: Limited edition
Style: Sandals

Designed by: CONDUR by alexandru, Bucharest, Romania

Manufactured: Handcrafted at CONDUR by alexandru, Bucharest, Romania

Materials & components Traceability

Upper: Premium genuine leather. The main visible components include black textured leather, metallic gold-finished leather elements, and ornamental chain. Origin of main upper materials: EU / selected premium suppliers.

Linings: *Soft* natural leather lining for enhanced comfort and breathability. Origin of material: EU.

Bottom: Leather sole with anti-slip protective insertion. Origin of material: EU.

Accessories: Decorative metallic chain, jewel-style buckle, and elements with metallic finish. Origin of components: EU / selected international suppliers.

Auxiliary materials: Water-based / low-impact adhesives, sewing threads, reinforcement layers, heel support components, edge finishing materials and structural support inserts.

Environmental footprint

Product carbon footprint: Environmental impact mainly associated with material processing, transportation and handcrafted assembly. A full product carbon footprint assessment is under internal development.

Energy efficiency: Produced in a controlled small batch to reduce unnecessary waste and overproduction.

Water consumption in production: Primarily linked to upstream leather and component processing. Priority is given, where possible, to suppliers operating under monitored environmental practices.

Environmental product declarations: The brand supports responsible sourcing, durability-focused design and progressive reduction of avoidable waste.

Packaging: Footwear is delivered in recyclable cardboard packaging, with a reduced-plastic approach where feasible.

Durability & repairability

Care guidelines: Clean gently with a soft cloth, avoid humidity, direct heat and aggressive cleaning products. Store protected to preserve the sculptural structure and decorative elements.

Product guarantee: Covered by the applicable legal conformity guarantee under normal conditions of use.

Possibilities for reuse or reconditioning: Suitable for professional cleaning, heel tip replacement, accessory maintenance and selected restoration.

End of life & recycling

Recycling instructions: Prioritise repair, resale or donation before disposal.

Recovery of valuable materials: Metal accessories, leather sole and selected structural elements may be recoverable through specialised channels.

Regulatory compliance certifications

Safety certifications: Manufactured in accordance with applicable EU product safety and material compliance requirements for footwear.

Compliance with specific EU requirements: Product intended to comply with applicable EU requirements regarding product safety, material restrictions and traceability obligations.

MAGIC BLUE ART LACE BOOT (Angelina Magic Blue)

condurbyalexandru.com

Code: 2500 Magic blue
Category: Limited edition
Style: Boot

Designed by: CONDUR by alexandru, Bucharest, Romania

Manufactured: Handcrafted at CONDUR by alexandru, Bucharest, Romania

Materials & components Traceability

Upper: Printed premium leather / coated upper with artistic multicolour finish. Origin of material: EU.

Linings: Soft natural leather for enhanced comfort and breathability. Origin of material: EU.

Bottom: Leather sole with anti-slip protective insert. Origin of material: EU.

Accessories: Gold-finish metallic eyelets, satin lace, zipper closure. Origin of components: EU / selected international suppliers.

Auxiliary materials: Adhesives, sewing threads, reinforcement layers, support elements and finishing compounds. Origin: EU / controlled supplier network.

Environmental footprint

Product carbon footprint: Environmental impact mainly associated with upper material processing, decorative finishing, transport and handcrafted assembly.

Energy efficiency: Produced in limited batches with reduced waste and controlled production volumes.

Water consumption in production: Primarily associated with upstream material finishing and decorative processing stages.

Environmental product declarations: The brand promotes durability, intentional production and more responsible use of materials and resources

Packaging: Footwear is delivered in recyclable cardboard packaging, with a reduced-plastic approach where feasible.

Durability & repairability

Care guidelines: Clean gently with a soft cloth, avoid prolonged moisture, direct heat and abrasive cleaning. Protect decorative surfaces and store with internal support to preserve shape.

Product guarantee: Covered by the applicable legal conformity guarantee under normal conditions of use.

Possibilities for reuse or reconditioning: Suitable for lace replacement, zipper maintenance, heel tip replacement, cleaning and selected aesthetic restoration.

End of life & recycling

Recycling instructions: Prioritise repair, resale or donation before disposal.

Recovery of valuable materials: Metal eyelets, zipper components, satin lace, leather sole components and selected structural elements may be recoverable through specialised channels.

Regulatory compliance certifications

Safety certifications: Manufactured in accordance with applicable EU product safety and material compliance requirements for footwear.

Compliance with specific EU requirements: Product intended to comply with applicable EU requirements regarding product safety, material restrictions and traceability obligations.

6.2 Structure of the project work

Topic/Theme: Create a footwear collection that considers the impact of globalisation, digitalisation, and sustainability.

Problem identification & target group analysis

- Define the market segment and user needs.
- Identify problems related to comfort, sustainability, and performance.
- Formulate a project brief with key objectives and constraints.

Research & analysis

- Analyse existing solutions, including materials, manufacturing techniques, and sustainability challenges.
- Assess legal requirements (e.g., REACH, CADS) and industry standards.
- Identify opportunities for innovation, digitalisation, and customisation.

Design framework & concept development

- Provide a clear and concise title for your project.
- Use digital tools to generate ideas.
- Use digital tools for sketching.
- Consider Eco-Design principles (e.g., Design for Recycling, Design for Minimum Waste).
- Define materials and performance requirements based on sustainability and user comfort.

Virtual prototyping

- Develop the virtual 3D model of the footwear product.
- Evaluate the prototype from various perspectives:
    - functional and comfort parameters;
    - aesthetics and design;
    - sustainability and environmental constraints;
    - performance and innovative aspects.

Physical prototyping

- Transform the virtual model into a physical prototype in a footwear company or/and in a Fablab.
- Evaluate the physical prototype.

Presentation & evaluation

- Compile a visual and written report documenting all project stages.
- Use images, technical drawings, and virtual models to present findings.
- Explain how the prototype meets the initial problem statement, comfort, and sustainability goals.

7 List of Figures

8 References

Allodi, P. M. (2022). Analysis of the Key Drivers and Sustainability Impact on Sneaker Purchase Decisions Among Italian Gen Z (Master's thesis, Universidade Catolica Portuguesa (Portugal)). Retrieved from: https://www.proquest.com/openview/f37404dfeb15e3afa62ecc6816687683/1?pq-origsite=gscholar&cbl=2026366&diss=y

Andrade, B., dos Santos, A., & Broega, A. C. (2023). Design for sustainability in the footwear sector: Survey on strategies and impacts mitigation. In International Fashion and Design Congress (pp. 472-482). Cham: Springer Nature Switzerland. Retrieved from: https://link.springer.com/chapter/10.1007/978-3-031-43937-7_42

Anggoro, P. W., Bawono, B., Jamari, J., Tauviqirrahman, M., & Bayuseno, A. P. (2021). Advanced design and manufacturing of custom orthotics insoles based on hybrid Taguchi-response surface method. Heliyon, 7(3). 10.1016/j.heliyon.2021.e06481 Retrieved from: https://www.cell.com/heliyon/fulltext/S2405-8440(21)00586-7

APICCAPS. (2014). Footwear consumer 2030: A background study incorporating global trends to foresight footwear market (World Footwear report). World Footwear. Retrieved from: https://www.worldfootwear.com/media/wf_uploads/wf20191132716572.pdf

Armillotta, A., Cavallaro, M., & Minnella, S. (2014). Direct digital manufacturing of shoe heels through Fused Deposition Modeling. In Proceedings of the Digital Design Manufacturing Conference (pp. 1-6). Fraunhofer Verlag. Retrieved from: https://re.public.polimi.it/handle/11311/978204

Chen, X., & Crawford, R. H. (2017). A Review of the Design Process: How Methods Impact Design Creativity. In Proceedings of the ASME Design Engineering Technical Conferences (pp. V003T04A009). American Society of Mechanical Engineers.

Cheng, S. H. (2023). Impact of generative artificial intelligence on footwear design concept and ideation. Engineering Proceedings, 55(1), 32. Retrieved from: https://www.mdpi.com/2673-4591/55/1/32

Cietta, E. (2026). Globalisation, spheres of influence and the new geographies of fashion: The outlook for footwear and bags. Expo Riva Schuh and Gardabags. Retrieved from: https://exporivaschuh.it/en/news/detail/globalisation-spheres-of-influence-and-the-new-geographies-of-fashion-the-outlook-for-footwear-and-bags

Curteza, A., Mihai, A. (2005). Design- elemente, principii, aplicatii, Performantica Publishing House, Romania. ISBN 973- 730-149-8

European Commission. (2022). Empowering consumers for the green transition. Proposal for a directive. Retrieved from: https://ec.europa.eu/environment/

European Parliament and Council. (2024). Regulation (EU) 2024/1781 establishing a framework for the setting of ecodesign requirements for sustainable products, Official Journal of the European Union. Retrieved from: http://data.europa.eu/eli/reg/2024/1781/oj

European Union. (2024). EU's Digital Product Passport: Advancing transparency and sustainability. data.europa.eu. Retrieved from: https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability

Firtikiadis, L., Manavis, A., Kyratsis, P., & Efkolidis, N. (2024). Product design trends within the footwear industry: A review. Designs, 8(3), 49. Retrieved from: https://www.mdpi.com/2411-9660/8/3/49

Ghimouz, C., Kenne, J. P., & Hof, L. A. (2023). On sustainable design and manufacturing for the footwear industry–Towards circular manufacturing. Materials & Design, 233, 112224. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0264127523006391

INESCOP. (2024). DIS4REC: Footwear disassembling technology for the optimisation of the recycling process. INESCOP – Centre for Technology and Innovation. Retrieved from: https://www.inescop.es/en/inescop/activities/proyectos-i-d-i/proyectos-i-d-i-regionales/ivace/60-2024/780-dis4rec

Jellema, A. H., Huysmans, T., Hartholt, K., & Van Der Cammen, T. J. (2019). Shoe design for older adults: evidence from a systematic review on the elements of optimal footwear. Maturitas, 127, 64-81. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0378512219301318

Kalidindi, S. R., Buzzy, M., Boyce, B. L., & Dingreville, R. (2022). Digital twins for materials. Frontiers in Materials, 9, 818535. https://doi.org/10.3389/fmats.2022.818535 Retrieved from: https://www.frontiersin.org/journals/materials/articles/10.3389/fmats.2022.818535/full

Kotelskaia, A. (2023). Digital tools in the footwear design process: From traditional practices to artificial intelligence. Retrieved from: https://www.theseus.fi/handle/10024/792430

Lauff, C. A., Kotys-Schwartz, D., & Rentschler, M. E. (2018). What is a Prototype? What are the Roles of Prototypes in Companies?. Journal of Mechanical Design, 140(6), 061102. Retrieved from: https://www.researchgate.net/publication/323198004_What_is_a_Prototype_What_are_the_Roles_of_Prototypes_in_Companies

Lin, L. Y., & Chen, C. H. (2015). Innovation and ergonomics consideration for female footwear design. Procedia Manufacturing, 3, 5867-5873. https://doi.org/10.1016/j.promfg.2015.07.891. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2351978915008926

Luca, A., & Iovan-Dragomir, A. (2018). Software Application for Footwear Traceability. In The International Scientific Conference eLearning and Software for Education (Vol. 3, pp. 188-193). " Carol I" National Defence University. Retrieved from: https://www.researchgate.net/publication/325569646_Software_application_for_footwear_traceability

Luh, Y. P., Wang, J. B., Chang, J. W., Chang, S. Y., & Chu, C. H. (2013). Augmented reality-based design customization of footwear for children. Journal of Intelligent Manufacturing, 24(5), 905-917. Retrieved from: https://link.springer.com/article/10.1007/s10845-012-0642-9

McKinsey & Company. (2025). The state of fashion 2025. McKinsey Global Fashion Index. Retrieved from: https://www.mckinsey.com/industries/retail/our-insights/state-of-fashion

METASKILLS4TCLF. (2024). Skills intelligence for forecasting and monitoring TCLF emerging skills needs. Retrieved from: https://www.metaskills4tclf.eu/Library/Uploads/WP3_Final_Report.pdf

Midjourney. (n.d.). Midjourney. Retrieved from: https://www.midjourney.com/

Mihai, A., Costea, M., Seul, A., & Chirilă, A. (2025). ShoeDES – Footwear design for the circular economy: Module 3. Footwear product design for circular economy. Performantica. ISBN 978-630-328-141-4. Retrieved from: https://shoedes.eu/Library/Uploads/R4-EN.pdf#page=127&zoom=100,68,212

Mihai, A., Curteza, A., Firicel, R., Streba, I., & Ionesi, D. (2025). Can we train future artisans to bring sustainable solutions to creative communities? CRAFT-IT4SD. Retrieved from: https://craft-it4sd.eu/can-we-train-future-artisans-to-bring-sustainable-solutions-to-creative-communities/

Mihai, A., Pastina, M., Harnagea, M., Rusu B., Volocariu, R., Dragomir, A., Ichim, M. (2009). Metode utilizate pentru conceptualizarea si dezvoltarea produselor de incaltaminte, Performantica Publishing House, Romania. ISBN 987-973- 730-648-7

Mihai, A., Seul, A., Costea, M., Chirilă, A., & Lupu, R. (2025). Footwear design engineering. Performantica. ISBN 978-630-328-172-8. Retrieved from: https://e-learning.digi4wearables.eu/#/modules/student-details/3

Mihai, A., Curteza, A., Firicel, R., Streba, I., & Ionesi, D. (2025, June 9). Can we train future artisans to bring sustainable solutions to creative communities? CRAFT-IT4SD. Retrieved from: https://craft-it4sd.eu/can-we-train-future-artisans-to-bring-sustainable-solutions-to-creative-communities

NewArc.ai. (n.d.). NewArc.ai. Retrieved from: https://www.newarc.ai/

Nuswantoro, W. B., Frannita, E. L., & Hidayahtullah, M. C. (2025). Toward customizable footwear: A systematic review on digital transformation in the footwear industry. Jurnal Teknologi Technoscientia, 18(1), 16–26. https://doi.org/10.34151/technoscientia.v18i1.5325. Retrieved from: https://ejournal.akprind.ac.id/index.php/technoscientia/article/view/5325

Polese, F., Ciasullo, M. V., Troisi, O., & Maione, G. (2019). Sustainability in footwear industry: a big data analysis. Sinergie Italian Journal of Management, 37(1), 149-170. DOI: 10.7433/s108.2019.09. Retrieved from: https://www.researchgate.net/publication/337736234_Sustainability_in_footwear_industry_a_big_data_analysis

Qubstudio. (2023). Product design process: 10 steps. Retrieved from: https://qubstudio.com/blog/ten-steps-of-the-product-design-process/

Redaelli, C., Pellegrini, R., Mottura, S., & Sacco, M. (2009, June). Shoe customers' behaviour with new technologies: the Magic Mirror case. In 2009 IEEE International Technology Management Conference (ICE) (pp. 1-10). IEEE. 10.1109/ITMC.2009.7461388 Retrieved from: https://ieeexplore.ieee.org/abstract/document/7461388

Seul, A., Mihai, A., Costea, M., Bodoga, A., & Curteza, A. (2023). The influence of materials on footwear behaviour: A finite element simulation study. Materials, 16(22), 7203. https://doi.org/10.3390/ma16227203 Retrieved from: https://www.mdpi.com/1996-1944/16/22/7203

SgT Group. (2022). Every step counts: Four key challenges facing footwear today. SgT Group. Retrieved from: https://www.sgtgroup.net/four-key-challenges-facing-footwear-today/

Skills4Smart TCLF project. (2021). Skills for Smart Textile, Clothing, Leather and Footwear Industries, 591986-EPP-1- 2017-1-BE-EPPKA2-SSA-B. Retrieved from: http://www.s4tclfblueprint.eu/

Spahiu, T., Almeida, H., Ascenso, R. M., Vitorino, L., & Marto, A. (2021). Optimization of shoe sole design according to individual feet pressure maps. Computers in Industry, 125, 103375. https://doi.org/10.1016/j.compind.2020.103375 Retrieved from: https://www.sciencedirect.com/science/article/pii/S0166361520306096

Vieira, J. (2023). Shoe Design: From Concept to Creation. LinkedIn. Retrieved from: https://www.linkedin.com/pulse/shoe-design-from-concept-creation-jean-vieira/

Volumental. (n.d.). Volumental. Retrieved from: https://volumental.com/

WGSN. (n.d.). WGSN – Trend forecasting & analytics. Retrieved from: https://www.wgsn.com/en

Zellerfeld. (n.d.). Zellerfeld – Printed shoes on every foot. Retrieved from: https://www.zellerfeld.com