



Distributed Manufacturing of Shoes Components Via Digital Fabrication: A Small Local-Based Business Case Study

Fabricação Distribuída de Componentes para Calçados via Fabricação Digital: Um Estudo de Caso em Pequeno Negócio de Base Local

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Abstract

This research aims to raise questions regarding a systemic change in the current footwear production and consumption model, through the use of strategies oriented towards Distributed Manufacturing and Digital Fabrication of shoes. It emphasizes the development of Distributed Economy solutions through the creation of value for actors in small local businesses in the sector. Through a single case study, the process of redesigning a shoe was conducted with a local company in the sector in partnership with a makerspace. The project was carried out with the support of design tools to develop solutions and as a result, a prototype of a shoe was obtained, made in collaboration between the actors, showing that the local-global capacity of the Distributed Manufacturing strategy via Digital Fabrication has the potential to provide sustainable alternatives to the complex global supply chains for footwear and a possible solution to the excessive consumption of resources in this sector.

Keywords: Distributed Manufacturing; Digital Fabrication; Design for Sustainability; Footwear

Resumo

Esta pesquisa busca levantar questões referentes a uma mudança sistêmica no atual modelo de produção e consumo de calçados, através da utilização de estratégias orientadas para a manufatura distribuída e a fabricação digital de calçados. Enfatiza o desenvolvimento de soluções da Economia Distribuída através da criação de valor para atores em pequenos negócios locais do setor. Através de um estudo de caso único, o processo de redesign de um calçado foi conduzido com uma empresa local do setor em parceria com um makerspace. O projeto foi realizado com o apoio de ferramentas do design para desenvolver soluções e como resultado obteve-se um protótipo do calçado, feito em colaboração entre os atores, mostrando que a capacidade local-global da estratégia de Manufatura Distribuída via Fabricação Digital tem o potencial de fornecer alternativas sustentáveis às complexas cadeias globais de fornecimento para calçados e uma possível solução para o consumo excessivo de recursos deste



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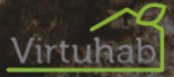
Palavras-chaves: *Manufatura Distribuída; Fabricação Digital; Design para a Sustentabilidade; Calçados*

1. Introduction

This article deals with partial results obtained in the master's thesis developed at the postgraduate program in Design at the Federal University of Paraná (UFPR), located in Curitiba, Brazil. The research is entitled “Circular and Distributed Design Oriented: A Method to Support the Pre-development Phase of Footwear”, was defended in February 2024 and approved by the Ethics Committee for Human and Social Sciences, under code CAAE: 71898323.9.0000.0214. The study is dedicated to professionals and researchers in the field of design working in the footwear sector. This sector is also the professional field of activity of the main author of this article, who works as a designer, pattern maker and manufacturer at a small and locally based brand of shoes, partner of this research. The study also had the support and partnership of a makerspace that enabled the development and production of one component for one of the company's shoe models through Digital Manufacturing (DM), phase of the research which is the focus of this paper.

Given this context, it is important to highlight some aspects of the footwear industry that encourage a reflection on the current production and consumption model of this sector, the main goal of this paper. The footwear value chain is very complex, centralized, and globalized. Most manufacturers outsource services or parts of their production due to the wide variety of products and the high competition on prices. The complexity of this context is exacerbated given the lack of support and encouragement for micro and small companies to use new technologies (Hines; Bruce, 2012). For Kongprasert and Butdee (2017), achieving sustainability in the footwear production and consumption system implies increasing the value in the sector's products and services, by making a transition to slower production cycles and locally based production systems. Also, the dominant economic model of the sector, based on large-scale centralized production, establishes dynamics that also distance consumers from the production process and reduce opportunities for local actors to appropriate and control their economic environment. Consequently, according to Vezzoli et al. (2018), this model mischaracterizes cultural identities and limits the diversity of local economic activities. Therefore, the network connections proposed by the Distributed Economy (DE), if properly designed, and considering the principles of sustainability, has the potential to promote the sustainable development of a given sector. Local actors can share their resources in different ways, including skills, knowledge, and their production or service capabilities (Santos et al., 2021).

Hence, this paper describes the developing process of a sole for a shoe through the use of Distributed Manufacturing (DM) via Digital Fabrication (DF) as a result of a redesign project of a shoe model designed by the research partner. The main objective established by the designers and leaders of the company for the shoe redesign was to implement the greatest number of strategies oriented towards the Distributed Economy (DE) in the short term. In order to achieve this, the strategy selected was DM via DF, given the difficulty presented by the company in acquiring inputs and components for the footwear production locally, as the region where the company is located (Curitiba, Brazil) does not have manufacturing industries of the sector. The redesign project focused on the Pre-Development phase of products, and it was made based on the model proposed by Rozenfeld et al. (2006), where the main objectives are



to guide the best decision about a company's product portfolio and the definition of the project's final objective. Also, according to Vezzoli et al. (2018), the initial phases of the product development process are the most efficient for implementing sustainable design strategies. Thus, through the research process a partnership with a local DF laboratory (makerspace) were sought to assist in solving the problem reported by the company related to the lack of access to local inputs (such as soles and insoles for the shoes) and also, to add value to the company product through the use of DM via DF, ensuring the valorization of local resources and skills, an important principle for the Distributed Economy concept.

2. The Unsustainability of the Footwear Sector

The footwear industry depends on a wide range of components made from different materials, including leather, rubber, synthetic or plastic materials, canvas, rope, and wood, among others (Dominique Muller; Paluszczek, 2017). Given the huge variety of shoe models and styles, there are also hundreds of different production processes and designs, which makes footwear a complex and delicate crafted product (Rathinamoorthy; Kiruba, 2020). Hence, the footwear sector's value chain determines the relationship between stakeholders, connects suppliers, manufacturers, distributors, wholesalers, retailers, customers, and organizes the flow in channels between them for the acquisition of raw materials, processing into finished products, and distribution to the final consumer (Boër; Dulio; Mass, 2007).

This industry has been experiencing accelerated growth, which, combined with the rising of input prices, triggers a strong competition between brands and manufacturers, resulting in significant impacts on the economic dimension of sustainability (Boër; Dulio; Mass, 2007; World Footwear, 2022). Also, the annual report of the United Nations Economic Commission (2018) points to the footwear sector as responsible for environmental impacts that contribute to health risks for humanity and the environment. Even though there have been efforts to use durable, biodegradable, sustainable, or low-emission materials, quantitative information on the long-term environmental implications of recently created smart materials is still scarce. The footwear industry also depends heavily on chemical products, which are the main causes of pollution and environmental degradation (Rathinamoorthy; Kiruba, 2020).

Despite the existence of new technologies, the vast majority of manufacturers still rely on artisanal practices as their main resource (ABICALÇADOS, 2022; Passos, 2014). The lack of transparency and traceability of the footwear value chain, also generates impacts on the social dimension of sustainability (Hines; Bruce, 2012). Given these facts, the role of Design for Sustainability (DfS) and innovation in the production processes and the sector's value chain, proves to be fundamental to rethink the initial design phase of shoes by implementing more sustainable strategies within the sector, which can be also considered a central technical challenge for small businesses (Rinaldi et al., 2022).

2.1 Distributed Manufacturing and Digital Fabrication

The Distributed Economy (DE) involves small-scale production units, located close to or in the same location as end users, who in turn become producers and have control over activities. They can be standalone or connected to share various forms of goods and services. DE's local units are capable of meeting nearby local needs, including artifact production and service demands throughout the product lifecycle. They can also involve the end user, who assumes

the role of manufacturer or service provider (Santos et al., 2021). The International Institute of Environmental Industrial Economics (2009) defines DE as an alternative structure for society and the economy, based on small-scale businesses in a local economic context, potentially leading to a more sustainable social and economic structure. It is a concept developed given the current industrial production systems, which promotes innovative regional development strategies, where production units can be much more flexible and resilient to respond to changes (Johansson; Kisch; Mirata, 2005).

The topic of DE is relevant to the footwear sector as the centralized current model has demonstrated a comparatively high level of impacts. Clark (2008) introduces the concept in the fashion industry as a tool to promote sustainability, strengthening the local economy, allowing personalization, and diversification of products, providing direct interaction between producer and user, implying greater transparency in the consumption and production system. The implications of DE also highlighted the generation of new use of the potential emerging digital technologies in the footwear sector, such as IoT (Internet of Things), AI (Artificial Intelligence), and DF (such as Additive Manufacturing technologies). This phenomenon enables mixing digital and physical technologies, greater flexibility in manufacturing and service provision, and knowledge-sharing among local actors (Vezzoli et al., 2018). DF is associated with new manufacturing skills through the use of technologies and digital control systems, and it can bring the designer closer to the manufacturing process of their creations and has the potential to reduce the impacts caused by the fashion sector by involving, respectively, distributed design and distributed manufacturing (DM) (Caccere; Santos, 2017; Pasetti, 2021; Perez; Santos, 2017). It also has the potential to enable customizations and manufacturing closer to or carried out by the end user (prosumer), potentially reducing the resources required for transportation and packaging. FabLabs, which are workshops for sharing equipment, production, and digital resources, encourage the spread of the Maker Culture and Self-production, these approaches imply the propagation of the DE concept (Santos et al., 2018).

An example is the shoe “microfactories” presented by Montes and Olleros (2020). In their study, the authors describe the processes of two innovative shoe factories, significantly smaller and highly digital and automated. These factories enable the production of personalized shoes in small batches. This, in turn, enables designers to involve groups of users and isolated suppliers to develop solutions and collaboratively configure a new product, service, or Product-Service System. This collaboration network includes laypeople, prosumers, producers, creative communities, specialists from different areas, and the role of the Designer becomes the articulation of this network (Santos et al., 2021). On-demand production also allows for small batch manufacturing or even custom fits, while also adapting product design and lifecycle management. It makes it possible to directly connect producers to consumers, or even other actors involved throughout the product life cycle (Boër; Dulio; Mass, 2007; Montes; Olleros, 2020; Morlet et Al., 2019).

Thus, small-scale production units can be supplied with local resources or via DF, reducing the impacts arising from the transport of raw materials and products (IIIEE, 2009). Given the arguments presented so far, it is clear that there is a possibility of a new relationship between companies in the footwear sector and their resource flows. With a more democratic management of its activities, it implies a systemic change for the footwear sector.

3. Methodological Procedures

This study aims to solve a practical problem by presenting a real solution and knowledge applied to a specific situation. Therefore, the nature of the research is applied and the approach is qualitative (Gil, 2017). The objective is exploratory in order to understand the research problem and research concepts (Prodanov; Freitas, 2013). Therefore, the research was carried out in 3 phases as described below:

Phase 1: A **systematic bibliographic review** was conducted to define the main constructs regarding the three areas of the research: Footwear Industry, Distributed Manufacturing, and Digital Fabrication.

Phase 2: A **single case study** was carried out through a **participatory observation** of a shoe redesign project in a small company of the footwear sector in partnership with a makerspace, both located in the city of Curitiba-Brazil. This phase took place on the premises of the research partners, and had the participation of the designers and leaders of the organizations. Within the context of developing the redesign of a product, a **workshop** was organized with the designers and leaders of the company, based on the Pre-Development phase of the Product Development Process model proposed by Rozenfeld et al (2006). The process involved the use of several design tools to support the creation process and decision-making, such as the **analysis of the company's product portfolio**; a **polarity matrix**, used to establish **priorities and requirements** for the project based on DE principles; a **brainstorming session** with the application of a **morphological matrix tool** to develop alternatives for the project; followed by a **decision matrix** to support the selection of the alternative to be developed integrating as many ED solutions as possible in the short term.

Phase 3: Consisted of the realization of the project in a real situation and further analysis. After selecting the alternative to be developed for the footwear redesign project, a prototype was made in co-creation between the footwear company and the makerspace, which made it possible to understand the viability of the shoe production using the DM strategy via DF in practice, and finally in-depth reflection was made based on the results obtained.

4. Results

The main activity of the footwear company partner of the research is the creation, development, production, and sales of shoes. The business model emphasizes the recovery and appreciation of the classic and traditional shoemaking process, where artisanal techniques guide the production model. The brand has been serving the local market for over 10 years with a small-scale production, reusing leather and textile leftovers from other local industries as a source of raw materials for the uppers (the superior part of the shoe). But most of the other inputs are provided by several partners from different regions of the country (such as rubber, ready-made soles, laces, eyelets and buckles). These components from different suppliers are prepared, cut and/or sewn in the brand's workshop, that is, they are handcrafted, resulting in the finished products locally. Nevertheless, the dependence on these inputs, that comes from external locations, reduces autonomy and possibilities in product design, and generates negative impacts caused by transportation. Despite the local production model, all the creation and production process are centralized, since the shoes production method consists of 3 main parts, that are produced separately and then glued and sewn together (sole, insole and upper).

As proposed in the Product Pre-Development phase by Rozenfeld et al, 2006, the **analysis of the product portfolio** must be the first activity carried out on a redesign project or a new product development. In this very first step, the designers and leaders from the organization discussed all the products from their portfolio, and one shoe model was selected for the project

with the support of a **decision matrix**. Some criteria were established considering environmental aspects of the products, customer acceptance and time of year for launch (summer or winter). The shoe selected for the redesign project was one of the brand's first successful creations and represents several of the company's concepts, such as quality and durability, and appreciation of the shoe craft. The shoe model is called Derby, and its production was discontinued in 2019 when the supplier of natural latex plates for the soles closed its activities. The designers tried to replace the artisanal production of soles from plates with ready-made soles to optimize the production process and reduce waste, but the cost of developing ready-made soles for this model with external suppliers became unfeasible for the business. Figure 1 presents the derby shoe model before the redesign project.



Figure 1: The Derby Shoe Model Before the Redesign Project: elaborated by the authors.

Once the product to be redesigned from their portfolio was selected, the group established **priorities and requirements** for the project that could be achieved in the short-term, based on DE principles and locally available resources for its production with the support of a **polarity matrix**: i) the shoe must guarantee easy repair and maintenance, extending its life cycle; (ii) the insole must be replaceable; (iii) the product design must maintain the elements that identify the brand, (iv) it must allow better use of leftovers from the business own production and/or enable the reuse or incorporation of leftover materials from other companies; (v) the project must meet the desires and needs of the local public by promoting better approximation and also prioritize partnerships with local suppliers or service providers.

Therefore, to assist the development of the next redesign phase, a **brainstorming** session was conducted to generate new ideas for the project and the group designed alternatives using a **morphological matrix**. Through the creation process, it was decided that the sole of the shoe (one of the three main components) could be created in partnership with a local makerspace, using DF tools. This decision was taken due to the lack of suppliers of this component locally, and as a way of taking a first step in decentralizing the footwear production, by integrating a local partner in this process. Another important decision made during this phase, was that customers would become the suppliers for some of the shoe inputs for the uppers, by providing disused textile or leather materials. which would be only produced on-demand. According to the designers, this is important in order to optimize the use of disused local materials, and also to bring the customer closer to the brand and meet their desires and needs in a co-creation process. Figure 2 represents the alternative designed and selected during this process, ensuring a product customization.

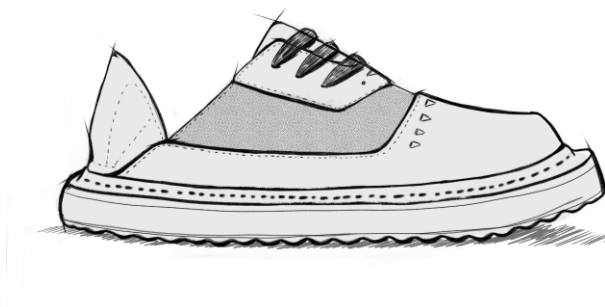


Figure 2: Alternative selected for the Derby Shoe Model Redesigned: elaborated by the authors.

The local makerspace selected to support the project provides services such as product sprints, courses and workshops, 3D scanning, 3D printing, CNC milling, laser cutting, electronics and IoT development, molding and casting services. A meeting between the designers and leaders of both organizations was held, to understand what could be accomplished in terms of developing a sole for the shoe. The decision-making was a collaborative process, where the makerspace founder was able to guide the designers through the options for developing and prototyping the shoe sole.

It was decided that a prototype of the desired sole would be first handcrafted by the designers in EVA (ethylene vinyl acetate), and afterwards, scanned in 3D at the makerspace. This was done to ensure that the sole was developed in an original way, including elements that identify the brand and with an exclusive design. After scanning the handcrafted sole, a mold was 3D printed, in order to produce the final sole with natural rubber (latex). According to the designers and leaders of the footwear company, this decision was made due to a proper selection of materials for the sole, to ensure one of the priorities and requirements established in the creation process. Printing the mold in 3D and shaping the sole with natural rubber guarantees greater durability to the shoe and easier maintenance and repair, a characteristic of the material selected, which makes it possible to combine the use of hybrid, artisanal and digital techniques. The sole was designed in a way that also incorporates information about the product, such as the company's brand, the name of the shoe model, size, and a message that communicates to the customer the maintenance and repair service provided for the shoe.

Once the sole was made at the makerspace via DF, the insole and upper were produced at the footwear company's workshop, and after glued and sewn together, with its artisanal footwear techniques, resulting in the prototype of the redesigned Derby shoe. The step by step and the images resulting from this process can be seen in Figure 3.

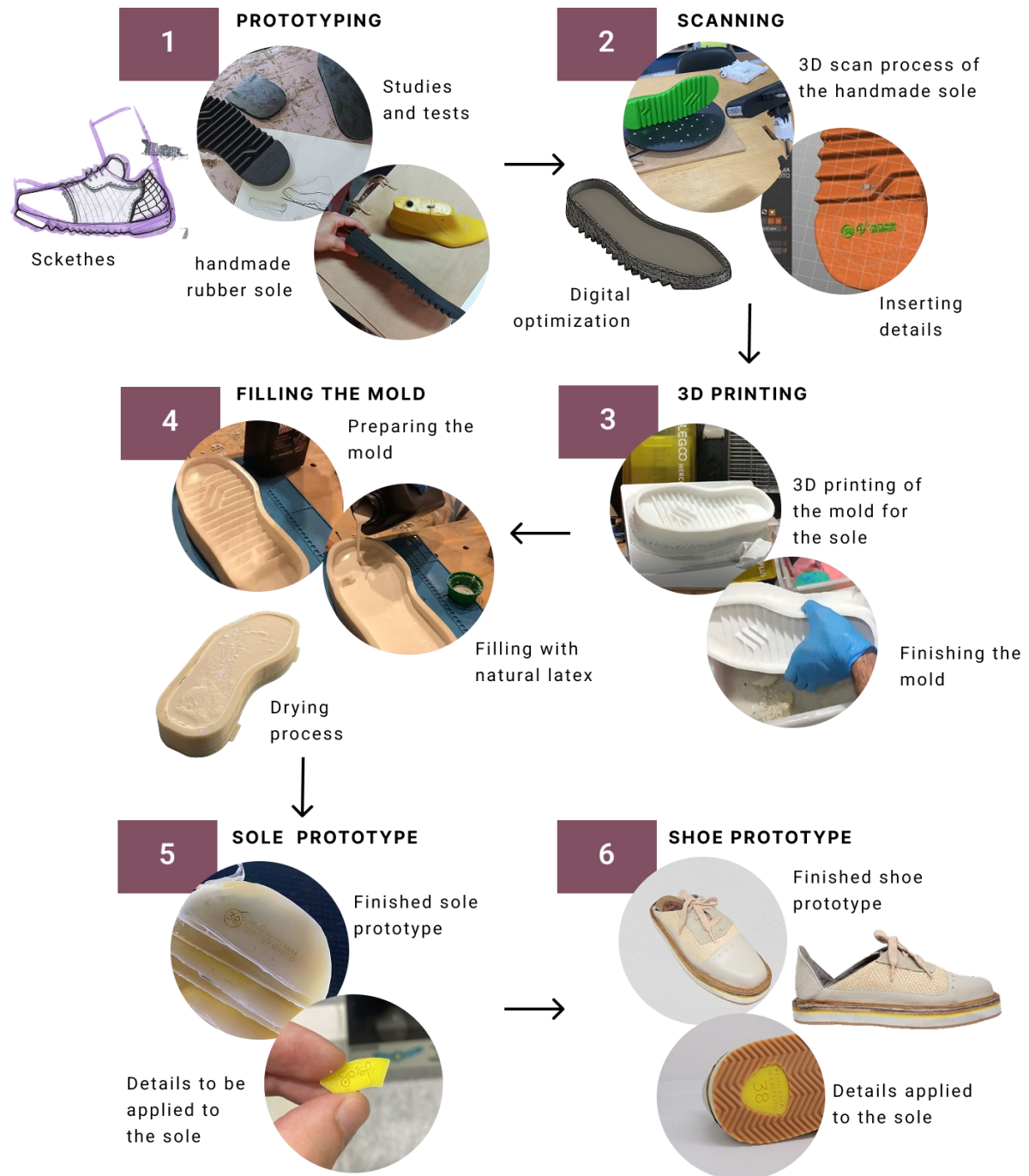


Figure 3: Shoe Sole Development Process Via Digital Fabrication: elaborated by the authors.

By producing the prototype with hybrid, digital and artisanal techniques, through the use of DM via DF, the local partnership proved to be efficient and the designers were able to incorporate the greatest number of viable strategies oriented towards DE in the short-term, such as: (i) reduction of impacts due to proximity to the makerspace; (ii) greater interaction between producer and user due to the small-scale and on-demand and customized production; (iii) better transparency in the production processes; and (iv) new use of the potential emerging digital due to the hybridization of processes (handcrafted and digital).



5. Discussion

Based on the results obtained, it is possible to reflect that this DM via DF model used on this project allows a reflection on the decentralization of the production process of the footwear company partner of the research. The development of the prototype proved that shoe production is feasible with the support of a local makerspace with DF resources. The process used to develop the sole carried out in this research, also raises reflections about carrying out future studies that incorporate the use of local materials in the sole production (such as leftovers from local rubber industries or even the use of different natural fibers), expanding also the use of circular economy strategies. Other advantages identified, deals especially the reduction of dependence that small local brands have on large inputs and components suppliers for footwear production. By developing the soles locally via DM and DF they can increase their autonomy in the design and production processes, increasing the diversity of their local economic activities, as proposed by (Santos et al., 2021).

This can also be implemented by large companies in the footwear sector, according to Armstrong et al., (2021), the local-global potential of the DM strategy can humanize production processes and provide a more sustainable alternative to complex global supply chains and a possible solution to the excessive resource consumption characteristic of mass production in centralized settings. The DM via DF strategy also allows a co-creation process that can help companies in the footwear sector to connect with their customers and improve the initial process of identifying their needs and desires. Furthermore, moving the production closer to the end consumer is a principle that can reduce carbon emissions, and local production also generates value for the business, considering that many consumers evaluate the quality of products according to their location (Vezzoli et al., 2014).

6. Conclusion

This project was able to generate solutions for the local production of shoes for the research partner through the association of the principles and concepts of DE through DM via DF. Even though the project resulted in the redesign of a shoe that incorporated the greatest number of viable strategies oriented towards DE in the short-term, environmental, social, and economic concerns in the development of the sector's products must be also oriented to change patterns that result in the reduction of excessive consumption. However, the company did not make profound changes to the existing production chain, a new local stakeholder was involved within the shoe redesign project in order to strengthen and value local resources and also skills and competences, in a collaborative process, an important step towards making the production less centralized and more local. It was observed that micro and small businesses have inherent characteristics such as agility in the decision-making process and greater proximity to their immediate market, which can facilitate the implementation of DM. Hence, it is possible to conclude that similar companies in the footwear sector can act as agents of change in the current production and consumption patterns from the perspective of DM via DF.

However, the solution for the integration of DM and DF in the sector also has repercussions on discussions about changing lifestyles and the development of new business models, as every activity implies an impact. Although digital technologies can support the implementation of distributed manufacturing, it is important to note that they also incur an indelible environmental impact. Thus, further research is recommended to understand the electronic waste associated with these technologies and its high energy consumption. Additionally, the search for the



production or provision of locally-based services may require knowledge and material or cultural resources that cannot be available locally. Therefore, it is considered that the implementation of this concept does not necessarily imply a positive impact if it is not the result of a careful design and planning process. Nevertheless, micro and small businesses in the footwear sector have specific needs and need personalized measures to implement DM via DF in their processes.

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