DEVELOPING INNOVATIVE BALLET POINTE SHOES: A LEAN STARTUP AND DESIGN THINKING APPROACH

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Received: 15.12.2023 Accepted: 08.03.2024 https://doi.org/10.24264/lfj.24.1.2

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ABSTRACT. This study aims to explore the development of innovative ballet pointe shoes through the implementation of Lean Startup and Design Thinking methodologies. The research employs a multi-phase approach, including problem identification, concept development, market testing, and model refinement. Through iterative improvements and user feedback, the study seeks to create a model of pointe shoes that offers enhanced comfort, adaptability, and durability for ballet dancers. The research emphasizes the use of polymers and 3D printing in the manufacturing process, presenting opportunities for advancements in pointe shoe design. By incorporating new technologies and materials, the study contributes to the field of classical dance footwear. The proposed innovative solution holds potential to elevate the dancer's experience and performance in pointe shoes.

KEY WORDS: pointe shoes, innovation, Lean Startup, Design Thinking, 3D printing

DEZVOLTAREA POANTELOR DE BALET INOVATOARE: O ABORDARE TIP LEAN STARTUP ȘI DESIGN THINKING

REZUMAT. Acest studiu își propune să exploreze dezvoltarea poantelor de balet inovatoare prin implementarea metodologiilor Lean Startup și Design Thinking. Cercetarea de față implică o abordare în mai multe faze, care includ identificarea problemelor, dezvoltarea conceptului, testarea pieței și rafinarea modelului. Prin îmbunătățiri iterative și feedback de la utilizatori, studiul încearcă să creeze un model de poante care oferă confort sporit, adaptabilitate și durabilitate pentru dansatorii de balet. Cercetarea pune accent pe utilizarea polimerilor și imprimarea 3D în procesul de fabricație, prezentând oportunități pentru progrese în designul poantelor de balet. Prin încorporarea de noi tehnologii și materiale, studiul contribuie la domeniul încălțămintei pentru dans clasic. Soluția inovatoare propusă are potențialul de a crește experiența și performanța dansatorului la purtarea poantelor de balet.

CUVINTE CHEIE: poante de balet, inovație, Lean Startup, Design Thinking, imprimare 3D

DÉVELOPPEMENT DE POINTES DE BALLET INNOVANTES : UNE APPROCHE LEAN STARTUP ET DESIGN THINKING

RÉSUMÉ. Cette étude vise à explorer le développement de pointes de ballet innovantes grâce à la mise en œuvre des méthodologies Lean Startup et Design Thinking. La recherche utilise une approche en plusieurs phases, comprenant l'identification des problèmes, le développement de concepts, les tests de marché et l'affinement du modèle. Grâce à des améliorations itératives et aux commentaires des utilisateurs, l'étude cherche à créer un modèle de pointes offrant un confort, une adaptabilité et une durabilité améliorés pour les danseurs de ballet. La recherche met l'accent sur l'utilisation de polymères et l'impression 3D dans le processus de fabrication, offrant ainsi des opportunités de progrès dans la conception des pointes. En intégrant de nouvelles technologies et de nouveaux matériaux, l'étude contribue au domaine des chaussures de danse classique. La solution innovante proposée a le potentiel d'améliorer l'expérience et les performances du danseur avec des pointes.

MOTS CLÉS : pointes, innovation, Lean Startup, Design Thinking, impression 3D

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INTRODUCTION

In the present study, an examination is conducted into the historical progression and transformation of pointe shoes. This involves an investigation into their origination, contemporary status, and the concerns dancers have in relation to this type of footwear. The objective is to gain insight into the potential for innovation and constraints that arise when suggesting novel approaches.

History of Pointe Shoes

Dance has a rich historical background, originating from the Italian Renaissance and flourishing in France during the reign of Henry II and Catherine de Medici. In 1581, under Catherine's patronage, the first ballet in history, The Queen's Comic Ballet, was created, marking a significant milestone in the development of dance [1]. The subsequent growth of ballet occurred during the reign of Louis XIV, leading to the establishment of the Royal Academy of Dance in 1661, which later became known as the Paris Opera in 1780 [2].

In the early stages of ballet, dancers relied on high heels for their performances. However, this changed in 1730 when Marie Camargo introduced flat shoes that enabled dancers to execute intricate jumps and movements that were not feasible with heels [3]. It wasn't until 1832 that Maria Taglione captivated audiences by performing on the tips of her toes, utilizing the first pointe shoes during her rendition of La Sylphide, a choreography devised by her father [4]. Since then, they became a fundamental part of the repertoire and training of classical ballet female dancers.

Anna Pavlova (1881-1927) is credited with refining the design of pointe shoes as we know them today. Pavlova incorporated hard leather soles for enhanced support and stiffened the toe area, enabling dancers to achieve greater stability. Despite her innovative modifications, Pavlova faced criticism from her contemporaries who regarded her techniques as cheating [5].

The renowned Capezio brand played a pivotal role in establishing pointe shoes on the international stage. In 1887, Salvatore Capezio initiated his shoemaking career by opening a repair shop in New York. He subsequently began crafting sturdier and more supportive pointe shoes for ballerinas. In 1892, Capezio became the official shoemaker of the Metropolitan Opera House, and his brand flourished with the patronage of prominent figures like Anna Pavlova. During her inaugural United States tour in 1910, Pavlova purchased Capezio pointe shoes for herself and her entire company, contributing to the brand's resounding success [6]. Later, other significant brands emerged, such as Freed of London in 1929 and the Australian brand Bloch in 1931.

Developments and Current Status of Pointe Shoes

Despite the passage of time, pointe shoes have undergone minimal evolution since their invention in the 19th century [7]. Various brands emerged over the years, but they all utilized similar materials for manufacturing, including satin, hessian, canvas, suede, leather, cardboard, and paper [8]. Consequently, the durability of pointe shoes remains relatively low due to the moisture generated by perspiration, which weakens the fabric and paper layers supporting the toes, ultimately affecting shoe stability. On average, ballet pointe shoes last approximately 12 hours of use [9].

In the 1990s, former American dancer Eliza Gaynor Minden introduced a groundbreaking design for pointe shoes made from thermoplastic materials. This innovative development revolutionized the dance industry, significantly enhancing the durability of the shoes compared to traditional counterparts [10, 11]. Since 1993, numerous attempts have been made to introduce new pointe shoe models incorporating 21st century materials and technologies. However, many of these endeavours proved commercially unsuccessful and were subsequently withdrawn from the market, such as the Capulet, the Flyte, and the Mayer. Others remained as conceptual or theoretical projects, including the Nike Arc Angles and the P-rouette 3D printing pointe shoes [12].

More recently, brands like So Dança and Merlet have introduced models with resemblances to the concept proposed in this

research. Additionally, a new brand called Act-Able has emerged, presenting a model of pointe shoes fabricated through 3D printing [12].

Pointe Shoes: Biomechanics, Parts and Manufacturing

Pointe shoes are a crucial tool in classical ballet, primarily used by girls. The appropriate age to start wearing pointe shoes varies, but generally, it is not recommended before the age of 12, unless specific physical and technical conditions are met [13, 14].

The biomechanics of the foot play a crucial role in the execution of pointe work. In classical ballet, the lower extremities rely on external rotation as the fundamental position, primarily originating from the hip joint. This foundational posture is commonly referred to as "*en dehors*" [15]. From this starting point of *en dehors*, dancers must strive for complete plantar flexion of the feet and ankles in order to rise onto pointe [13]. This intricate movement entails elevating the body onto the toes while maintaining the external rotation, gradually passing through demi-pointe before ultimately achieving the full pointe position (Figure 1).

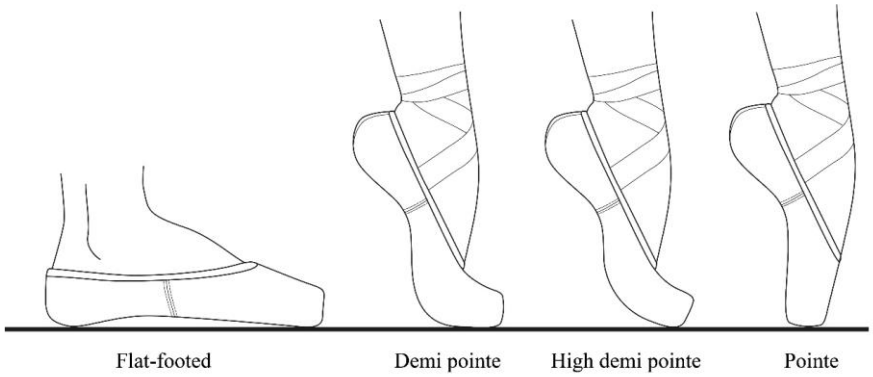

Figure 1. Biomechanics of getting over the pointe

A pointe shoe primarily consists of an internal structure composed of the box and shank, which provide support to bear the body's weight, and the textile component that covers the foot, known as the upper. Figure 2 illustrates the constituent parts of any pointe shoe.

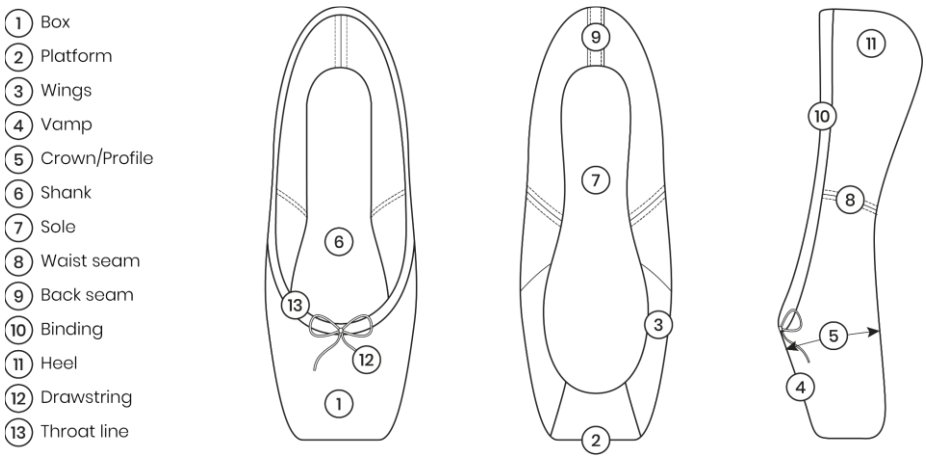

Figure 2. Parts of a pointe shoe

The upper is made of satin on the outside and a cotton lining on the inside [16]. The lining can be made from various moisture-absorbing or quick-drying materials to improve comfort.

The box (Figure 2), located at the front of the shoe, covers the dancer's toes, and provides support along with the shank. Traditionally, the box has been constructed using layers of paper or cardboard and burlap made from jute, glued together for rigidity. The box is the part of the shoe most affected by perspiration in terms of its durability. As reported by the Pittsburgh Ballet [17], an average professional ballerina exhausts approximately 100 to 120 pairs of pointe shoes per season. However, newer designs, like those pioneered by Gaynor Minden, fuse the box to the shank using elastomers, significantly increasing durability [18, 2].

The platform (Figure 2), the flat oval-shaped area on the bottom of the box, enables balance while on pointe. It is typically covered with satin, although some brands use suede. The platform's width has increased over time, potentially enhancing stability [18].

The side panels of a pointe shoe, known as wings (Figure 2), play a supportive role for the outer toes and sides of the feet when dancing on pointe [19].

Positioned on the lower front portion of the shoe, the vamp (Figure 2) covers the top of the toes. Its length is determined by factors such as the dancer's toe length, arch and ankle flexibility, and the type of instep they have.

The height of the crown (Figure 2) depends on the dancer's instep height and the compressibility of their foot [19].

Regarding the shank, located beneath the arch, it traditionally consisted of materials such as cardboard, leather, or a combination of both. However, modern pointe shoes utilize a variety of materials, including natural substances and synthetic components, to create shanks with different characteristics and properties [20, 12].

Pointe shoes are indispensable for ballet dancers, and their design incorporates biomechanical considerations and various components that provide support, durability, and comfort. A comprehensive understanding of these elements is crucial for both dancers and shoe manufacturers to optimize performance and minimize the risk of injuries.

EXPERIMENTAL

Methods

To undertake the development of innovative ballet pointe shoes, two methodologies will be combined.

The first of these is the Lean Startup methodology, developed by Eric Ries (2012), which focuses on creating and developing businesses in an agile and efficient manner [21]. Its aim is to minimise the risk in entrepreneurship by avoiding the development of products that customers do not desire or need. It is based on constructing a Minimum Viable Product (MVP) to obtain early feedback from customers and then iterate and pivot based on the results obtained [21, 22]. The idea is to quickly learn from the market and adapt to meet the real needs of users. Lean Startup also places emphasis on using metrics and data to make informed decisions rather than relying solely on intuitions and assumptions [23].

The second methodology is Design Thinking, which adopts a people-centred innovation approach [24]. It is based on deeply understanding users, empathising with them and their needs, and generating creative solutions through ideation and prototyping [24]. The methodology aims to address the real problems of customers and create meaningful and effective solutions that fulfil their needs and desires.

Both methodologies share a strong customer orientation and a mindset centred on experimentation and learning. Both approaches seek to deeply understand the needs, desires, and problems of users to develop relevant and effective solutions. Both Lean Startup and Design Thinking value iteration and rapid prototyping to obtain early feedback and validate ideas before investing significant resources [25]. Additionally, both promote an open and flexible mindset, allowing adaptation to changes and pivoting based on data and results obtained. Together, these similarities make the combination of both methodologies highly effective for generating new products and creating successful businesses.

According to Marion, Cannon, Reid, and McGowan (2021) [25], Design Thinking helps to better identify and understand customer problems and needs, providing a solid foundation for the development of the MVP in Lean Startup. By integrating both methodologies, a prototype can be quickly created based on the ideas generated from the Design Thinking process. Subsequently, this prototype is tested with customers, and Lean Startup comes into play to measure the response and learn from the results, which are analysed and used to make adjustments and improvements to the product. This create-measure-learn cycle is repeated until a product that satisfies the real needs of customers is achieved.

Phases of the Research

The research consists of 4 phases.

Phase 1: Identification of the Problems and Needs of the Users

This initial phase focuses on qualitative research, aligning with the principles of Design Thinking in its first stage, “empathize”. Firstly, qualitative interviews were conducted, recording audio with four professional dancers and thirteen classical dance students from different levels of a private academy in Valencia, regarding their training and use of pointe shoes. Secondly, two focus groups were conducted, recording audio with five 4th-year and nine 5th-year students from the Professional Degree of Conservatory of Dance in Riba-Roja de Túria. Finally, the latter group was asked to fill out a questionnaire after the focus group sessions, yielding 11 responses. This approach facilitates the identification of user needs and the evaluation of their relative importance. The results played a pivotal role in determining specific design requirements.

Phase 2. Definition of the Concept, Design and Testing of the MVP: Model 1

This phase focuses on the development of the Minimum Viable Product (MVP), aligning with the principles of the Lean Startup methodology. The first step involves defining the design concept, which addresses the problems identified in Phase 1. Subsequently, a concept test was conducted using a series of rapid prototypes to validate the concept with the participation of 24 dance students from the dance schools involved in Phase 1. Following the analysis of the test results, a usability test was conducted with several initial prototypes that were crafted by footwear industry professionals to be tested with 3 dance students and one professional dancer. Based on their feedback, relevant adjustments were made to proceed with the development of Model 1 as a validated MVP.

Phase 3. Market Testing of Model 1

As part of the Lean Startup methodology, this phase involved employing both qualitative and quantitative approaches for measurement and learning. Model 1, serving as an MVP, underwent thorough testing with 60 dancers of varying dance levels, who wore the shoes for a minimum period of one and a half months. An anonymous questionnaire was administered to gather valuable feedback, and conversations were held with certain dancers who reported specific issues, documenting them through videos and photos. The survey results were then analyzed to derive insights and make informed decisions for further iterations.

Phase 4. Redesign and Testing: Model 2 and 3

In this qualitative-focused phase, a redesign was undertaken to develop Model 2, which was subsequently tested at a summer dance campus involving 11 ballet students with varying skill levels. The students' usage of the model was meticulously observed, and they were queried about their experiences and sensations while dancing with the shoes. The results of this qualitative evaluation were then carefully analysed. These insights led to the conclusion that refinements and adjustments were needed to enhance the functionality of the product. Subsequently, to produce Model 3, several final design modifications were implemented based on the qualitative findings from the testing phase. The model 3 was then evaluated with 7 students from the Professional Degree of

Conservatory of Dance in Riba-Roja de Túria and two semi-professional dancers, who further contributed their feedback through specific questions about their experiences while dancing in the shoes. The combination of qualitative feedback from both phases served as a crucial guide to iteratively improve the pointe shoe design to better meet the users' needs and expectations.

RESULTS AND DISCUSSIONS

Phase 1: Identification of the Problems and Needs of the Users

The results of this phase were considered in two separate groups based on the user's profile, either a student or a professional dancer, as their knowledge, issues, and needs regarding pointe shoes differ.

Students

To analyse the outcomes of the interviews, focus groups, and questionnaires, two Design Thinking techniques were employed: the table for qualitative interview analysis (Table 1) and the empathy map (Figure 3).

These techniques considered the information gathered from the students who currently use or have used pointe shoes for a minimum of 3.5 hours per week during their training. This group comprised 21 students out of the total 27 participants. Six students from the private academy were excluded from this analysis as they use pointe shoes for less than 2 hours per week, indicating a beginner level.

The Table 1 allows to gather information from the interviews into a table, categorizing their needs, issues, and desires while assigning them a level of relevance.

Table 1: Qualitative interview analysis

	Needs	Problems	Desires	Observations
High relevance level	Prolonging the lifespan of pointe shoes when they are in the optimal state for dancing, as currently it's approximately one week.	Low durability in relation to their average price of €70: - 28.8% last between 2 and 4 weeks - 14.3% last between 1 and 2 months - 35.7% last between 2 and 3 months	Improved durability-to-price ratio. Incorporating reinforcement in the platform to enhance fabric longevity.	During performances, switching to new or old pointe shoes from those in good condition.
	Education to understand their foot characteristics and the necessary features for their pointe shoes. Pointe shoes that fit well, providing excellent support and mobility.	Lack of knowledge about the different parts of pointe shoes and their requirements.	Adjustable width to fit each foot. Pointe shoes to enhance the aesthetics of the foot.	Lack of awareness about the components of pointe shoes and the characteristics they should have based on their feet. Some students have 2 or more pairs available to alternate their use.
	Customization.	Differences in foot strength can result in one shoe softening or breaking before the other.	Having the option to select varying levels of hardness for each foot, as well as the color and finish of the pointe shoes.	Nine out of the eleven conservatory students who responded to the questionnaire affirm having one foot stronger than the other.
Moderate Level of Relevance	Adaptability.	Pain during use, especially when they are new or too soft.	Comfort.	Some teachers prohibit the use of toe caps. Students with bunions or the second longest toe experience more issues with pain and adaptability.
	The manufacturing process doesn't exert as much influence on the outcome.	The pointe shoes lack consistency and display variations with each purchase.	That the pointe shoes are consistently the same.	Traditional pointe shoes are crafted manually using materials susceptible to moisture. Consequently, the shoes may exhibit slight variations in shape and size with each manufacturing process.
	Thinner sole.	Lack of stability for flat feet.	Provide stability for flat feet.	This is particularly noticeable when performing a step called "*penché*".
	Providing effective guidance to reduce the likelihood of errors and expedite the process of finding their ideal pointe shoes.	Trial and error process to discover the suitable pointe shoes.	Finding their ideal pointe shoes on the first try.	Not all stores provide adequate guidance. None of the 21 participating students claim to have found their ideal pointe shoes.
	Minimize or eliminate the preparation time for the pointe shoes.	Time taken for sewing them.	Ribbons come sewn.	Out of the 11 surveyed students, 7 expressed a dislike for sewing them. In some instances, their mothers sew them instead.

	Needs	Problems	Desires	Observations
	That the pointe shoes are prepared for immediate use.	Painful breaking-in process.	Painless breaking-in process.	Most of them soften them slightly with their hands or feet. However, only one student trims the shank and darns the base.
Low Level of Relevance	Customization.	Difference in size between left and right foot.	Being able to purchase a pointe shoe of each size.	A student purchases two pairs simultaneously, each in a different size, intending to wear one on each foot. This practice is feasible due to the absence of left and right designations on pointe shoes. A majority of participants note that one shoe tends to feel tighter than the other, attributed to the inherent dissimilarity between our feet.
	Reduced noise generation.	Excessive noise from pointe shoes impacting the floor, especially noticeable during jumps.	Noiseless pointe shoes.	The noise level varies based on the brand. Professional dancers usually tap the shoes to soften them before wearing, reducing the sound.

The empathy map (Figure 3) enables the creation of a record that captures all the aforementioned information, along with the user's environment.

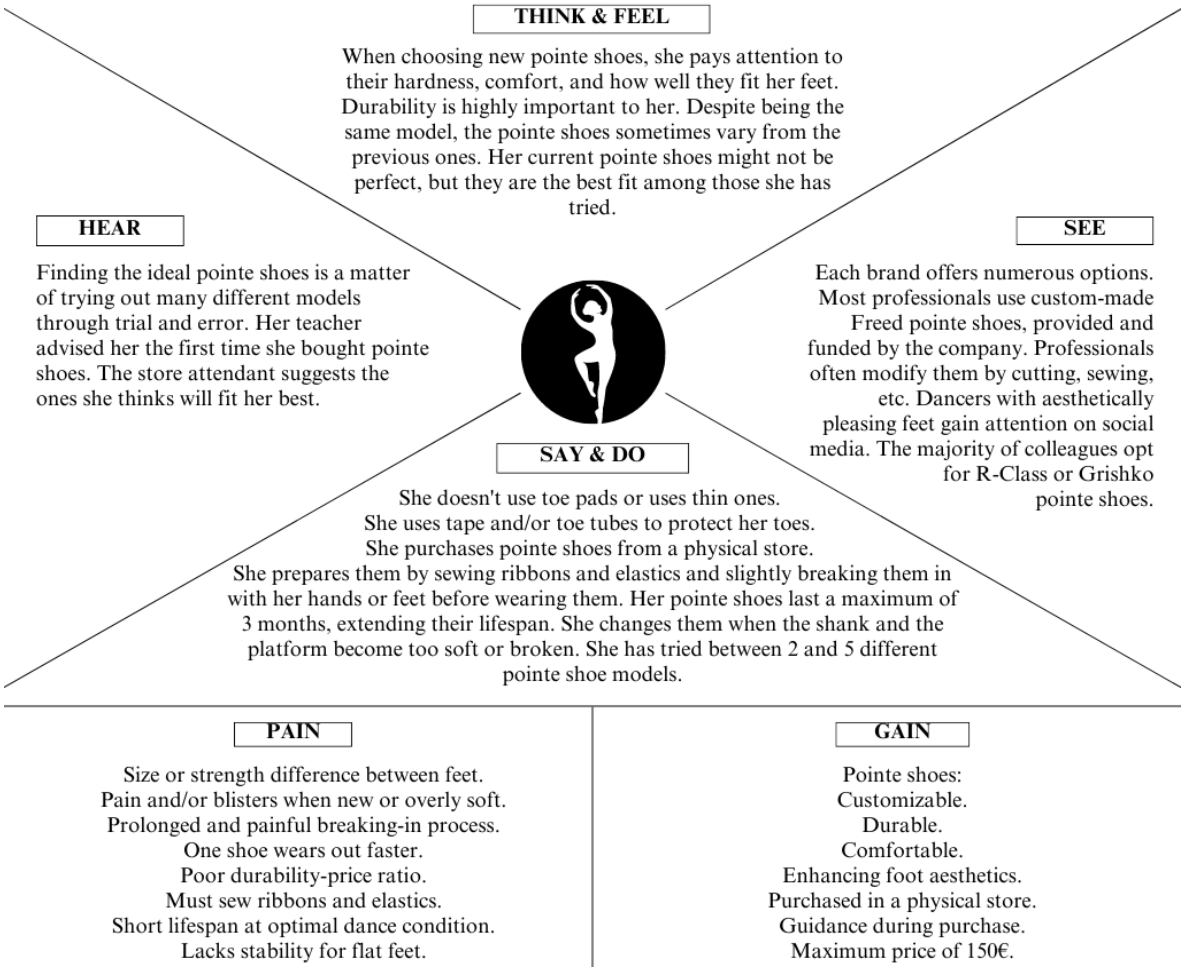

Figure 3. Empathy map

Professionals

The most common issues highlighted by the 4 professional dancers are flat-footed stability and lack of adaptability due to differences in foot strength. The most valued quality was determined using Equation 1.

$$P_T = \sum_{i=1}^{i=5} i \cdot \%_c \quad (1)$$

where, P_T is the total score, i is the score from 1 to 5, $\%_c$ is the percentage of dancers who voted for each quality.

Comfort and aesthetics stood out as the most highly regarded attributes (Figure 4). While durability holds lesser significance due to the company covering shoe expenses, participants do acknowledge the limited longevity of pointe shoes in optimal dancing condition. Typically, a monthly allowance is allocated for pointe shoes, and in cases where this allowance is constrained, durability gains prominence. Colour holds no significant importance, since performers are mandated to apply makeup to diminish any shine.

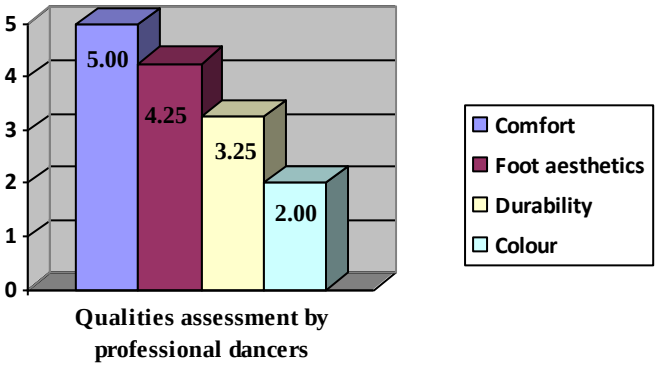

Figure 4. Score of the qualities valued in the choice of pointe shoes by professionals

List of Design Requirements

When defining the design requirements, students are considered as the target audience, as the market is much larger. There are more than 250,000 ballet students worldwide, as this number is examined each year by the Royal Academy of Dance (RAD), a British organization formed in 1920 that offers internationally recognized training certificates for different levels [26]. However, based on data obtained from the U.S. Bureau of Labor, Zippia, and the websites of the major companies in the US, Canada, Europe, and Russia, it is estimated that there are approximately 12,000 professional dancers worldwide [27, 28].

Therefore, based on the results obtained in the previous phase, a list of design requirements is proposed according to the target audience:

Table 2: List of design requirements

	Requirements
Durability	Pointe shoes should last a minimum of 3 months for dancers using them between 4 and 8 hours per week. Therefore, they must last a minimum of 72 hours
Comfort	Pointe shoes should be comfortable, so materials that enhance this characteristic should be considered in the design.
Adaptability	Pointe shoes should accommodate differences in foot strength; thus, they should be customizable in terms of hardness.
Foot aesthetics	They should enhance the aesthetics of each dancer's feet, so the goal will be to achieve customization of the shoe's point of curvature to adapt to the dancer's arch.
Colour	A traditional colour will be used as much as possible.
Price	It must be below €150.

Phase 2. Development MVP: Model 1

Concept Definition and Testing

Based on the user research findings, the following concept is proposed: pointe shoes with an internal polymeric structure and interchangeable shanks. This concept allows the dancer to use different levels of hardness or points of curvature for each foot and change them at will, according to the requirements of the moment or the choreography. In this way, the desired adaptability and increased durability are achieved.

Polymers are not affected by sweat; therefore, the durability will be significantly higher. To determine which polymer and manufacturing process are suitable for the internal structure, several tests were conducted, and quotations were requested. After evaluating the different options, 3D printed Polypropylene (Fused Deposition Modeling - FDM) was chosen for the box, due to its suitability in technical properties and cost. Additionally, laser cut and machined

Polyacetal was selected for the shanks, for the same reasons.

In order to validate the concept, several preliminary prototypes were created by separating the fabric from the internal structure.

Two focus groups were conducted at the dance schools that had participated in the previous phase. During these sessions, the prototypes were presented to the participants, and they were asked to simultaneously fill out an online survey (if possible) with general questions about pointe shoes and specific questions about the presented prototype. A total of 24 anonymous responses were collected to ensure the utmost sincerity from the participants.

The results of the survey show that durability is the most valued quality in pointe shoes, with a score of 3.79, followed by comfort with 3.75, foot aesthetics with 3.5 and colour with 3.16. The total score for each quality is calculated using Equation 1.

58.3% of the participants rated their interest in having different hardness in each foot with a score of 3 or more points (with 1 being the minimum and 5 being the maximum). However, only 16.7% scored their interest in using different sizes in each foot with 3 or more points.

Regarding the presented prototypes, 45.8% rated the usefulness of being able to change the shank with the maximum score (5), and another 50% rated it above 3.

An 87.7% expressed interest in purchasing the pointe shoes, of which 69.2% said they were willing to spend up to 150 € on pointe shoes that lasted longer, were more comfortable, and made their feet look beautiful. 72.2% considered a price range between 20 and 30 € for replacement shanks acceptable.

Out of the 24 participants, 70.8% were able to try the prototypes, of which 35.3% rated their comfort with a 5, and 52.9% with a 4.

Design and Testing of the MVP: Model 1

After the concept testing, Model 1 of the pointe shoes was designed. Two students and one professional dancer were selected to conduct the usability test using a functional prototype manufactured by footwear professionals. After a quick testing, it was determined that modifications should be implemented to improve the biomechanics of the pointe shoes: the thickness of the shanks was reduced to enhance flexibility in the metatarsal area, the sole rigidity was increased to prevent creasing in the arch area and the thickness of the lower wall of the box was reduced.

Finally, Model is represented and registered in the PCT/EP2021/052766 [29]. A detailed definition of each of its components is provided in Figure 5.

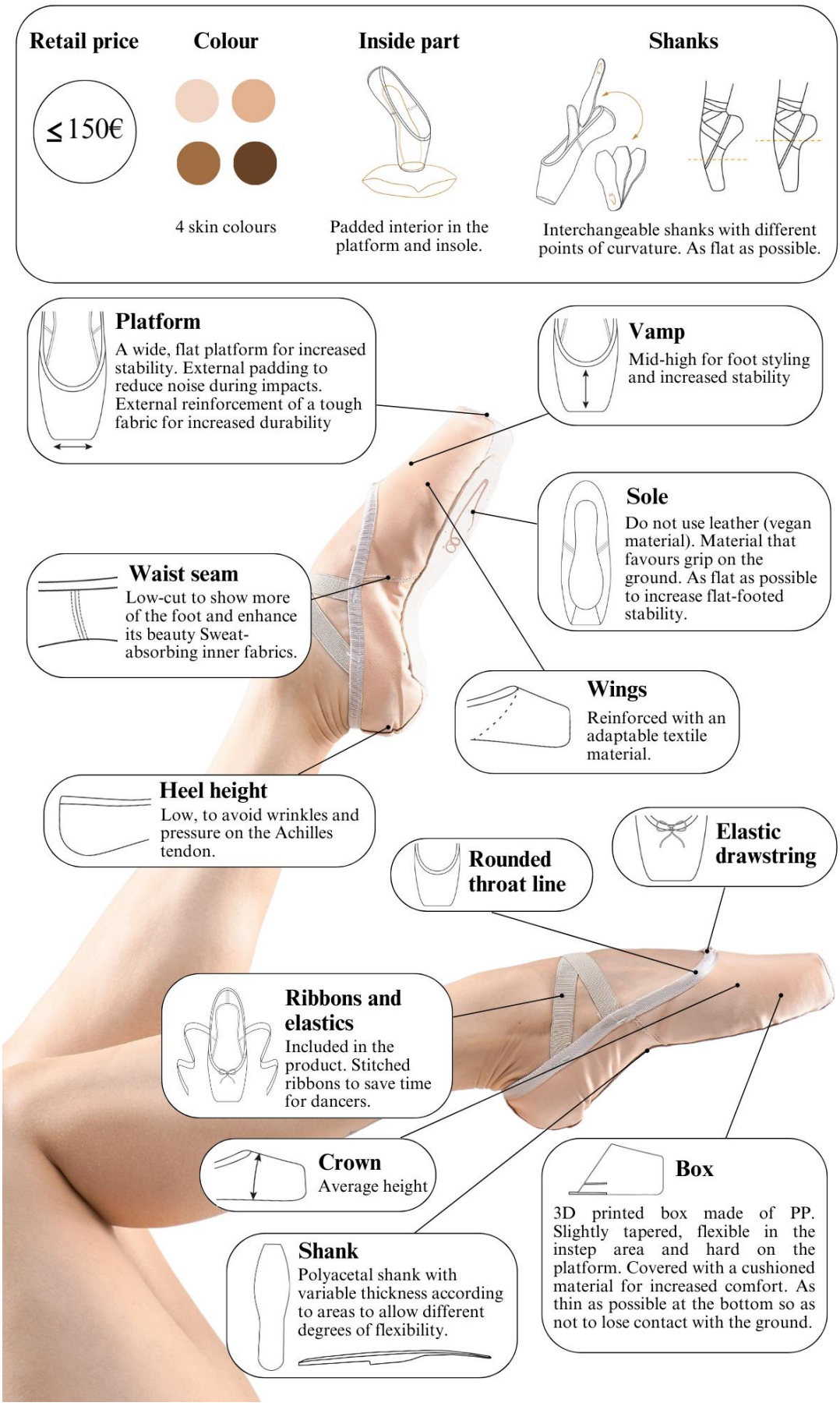

Figure 5. Description of MVP: model 1

Phase 3. Market Testing of Model 1

In the present study, a market test of the MVP was conducted with a group of 60 ballerinas who acquired and used pointe shoes for a minimum period of one and a half months. The purpose of this test was to evaluate the usability of the pointe shoes. To achieve this, a questionnaire was administered, guaranteeing anonymity in responses. Data from 33 ballerinas who completed the questionnaire were collected, while 5 left it incomplete, resulting in a total of 38 participants. Additionally, conversations were held with some of the respondents who directly reported their difficulties, documenting these issues through visual materials such as videos and photographs.

The results of the survey are presented below:

71.1% of the ballerinas expressed their intention to continue using these pointe shoes, while 5.3% showed lack of interest in continuing, and 10.5% were undecided. The remaining 13.2% chose not to respond to this question.

It was observed that 47% of the participants reported using pointe shoes for a weekly duration of 2 to 5 hours, while 41% indicated a usage period of only 2 hours. This distribution implies that a considerable portion of the participants might comprise beginner ballerinas or individuals engaging in ballet as an occasional recreational pursuit. Additionally, a minority of 12% reported using pointe shoes for over 5 hours on a weekly basis.

26% of the participants indicated that when stretching their feet, the pointe shoe did not adapt adequately, leading to undesirable aesthetic implications for ballet (see Figure 6).

Figure 6. Correct position on the left with a traditional pointe shoe and incorrect position on the right with pointe shoe model 1

44.7% of the ballerinas reported some kind of issue with the pointe shoes. The main problems were difficulty in correctly executing the rise onto pointe (34.2%) and the inability to roll down from pointe in a controlled manner (26.3%). Likewise, 15.8% of the respondents expressed difficulties in performing both movements.

Within the group of ballerinas who experienced problems when rising onto pointe, 61.5% were unable to perform the movement correctly (see Figure 1). On the other hand, the remaining 23.1% reported feeling a resistance that pushed them towards the ground, impeding the required biomechanical movement for the rise onto pointe.

10.5% of the respondents stated that the pointe shoes tended to stick to the floor during dance, while 18.4% indicated that this happened to a lesser extent but was tolerable. Given the relevance of this percentage, the possibility of modifying the material used in the base and sole was considered.

Another identified problem was the low heel height. 15.8% of the ballerinas experienced frequent slippage of the pointe shoes, 10.5% did so occasionally, and 26% had experienced this at some point.

The comfort of the pointe shoes was the aspect most highly valued by the ballerinas, with 47% rating their comfort with a score of 5 points (the highest) and 29% with 4 points.

Therefore, it was concluded that pointe shoe model 1 should undergo modifications to address the identified problems and improve certain functional aspects. However, the results were positive regarding the concept of pointe shoes, as a high percentage affirmed their desire to continue using them.

Phase 4. Development of the Model 2 and Model 3

Based on the market test results of the model 1, a series of changes were proposed to the internal structure of the pointe shoes with the aim of addressing the identified functional issues.

Design of Model 2

The box was modified by increasing the length of its cuts to enhance flexibility, and the base was slightly inclined to eliminate the need for the foot to reach a 90° angle to rise onto pointe (Figure 7).

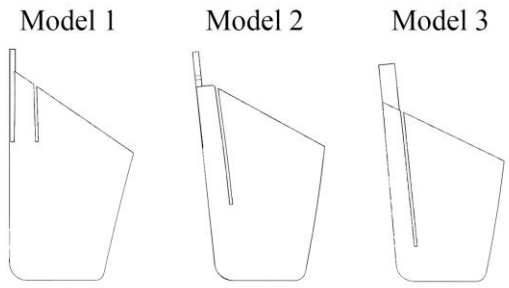

Figure 7. Box of the 3 models designed by the author

The last was redesigned to provide curvature to the sole of the pointe shoes, addressing the aesthetic issue of adaptability. To further improve this aspect, the wings were also shortened, as a trial conducted with two of the ballerinas who reported problems in the first phase revealed that the pointe shoes' aesthetics improved if they shortened the wings.

Regarding the platform reinforcement, another vegan fabric with better gliding properties was selected for testing.

With these changes, Model 2 was obtained.

Testing of Model 2

To conduct the testing of Model 2, the participation of 11 ballerinas was enlisted, who tested the ballet shoes during a two-week summer course. Among them, 5 dancers belonged to the beginner level (12-13 years), 3 to the intermediate level (14-15 years), and 3 to the advanced level (16-18 years).

Throughout this period, the performance of the ballerinas with the new pointe shoes was observed during their classes. At the end of the course, they were requested to complete a questionnaire detailing the positive and negative aspects of the shoes.

In the beginner level, 4 out of 5 students successfully adapted to the new pointe shoes, but some had difficulty fully supporting the platform while rising to pointe and controlling movements while rolling down. These shoes were perceived as somewhat soft.

In the intermediate level, none of the 3 students performed well with the new pointe shoes and only used them for one or two classes. They found the shoes too soft and inadequate for rising to pointe.

Among the advanced level, one dancer successfully mastered the new pointe shoes and continued using them. However, the other two dancers faced challenges due to the unflattering aesthetic and feeling insecure during movements from demi-pointe to pointe, finding the shoes too soft.

Figure 8. Beginner-level dancer, advanced-level dancers and intermediate-level dancer testing model 2

The test results conclude that while the pointe shoes fit better on the feet, achieving a fully elongated position has not yet been fully attained. It is suggested to reconsider the internal structure of shoe to improve the demi-pointe to pointe transition.

The platform material allowed sufficient gliding for turns but concerns regarding its durability were raised. Therefore, durability tests are proposed by combining the material with other fabrics to increase thickness and resistance. It was also identified as an appropriate moment to modify the shoe pattern, aiming to elevate the heel height to address issues raised during market testing, and lower the vamp height to reduce resistance during rising to pointe. Additionally, the proposal involves closing the throat line in the front, as it was observed during testing that it remained too open for most dancers.

Design of Model 3

For the development of Model 3, significant modifications were made to the internal structure of the pointe shoes.

The box was redesigned to enhance resistance during demi-pointe movements, making the transition to *en pointe* easier. The box's height was reduced, and the cuts were lengthened to improve flexibility in the toes (Figure 7). A rubber piece was added to the rounded edge that connects the sole to the platform, allowing slight deformation and providing support when the platform is not fully reached.

In regard to the shank, adjustments were introduced to augment its durability during demi-pointe motions. This component features diverse thickness levels, strategically chosen to attain the desired balance of flexibility and rigidity in various regions. To achieve this, the former practice of incorporating a metatarsal step to create thickness differentiation between the toe and arch sections (Figure 5) was replaced. Instead, a seamless curve was adopted, which not only bolsters resistance against flexion but also mitigates the buildup of tension. Consequently, this alteration diminishes the susceptibility to fractures within this specific area.

Regarding the upper, the patterns for the new last were designed, considering the conclusions obtained from the market testing.

With regard to the platform fabric, which is also used on the sole for aesthetic uniformity, various combinations were considered. The fabric tested in Model 2 was combined with other fabrics to provide increased resistance and thickness.

Testing of Model 3

Two testing modalities were conducted: one without direct observation and another with direct observation. In the first case, work was conducted with semi-professional dancers, managing remotely with feedback through photos, videos, and conversations. The second modality took place at the Riba-Roja de Túria Dance Conservatory, where students from different levels were selected: 2 students from 2nd-year, 3 from 4th-year, and 2 from 5th-year of Professional Grade. Their usage was observed, and communication was maintained for two weeks.

The semi-professional dancers performed well with the new pointe shoes, with one feeling better than her previous shoes and the other experiencing slight pressure on the foot pushing downwards. The

2nd-year conservatory students found the size and width of the shoes not ideal and chose not to continue using them after the observation period. However, the 4th-year conservatory students mastered the pointe shoes and decided to continue using them, praising their comfort and durability despite some difficulties in jumping. The 5th-year conservatory students had no issues with the shoes but preferred to stick with their current ones, with one student mentioning discomfort with the wide heel sole.

Figure 9. Semi-professional dancer, 2nd-year student, 4th-year student and 5th-year student testing model 3

In conclusion, based on the testing conducted, it can be affirmed that a design for pointe shoes suitable for 100% of the testers has been successfully developed. Among the 7 testers, 3 expressed a preference for the new shoes and intend to continue using them, whereas 2 testers opted to return to their previous models. Additionally, 2 testers found the new pointe shoes appealing, but they encountered sizing issues. Therefore, providing them with the correct size for evaluation will determine their continued usage.

Regarding the durability evaluation of different fabric combinations used in the platform, the continuous usage of the pointe shoes by the three 4th-year students during the testing and observation phase allowed to test these combinations. All combinations deteriorated in less than a month, with an average usage of 6 hours per week, except for one combination. The blend of microfiber fabric reinforced with polyester and cotton fabric demonstrated satisfactory durability. It was observed that the fabric undergoes gradual layer-by-layer breakage. The final layer experiences breakage after roughly 100 hours of use. Despite this, the breakage is minor, and the shoes continue to function adequately for an additional 45 hours. After surpassing the 145-hour mark, the breakage becomes substantial, necessitating a change of shoes.

Figure 10. Breakage after 61 hours, breakage after 100 hours and breakage after 145 hours

CONCLUSIONS

Ballet pointe shoes serve as essential tools for dancers, yet there have been limited advancements and innovations in the past century. This study addresses the creation of innovative pointe shoes through the implementation of Lean Startup and Design Thinking methodologies, whose combination has proven highly effective in developing new products within the field of classical dance. This research offers promising opportunities to enhance footwear and improve the

dancer's experience. By adopting an experimental approach, the study successfully identified the needs and challenges of dancers concerning pointe shoes, leading to the generation of creative and viable solutions.

The research process was divided into four phases, each providing valuable information for iterative improvements in the shoe design. Through this iterative process, pointe shoes were developed, yielding positive results in tests with dancers, displaying a durability of 72 hours under ideal conditions (utilized on a linoleum surface), and featuring a manufacturing cost that allows for a retail price of €150.

These pointe shoes stand out for their comfortable design and adaptability to each dancer's requirements, facilitated by interchangeable shanks, without the need to go through the breaking-in process. This highlights their potential to enhance performance and the dancer's experience.

A significant finding was that the proposed model was not discarded due to internal structure failure, but rather due to the tearing of the fabric covering the platform. Remarkably, the shoe box remained intact even after more than 145 hours of use, demonstrating its resilience and durability. The shank's lifespan was estimated to endure at least 100 hours of intensive use.

Regarding materials and the manufacturing process, it was demonstrated that polymers are suitable for this type of footwear, offering increased durability and reduced impact noise. 3D printing emerged as the optimal manufacturing method for the shoe box, providing the advantage of variations and customization, while also being more accessible in terms of initial investment.

In summary, this study successfully produced pointe shoes that offer solutions to existing issues, leveraging new technologies and materials, thereby enhancing the dancer's experience. These innovations represent a significant advancement in pointe shoe design and pave the way for future enhancements and customizations in classical dance footwear.

It is crucial to emphasize that this study only marks the beginning of the journey towards innovation in pointe shoe design. Further research and additional testing are recommended to further refine the product and address any other issues or limitations that may arise.

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