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Design Science Research of weft-knitting spacer project for users with genodermatoses

Design Science Research no projeto de malha spacer de trama para usuários com genodermatoses

Investigación Basada en el Diseño en el proyecto de malla de tejido de espaciador para usuarios con genodermatosis

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Abstract

This study proposes a methodology based on Design Science Research (DSR) to systematize the development of spacer weave fabrics for biomedical applications, with an emphasis on apparel for patients with Epidermolysis Bullosa (EB) and other genodermatoses. The specific objectives include facilitating designers' technical understanding of the production process and contributing to the teaching of technical textile structures. The research adopts a qualitative, applied approach, utilizing the DSR model proposed by Pimentel, Filippo, and Santos (2020). Textile design software (Raynen) and electronic rectilinear knitting machines were used for prototyping. Spacer weave prototypes were developed based on structural parameters such as density, yarn pitch, tension, and fiber type. Two structures were created: a plain jersey fabric (control) and a derivative with pores and surface reliefs to improve permeability and comfort. The DSR approach proved effective in systematizing the development of these structures, promoting the integration of theory and practice. Furthermore, the need to incorporate visual tools (such as 3D simulations) into textile design teaching was highlighted to improve communication between designers and technicians.

Keywords: Epidermolysis Bullosa. Textile structures. Spacer knitting. Design Science Research. Education.

Resumo

O estudo visa propor uma metodologia baseada em Design Science Research (DSR) para sistematizar o desenvolvimento de malhas spacer de trama destinadas a aplicações biomédicas, com ênfase em vestuário para pacientes com Epidermólise Bolhosa (EB) e outras genodermatoses. Os objetivos específicos incluem: facilitar a compreensão técnica de designers sobre o processo produtivo e contribuir para o ensino de estruturas têxteis técnicas. A pesquisa adota uma abordagem qualitativa de natureza aplicada, utilizando o modelo-DSR proposto por Pimentel, Filippo e Santos (2020). Foram utilizados softwares de design têxtil (Raynen) e teares retilíneos eletrônicos para prototipagem. Desenvolveram-se protótipos de malha spacer com base em parâmetros estruturais como densidade, inclinação dos fios, tensão e tipo de fibra. Duas estruturas foram criadas: uma malha jersey (controle) e uma derivada com poros e relevos superficiais para melhorar a permeabilidade e o conforto. A abordagem DSR mostrou-se eficaz para sistematizar o desenvolvimento dessas estruturas, promovendo a integração entre teoria e prática. Além disso, destacou-se a necessidade de incorporar ferramentas visuais (como simulações 3D)

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no ensino de design têxtil para melhorar a comunicação entre designers e técnicos.

Palavras-chave: *Epidermólise Bolhosa. Estruturas têxteis. Malhas spacer. Design Science Research. Ensino.*

Resumen

Este estudio propone una metodología basada en la Investigación en Ciencias del Diseño (Design Science Research, DSR) para sistematizar el desarrollo de ribs de punto de spacer (spacer weave fabrics) para aplicaciones biomédicas, con especial énfasis en indumentaria para pacientes con epidermólisis bullosa (EB) y otras genodermatosis. Los objetivos específicos incluyen facilitar la comprensión técnica de los diseñadores sobre el proceso de producción y contribuir a la enseñanza de estructuras textiles técnicas. La investigación adopta un enfoque aplicado y cualitativo, empleando el modelo DSR propuesto por Pimentel, Filippo y Santos (2020). Para la prototipación, se utilizaron software de diseño textil (Raynen) y telares rectilíneos electrónicos. Los prototipos de tejido de spacer se desarrollaron a partir de parámetros estructurales como la densidad, el paso de hilo, la tensión y el tipo de fibra. Se crearon dos estructuras: una felpa plana o jersey (muestra de control) y una derivada con poros y relieves superficiales para mejorar la permeabilidad y la comodidad. El enfoque DSR demostró ser eficaz para sistematizar el desarrollo de estas estructuras, fomentando la integración entre la teoría y la práctica. Asimismo, se subrayó la necesidad de incorporar herramientas visuales (como las simulaciones 3D) en la enseñanza del diseño textil para optimizar la comunicación entre diseñadores y técnicos.

Palabras clave: *Epidermólisis Bullosa. Estructuras textiles. Tejidos de malla espaciadora. Investigación en Ciencia del Diseño. Educación*

1 Introduction

In the current era of significant technological advancement across all fields, universities and training centres face a shortage of knitwear design specialists. This issue is exacerbated by a communication gap between designers and the knitwear industry, which highlights varying levels of complexity in their interactions (Bettencourt; Catarino; Black, 2023).

Eckert (1999), in the article "*Managing Effective Communication in Knitwear Design*", discusses several points that help reflect on the gaps in the design field, particularly in knitwear development. According to the author's study, the primary challenges are: I. Inherent Difficulties in Communication: Designers often use technical sketches and descriptions that can obscure critical details. They tend to focus strongly on aesthetics and possess limited technical knowledge of the structure construction process. Conversely, technicians often have little aesthetic sensitivity. This disconnect means there is no efficient system for describing knitwear structures completely and accurately. II. Cultural and Organizational Factors: Companies often struggle to identify these communication gaps, which can lead to errors that are predominantly technical in nature.

The knowledge of designers and technicians rarely intersects harmoniously, and there is scarce time allocated for development and refinement between their teams. To overcome these difficulties, several proposals have been made: I. Support Systems: Using advanced CAD tools to translate incomplete design specifications into clear technical instructions. II. Cross-Training: Training designers in technical aspects and technicians in aesthetic aspects. III. Modifications in Teaching**:** Reorganizing the design process, inspired by engineering principles, to significantly reduce current problems (Stacey; Eckert; Wiley, 2002).

Within the broader context of design, several projects have emerged focused on using textile structures of healthcare products, known as biomedical textiles. These designs are notable for their versatility in combining desired characteristics and properties for use as implants (e.g., scaffolds), sutures, diapers, gauze, and dressings. These textile structures exhibit biocompatibility, and their architecture encompasses: I. Adequate physical and mechanical properties; II. porosity and permeability—criteria that can be optimized.

Genodermatoses comprise a group of genetic disorders that affect the skin and are primarily characterized by heterogeneous clinical manifestations. Notable conditions within this group include: I. Epidermolysis Bullosa (EB): Characterized by skin fragility and blister formation followed minimal trauma. II. Buscke-Ollendorff Syndrome: Distinguished by cutaneous elastomas and osteopoikilosis. III. Segmental Darier Disease: verrucous and papular lesions in localized areas, among other features (Salik; Richert; Smits, 2023). EB involves a structural anomaly in the skin that drastically reduces its resilience to mechanical stress. Depending on the site of the molecular defect, this can lead to clinical manifestations such as scaling, blisters, erosions, ulcerations, wounds, or scarring (Retrosi *et al.*, 2022).

The absence of a cure for EB necessitates ongoing skin management for patients. However, no current treatments have replaced the need for daily wound care and specialized dressings, which aim to improve tissue integrity and prevent infections. Friction from clothing requires particular attention due to its potential to cause discomfort, wounds, and blisters, thereby increasing the need for care (Lam; Luo; Li, 2022; Wu; Jiao, 2024).

Textile structures, particularly spacer knits, have been used to protect the human body from impacts. If designed with structural parameters appropriate for EB—such as specific fiber types, thickness, composition, and dimensional properties—they show promise for managing these skin problems. Furthermore, these fabrics can be engineered to find additional requirements like energy absorption and fluid management (Rudy; Wardiningsih, 2021).

Within this context, it is we propose the development of spacer knit fabrics. Using a Design Science Research (DSR) methodology, this study aimed to systematize the construction of fabric structures for biomedical applications in apparel, specifically for users with genodermatoses. In addition to structuring and illustrating the production process, the study seeks to:

1. Facilitate the designer's technical understanding by detailing the production process and illustrating each step.
2. Support the teaching of technical textile structures to bridge the gap between theory and practice.

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3. Generate prototypes of spacer knits based on literature, focusing on clothing for patients with Epidermolysis Bullosa (EB), to ensure functionality and comfort.

2 Basic concepts of weft knit textile structures

Knitted fabrics are structures produced by forming loops of yarn. These structures are classified into two main types: weft knits (Figure 1 – A) and warp knits[4] (Figure 1 – B). Figure 1 – A provides a schematic illustration of the weft knit structures (purl stitch, rib, jersey e interlock) highlighting the main loop used in their construction. In contrast, Figure 1 – B presents the backing structure used in warp knits, which typically feature two of the most common loop types: open and closed. The combination of these loops results in the formation of various distinct structures.

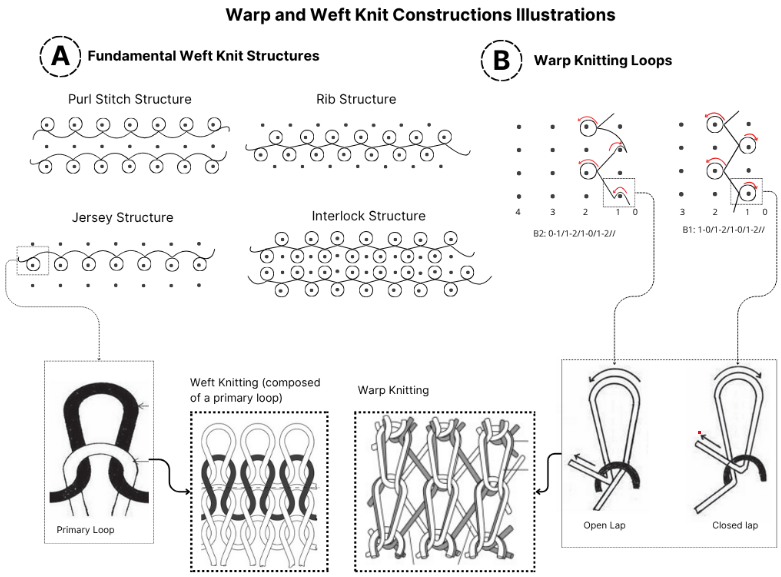

*Figure 1. **A**. Fundamental structures of weft knits (jersey, rib, purl, and interlock) and their principal loops. **B**. Representation of open and closed loops in a warp knit pattern. Source: (A) Adapted from Araújo, (1988); Francis; Sparkes, (2011), (B) Adapted from El Mogahzy (2009).*

In terms of production, weft knits are produced horizontally, with the loops forming a structure in the vertical orientation (course direction). In contrast, the second type, warp knits, are produced longitudinally from a set of yarns. The loop, as the central element in knit production, is formed by flexion, as exemplified in Figure 2– D[5] (Araújo, 1988).

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[4] The term "malha de teia" is primarily used in Portugal; however, this text will adopt the Brazilian Portuguese term "urdume" (warp knit).

[5] Loop formation is an essential element in the manufacture of knitted structures. This process, based on the principle of yarn bending, is common to both weft and warp knitting technologies (Ray, 2012a; Spencer, 1983).

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The weft knit structure is formed by the passage of a yarn through the needle bed (Figure 2 – A and C), where selected needles are actuated according to a pre-defined program. The idle needles rise to grasp the yarn, and a loop is formed on the hook. The needle then rises, carrying the loop beyond the latch. The needles retain this loop until a new yarn is received, which will form a new loop (Figure 2 – B and D). The yarn is deposited onto the needle hook through the opening of the latch. As the needle moves downward, it transfers the originally held loop, and the closing latch releases the previously formed loop, which remains suspended on the shanks of the new loop. The loops in the horizontal direction of the knitting are called courses, while those in the vertical direction are called wales (Figure 2 – B and D) (Araújo, 1988; Francis; Sparkes, 2011).

Figure 2 – A depicts a straight bar knitting machine with a double "V" bed. At Figure 2 – B illustrates the upward and downward movement of the needles as they pass through the cams and the influence of this movement on loop formation. It details the individual needle movement: (1) a needle in the standard position (loop on the hook), and (2) a needle beginning its upward movement (loop descending to the latch). Figure 2 – C shows a representation of the knitting system, the structures produced on the machine, and the direction of movement. The formation of structures on both the front and rear beds is visible, along with the upward and downward needle movement in a technical view of the machine's longitudinal direction. Finally, Figure 2 – D illustrates the process of loop formation and the bending of the yarn over the needle. In general, knitting production machines are built with one or two needle beds, enabling the creation of various types of structures.

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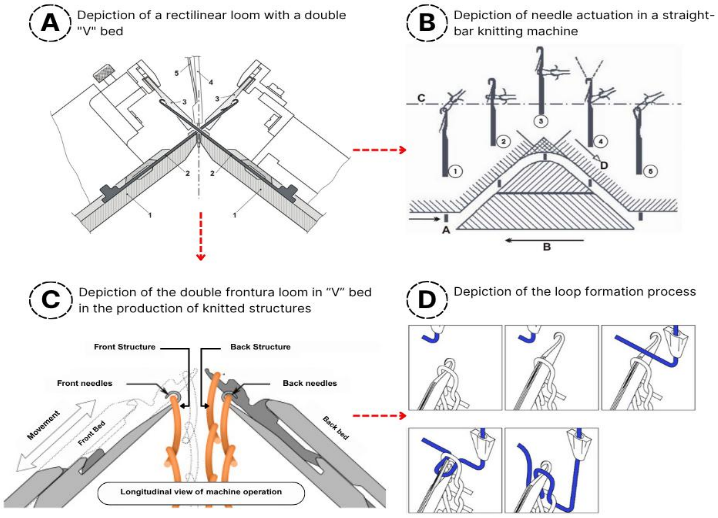

*Figure 2. **A**. Representation of a rectilinear knitting machine with a double "V" bed. **B.** Representation of the cam movement process in a knitting machine (individual needle selection). 1-3. Needle ascending movement, with point 3 indicating the needle at its highest position (loop beyond the latch). 4. Descending movement, where the needle receives the yarn (retaining the loop until the new yarn is received). 5. The yarn is deposited onto the needle hook following the latch opening (formation of a new loop and casting off of the previous loop). **C**. Representation of the "V" beds in the production of a knit with two beds (front bed and back bed and their respective needles). **D**. Representation of the loop formation process on the needle. Source: Adapted from Stoll, ([s. d.]);Yu; McCann, (2020);Albaugh; Hudson; Yao, (2019).*

Figure 3 above, the formation of a weft-knitted structure and the representation of the loops (normal loops, float loops, and tuck loops) can be observed (Figure 3 – A, B, C). Also visible are the individual representations of each loop type (Figure 3 – D, E, F) and their technical depiction in the stitch structure or structural design (Figure 3 – G, H, I).

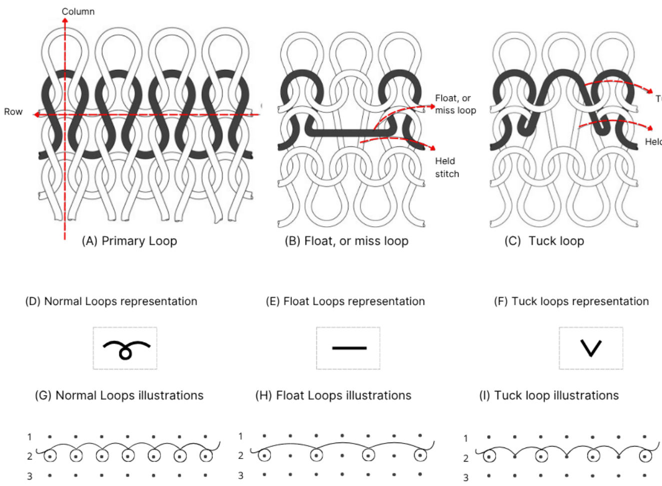

*Figure 3. **A**. Representation of a knit with normal loops (Courses and wales), **B**. Float or miss stitch loop, and **C**. tuck loop. **D**. Technical representation of a normal loop, **E**. technical representation of a float loop, **F**. technical representation of a tuck loop, **G**. stitch structure with normal loops, (H) stitch structure with float loops (miss stitches), and **I**. stitch structure with tuck loops. Source: Adapted from Francis; Sparkes (2011).*

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The loop, the fundamental element in the formation of weft knits, is classified into three basic types: normal loop, float (or miss stitch) loop, and tuck loop. The combination of these three loop types allows the designer to impart specific properties to the knit fabric without necessarily relying on the properties of the yarns. A float loop is formed when a needle already holding a knitted loop remains inactive while other needles in the same course form new loops. The combination of a held loop with a normal loop produces a float (Figure 3 – B, E and H). The tuck loop originates when a needle already holding a loop receives an additional new loop; the additional loop is tucked behind the held loop (Figure 3 – C, F and I). A normal loop – characterized by continuous courses and wales – is formed in a standard knitting action (Figure 3 – A, D and G)(Francis; Sparkes, 2011).

3 Definition and Characteristics of Weft and Warp Spacer Structure/Sandwich Fabrics

Spacer fabric structures consist of two knitted layers, whose separation is ensured by a resilient yarn, typically a monofilament, inserted in a perpendicular direction [6] (Benvenuti *et al.*, 2021).

The production of spacer knit structures first emerged in warp knitting and was subsequently applied to weft knitting as well. The primary advantage of the weft-knitted spacer production process is its relative simplicity, as the two outer faces and the yarn connecting them are knitted together simultaneously. The process is as follows: in the first course, after yarn guide selection, the cams perform the individual needle selection that receive the yarn on one of the two needle beds. In the second course, the process occurs on the opposite needle bed, resulting in a tubular-type structure. Subsequently, in a third course, the yarn guide with the spacer yarn performs the process of joining the two faces (Figure 4 – B). However, the thickness of these structures is limited and typically ranges between 2 and 10 mm (Benvenuti *et al.*, 2021).

In contrast, warp-knitted spacer fabrics possess a distinct construction, being structures formed by layers that are both produced and interconnected by a spacer yarn. The yarns linking the faces can secure the layers directly or separate them, creating a

[6] Although the spacer fabric is inherently three-dimensional, its constituent layers themselves may be composed of non-three-dimensional structures, such as jersey knit.

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gap. It is precisely this three-dimensional space formed between the layers that constitutes the defining characteristic of these structures, which can exhibit various conformations. There also exists the possibility of achieving a wide range of thicknesses, depending on the machinery, yarns, and structures employed, which represents a fundamental differentiator for these fabrics. Typically, their thickness ranges from 1 to 15 mm (Figure 4– A) (Anand, 2016; Benvenuti *et al.*, 2021).

The production of both types of spacer fabrics requires machines with a double needle bed. In warp-knitted spacers, yarn feeding is performed by at least six guide bars (Chang; Hu, 2022); in weft-knitted spacer fabrics, the needles can be supplied by at least two yarn guides (Ray, 2012b). Figure 4 identifies the manufacturing models for spacer fabric structures. In Figure 4 – A, Ilustrates the model of a double-needle-bar Raschel machine used in the production of warp knits. In Figure 4 – B, the illustrative model of a double-needle-bed "V"-bed flat knitting machine used in the production of weft knits is shown.

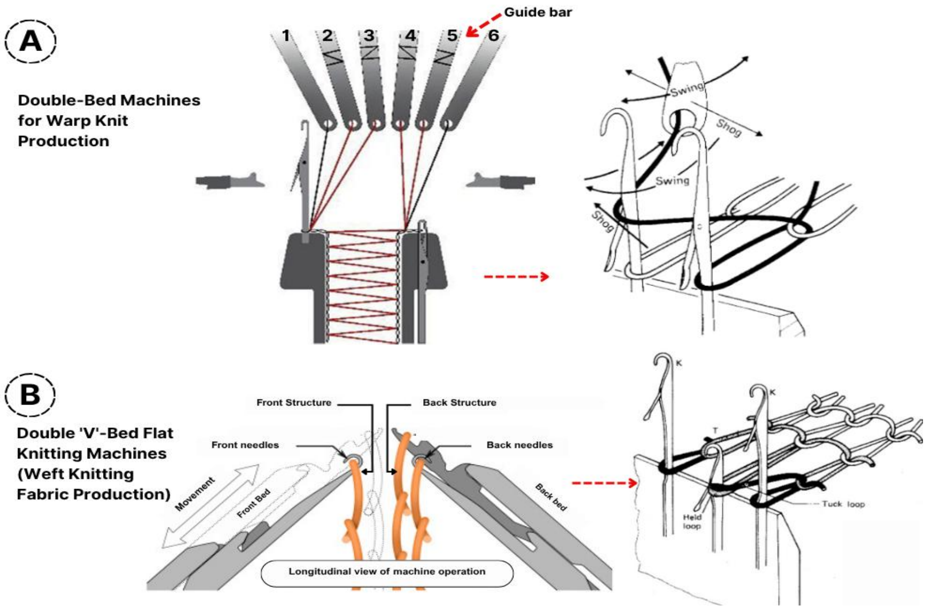

Figure 4. Schematic drawing of the machines used for the production of weft and warp spacer fabrics. ***A.*** *Double-needle bar warp knitting machine (on the left). Double needle bar assembly (on the right), showing the movement (rising and falling) of the guide bar and the directions of the bar movements (swinging and shogging).* ***B.*** *Double-bed V-bed flat knitting machine (on the left) for performing needle movement (rising and falling); yarn insertion is carried out by the yarn carriers (on the right). Source: Adapted from Chang; Hu (2022); Spencer (2001); Yu; McCann (2020).*

For the production of warp-knitted spacer fabrics, the process requires two front guide bars (1, 2) to form the surface structure on one side, while the two back guide bars (5, 6) form the surface structure on the opposite side. Consequently, the central guide

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bars (3 and 4) connect the two outer faces to create the spacer yarn layer, as previously shown in Figure 4 – A (Ye; Hu; Feng, 2008). In double-bed V-bed flat knitting machines for weft knitting, the production model can be implemented with one or two yarn carriers that feed the needles on the beds, which are then interconnected by a third yarn carrier, as shown in Figure 4 – B.

Importantly, both outer faces can be produced using distinct materials, such as monofilament and multifilament yarns, and can feature different geometries (Figure 5). Furthermore, the design of the fabric's internal layer can be engineered to assume various forms and incorporate other structures such as tubes or pleats, which adds versatility to the structural design of the fabrics (Ray, 2012b).

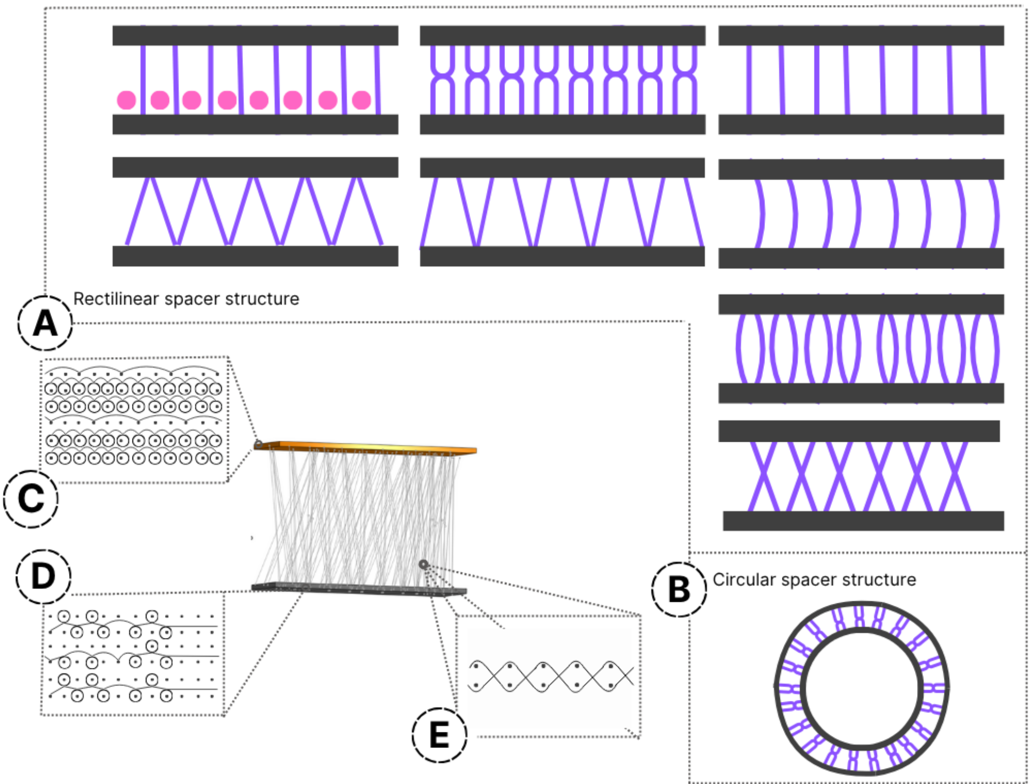

*Figure 5. **A**. Graphical representation of different spacer yarn arrangements in rectilinear spacer fabrics (connection yarn layouts). **B**. Textile structure of a circular spacer knit. **C, D**. Examples of stitches that can be applied to one of the outer fabric faces. **E**. Representation of spacer yarns in a zig-zag pattern. Source: Adapted from Dejene et al. (2024).*

Figure 5 illustrates some of the structural arrangements of spacer fabrics documented in the literature. In Figure 5 – A graphical reproductions depict structural arrangements of rectilinear knits with spacer yarns configured in "X", "I", "V", and zig-zag patterns; the geometry of these connecting yarns influences the mechanical properties of the fabrics. Figure 5 – B presents a circular arrangement, applicable when the knitting

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machinery is of a circular type. Figure 5 – C and D provide a representative illustration of the stitches on the outer faces, while Figure 5 – E, finally shows the representation of the spacer yarn connecting the outer fabric faces in a zig-zag configuration. In this context, spacer yarns function analogously to "springs" when subjected to compression (Rudy; Wardiningsih, 2021).

3.1 Geometric Parameters

Outer faces – consist of two fabric surfaces constructed in parallel but separated layers, interconnected by a spacer yarn. The structural design significantly influences the characteristics and properties of the spacer fabric. It can facilitate impact control and damping processes, in addition to contributing to the promotion of gaseous exchange (air permeability and moisture absorption), making it ideal for providing thermal comfort (Table 1)(Chen *et al.*, 2018; Lotz *et al.*, 2019; Tekmedash; Ezazshahabi; Asayesh, 2025).

Table 1. Parameters for the development of the outer faces.

SURFACE YARNS	CHARACTERISTICS
Elastic Yarns	The use of elastic yarns enhances the compression resistance properties of the surface structures.
Different Yarns	The yarns of the outer faces can be different and may comprise more than one yarn type or blended yarns. Consequently, certain yarn properties require particular attention.
Surface Density/Arrangements	Denser surfaces increase compression resistance properties. The converse is also true; less dense arrangements exhibit lower resistance but improve recovery.
Type of Outer Face Structure (Geometry)	The design (geometry) of the surface structure directly affects the arrangement of the connecting or spacer yarns.

Source: Adapted from Albaugh et al. (2021); Tekmedash; Ezazshahabi; Asayesh (2025)

Spacer Yarns – These are elements also influenced by the material properties. In addition, certain characteristics of their spatial organization directly affect the fabric's properties and applications (Table 2).

Table 2. Parameters for the selection and arrangement of spacer/inner yarns.

Spacer Yarns	Characteristics
Yarn Inclination Patterns	Patterns with larger openings, such as grid, diamond, or hexagonal, result in a lower compression modulus. The most common arrangements are the I, X, or IXI configurations, the latter being the most frequently used due to its stability.
Yarn Height	Height directly influences fabric characteristics (e.g., volume, damping, and compression). Yarn height directly interferes with airflow, as taller

	yarns facilitate airflow while shorter ones reduce it; these characteristic impacts moisture management and enables thermal control.
Yarn Inclination	Inclination directly affects elasticity, flexibility, and mechanical properties, also allowing for the control of elasticity itself, drape, and directional strength. It provides crucial control over energy absorption and dissipation, enabling the even distribution of impact forces.
Density	Density is determined by the number of yarns connecting the two outer faces per centimeter. Thus, a high number of yarns per centimeter produces a more rigid fabric with consistent compression properties, unlike a lower yarn count per centimeter, which results in a fabric with greater variation in compression behavior.
Angle of Inclination	The angle influences compression properties. It refers to the minimum and maximum inclination between the outer faces: I. Maximum angles allow for minimal overlap between the yarn paths. II. Minimum angles depend on yarn density and fabric thickness – and still allow the gaps between the surfaces to close. Consequently, it is understood that the angle affects the bending behavior of the inner yarns.
Yarn type	The type of spacer yarn is important in the production of the structures: I. Monofilament tends to have higher compression resistance. II. Multifilament tends to have lower compression resistance.
Yarn Diameter	Diameter is related to strength: I. Yarns with a larger diameter tend to improve compression resistance properties. II. Yarns with a smaller diameter reduce compression resistance.

Source: Adapted from Dejene; Gudayu, (2024); Halbrecht et al. (2023); Tekmedash; Ezazshahabi; Asayesh, (2025)

Loop spacing – refers to the distances between the connection points within the same layer of the knit structure. It is crucial to ensure that the points do not overlap during the process (Figure 6 - A) (Kurbak, 2017).

Pattern displacement – is related to the inclination or curvature of the tuck stitches between the external faces of the fabric. The held loops are inclined towards the interior of the knit, exhibiting an elliptical curvature. This curvature adjusts to accommodate the diameter of the spacer yarn(s) (Figure 6 - B) (Kurbak, 2017).

Face knitting sequence – concerns the order in which the external faces are knitted and the sequence in which this process occurs (Figure 6 - C) (Albaugh *et al.*, 2021).

The systematized parameters can be observed in Figure 6.

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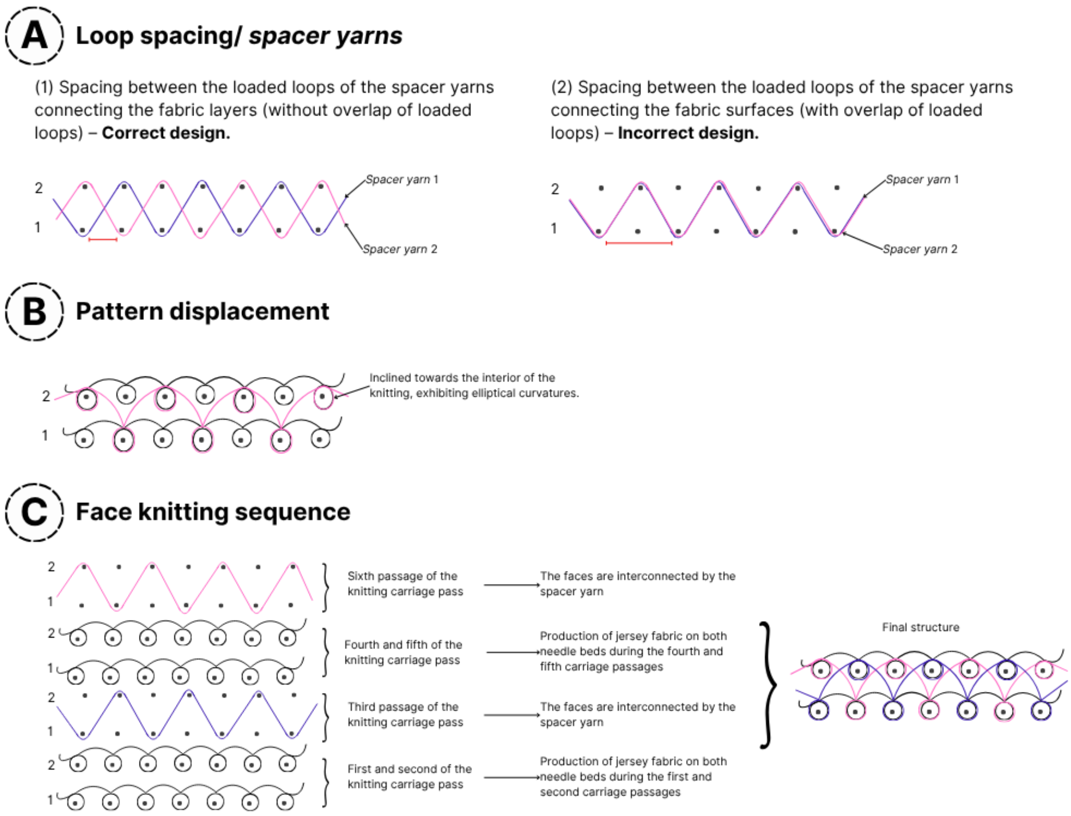

*Figure 6. **A.** 1. Demonstration of the correct binding of the spacer yarn between the knit loops without overlap. 2. Demonstration of the incorrect binding of the spacer yarn and the presence of the tuck loops on the external faces. **B**. Formation of a displacement and emergence of an elliptical curvature. **C** Manufacturing sequence of the external faces – first and second carriage passes in the production of a jersey structure, subsequently joined by the spacer yarn. With each binding pass of the external faces, the spacer yarn forms a tuck loop in the direction opposite to the previous one, so as to generate a uniform distribution and prevent irregular areas in the knit fabric.*

Yarn tension is an aspect that can be controlled by the machines. This tension is regulated during yarn input, which influences the formation of the knit structure and the cover factor. For most materials, low tension is ideal, as it reduces defects and shrinkage. However, elastic yarns are knitted under tension in spacer fabrics; the force induced by tension causes contraction of the external face structures (Albaugh *et al.*, 2021).

Stitch size is determined by a set of factors, including the input yarn tension, which refers to the amount of yarn used to produce the loop as it is formed, as determined by the cam drive programming. Consequently, the stitch size affects the density and stiffness of the knitted structure. In spacer fabrics, the density of the external faces can influence shrinkage due to the density of the structures (Albaugh *et al.*, 2021). Furthermore, the addition of more elastic stitches and higher tension enhances the damping properties of the structures (Tekmedash; Ezazshahabi; Asayesh, 2025).

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3.2 Textile structures in biomedical and hygiene applications

Certain subtypes of EB may result in complications such as stenoses, strictures, synechiae, and pseudosyndactyly. The formation of milia, pigmentary disorders, microbial superinfection, nail dystrophy, and alopecia (cicatricial or atrophic) may also occur, which are indicative signs of various EB subtypes (Laimer; Prodinger; Bauer, 2015). Skin fragility and subsequent injury primarily manifest in areas more susceptible to traumatic pressure, namely on the extensor surfaces of acral regions (hands, feet, elbows, knees) (Miyamoto *et al.*, 2022).

Newborns and children with EB are also referred to as "butterfly children," as their skin exhibits severe fragility, akin to the wings of this insect. In these cases of EB, priority has been given to resolving daily clothing-related problems, specifically concerning garment friction and the potential for enhancing functional performance during wear by these individuals.

The biomedical applications of textile structures have not been confined to clothing; there has been a significant incorporation of spacer fabrics in biomedical applications aimed at hygiene and disease prevention. For instance: I. Fluid absorption and management address the need to wick and transport moisture away from the skin, thereby reducing irritation and infection; II. Pressure ulcer prevention is achieved through the 3D structure, which dissipates body pressure, maintains skin dryness, allows for gas exchange, and stabilizes the skin's microclimate; III. The construction of dressings and bandages utilizes structures that promote breathability and wound healing, providing exudate absorption to prevent moisture accumulation; IV. The development of orthoses and prostheses is essential for creating items like knee braces and orthopedic vests, aiming to provide compression and ventilation, thereby enhancing comfort and structural adaptability (Ahmed et al., 2023; Davies, 2011).

4 *Design Science* and *Design Science Research Model*

Research processes in scientific fields such as Engineering, Computer Science, Design, and Education share similarities and can be grouped within the category of sciences currently operating under the logic of design – to such an extent that they are referred to in the specialized literature as Design Science (DS). The paradigmatic focus of the fields integrating this practice is the production of knowledge concerning to the design of artifacts: whereas the natural sciences study what things are, design defines what ought to be to fulfill a purpose, according to Pimentel et al. (2020). The origin of the Design Science Research (DSR) paradigm can be traced back to the work The Sciences of the Artificial, in which Herbert A. Simon (1916) highlights the role of the artificial sciences produced in the fields of Engineering, Computer Science, Education, and Design. The emphasis is placed on the role of these "sciences" in constructing knowledge about the very process of artifact conception, ensuring they are suitable for and meet specific objectives, thereby enhancing innovation capacity (Simon, 1916).

Aiming to improve the production, data analysis, and presentation of results in the field of DSR, in accordance with the research and guidelines previously established in Design Science Research, Peffers et al. (2007) developed the Design Science Research Methodology (DSRM). This methodology employs the abductive method, which is characteristic of designers' projective thinking. The DSRM comprises six stages, as presented in Figure 7.

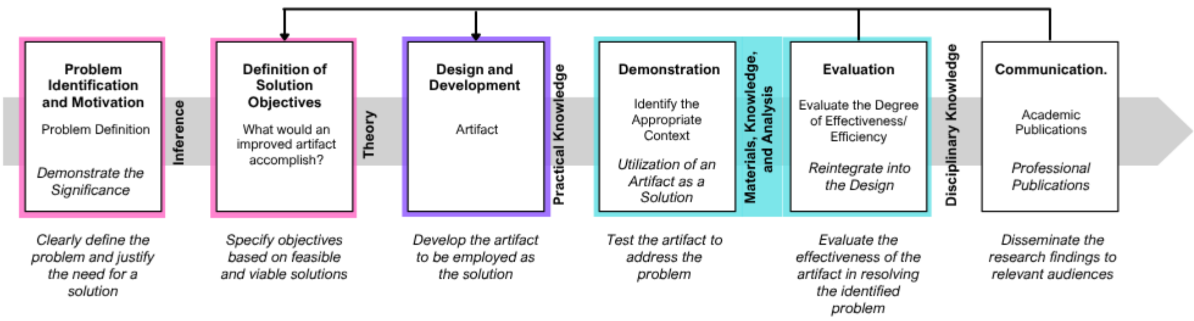

Figure 7. Design Science Research Methodology.

The primary objective is the characterization of artifacts through appropriate methods, these artifacts being: construct, model, method, and instantiation *(Peffers* et al.*, 2007; Pimentel; Filippo; Santos, 2020)*. It should be noted that the focus of the artifact can be concentrated on the following aspects: technical, organizational, and strategic (Cleven; Gubler; Hüner, 2009).

Pimentel et al. (2020) present an expanded version of the Design Science Research Model (DSR Model). According to the authors, the model suggests an integration between artifact production and scientific knowledge production – which is

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achieved through the development of design and knowledge cycles. The model, therefore, emphasizes the importance of behavioral conjectures during the artifact design process. Furthermore, the DSR Model structures the research into interrelated elements, such as literature review, state of the art, empirical evaluation, and acceptance criteria, in order to ensure methodological rigor and practical relevance (Figure 8).

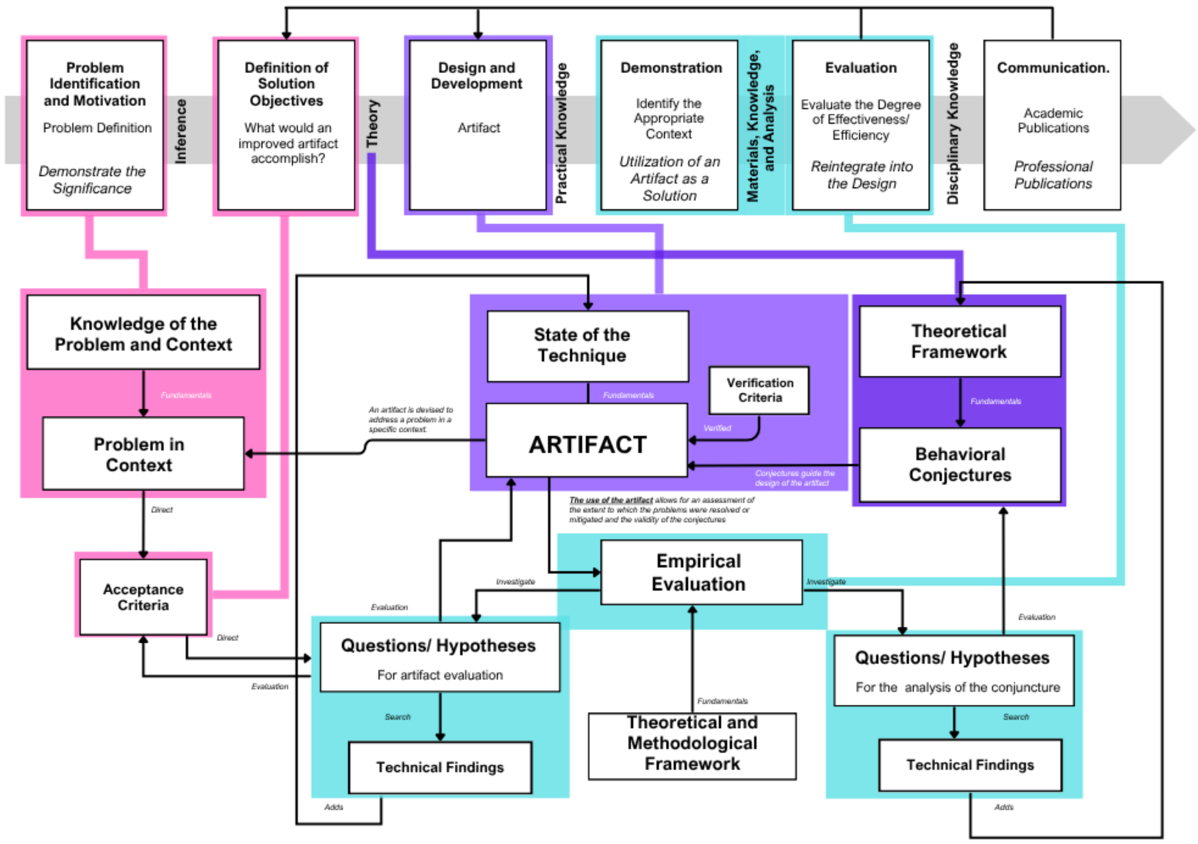

Figure 8. Methodology model to be applied for the development of spacer fabrics and the generation of knowledge in design and for the design of textile structures. Source: Extracted and adapted from Pimentel; Filippo; Santos (2020).

The use of the DSR Model allows for the integration of several points, based on Pimentel; Filippo; Santos (2020):

I. Theoretical Foundation: The theories guiding the design of artifacts, but without a dedicated stage for systematization, are superseded by the explicit need to construct a theoretical framework that ensures rigor between theory and practice.

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II. Empirical Evaluation: An environment of flexibility is created for working with quantitative and qualitative approaches; this includes the evaluation of theoretical conjectures and the pursuit of theoretical findings, thereby expanding the scientific contribution.

III. Structure and Flexibility: These factors underpin the production and clarification of sequential stages and provide guidance on what must be done, without the need for a rigid order; furthermore, they pave the way for adaptation to different paradigms and methodologies.

IV. Emphasis on Knowledge Production about the Artifact: A culture that values both technical development and scientific knowledge is fostered (Pimentel; Filippo; Santos, 2020).

5 Application of the *Design Science Research* Model

The application of the DSR Model as presented by Pimentel, Filippo, and Santos (2020) provides significant insights for the development of artifacts through textile design, with particular emphasis, in this case, on technical spacer fabrics that address real-world problems, such as in the case of users with Epidermolysis Bullosa. The methodology has a precise application in the following stages (Figure 9):

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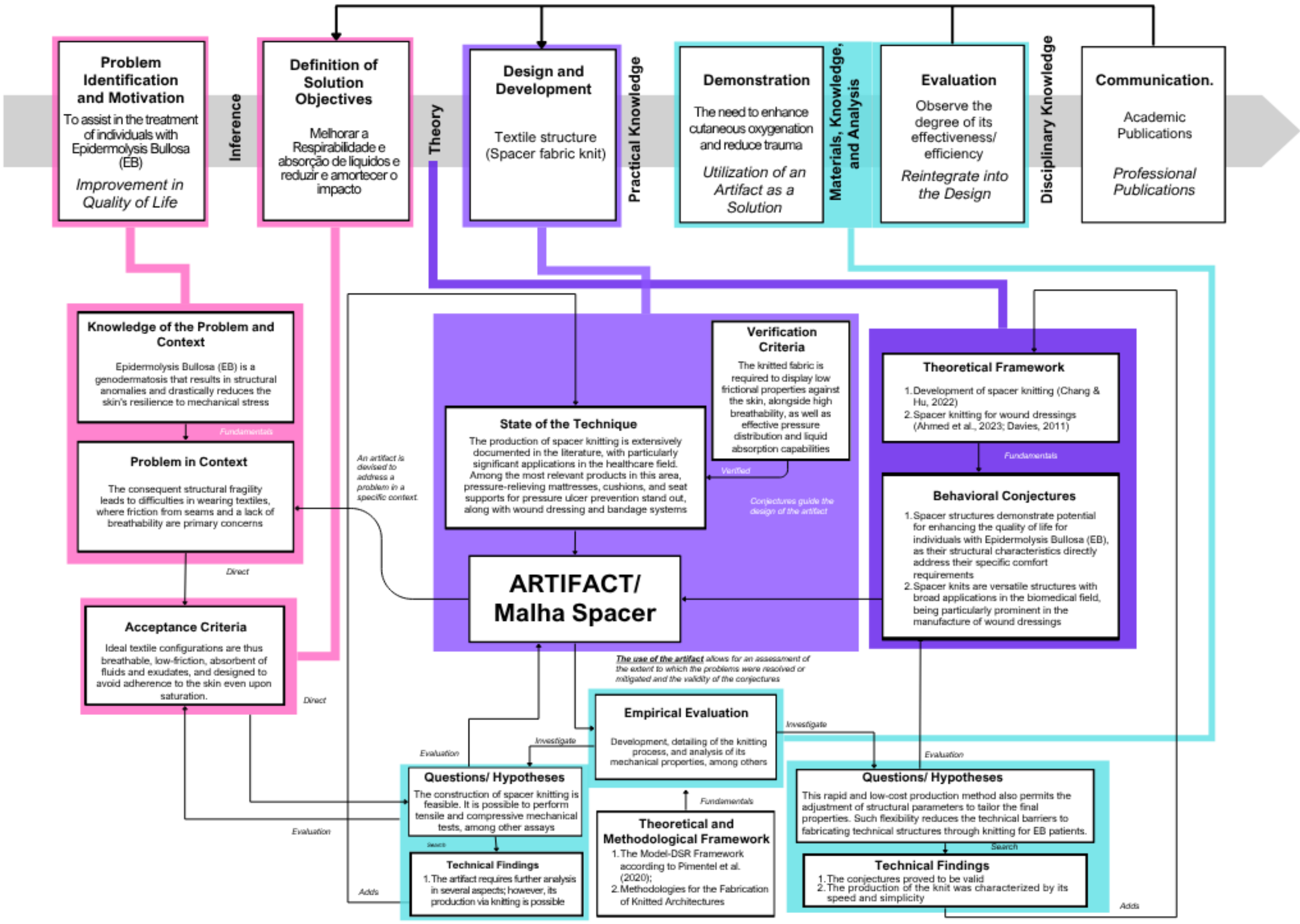

Figure 9. DSR Model applied to the development of spacer warp-knitted mesh for biomedical textiles.

Source: based in Pimentel; Filippo; Santos (2020)

1. Problem Identification: The problem in question is identified as Epidermolysis Bullosa (EB) – a genodermatosis – that causes skin fragility and creates a demand for clothing that minimizes friction and other physical complications, such as infections and discomfort, thereby improving the individuals' quality of life. In this context, the DSR model systematizes this demand into technical requirements (for example, thermophysiological comfort, friction reduction, among others). This stage involves an elaboration of the problem, including: I. knowledge about the problem and its context, which can be acquired through a literature review on the disease, its causes, consequences, and the needs of individuals with EB; II. organization of data/information to substantiate an objective definition of the problem and its potential acceptable solutions.

2. *Definition of Solution Objectives*: In this case, the objective is to construct a

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three-dimensional textile structure (spacer fabric) that offers low skin friction, efficient pressure distribution, liquid absorption capacity, breathability, and comfort. To this end, the acceptance criteria for the objectives are: I. established based on the theoretical framework, drawing from both the literature on knitted fabrics and their applications in healthcare.

3. Artifact Design and Development: In this stage, the researchers mobilize and integrate all the knowledge summarized in the theoretical framework, as well as the previously outlined conjectures and objectives, proceeding from: I. State of the Art. Based on the theoretical framework concerning knitted structures, viable alternatives are developed, articulated with practical knowledge, for adjusting production parameters and consequently modifying the knitting structure. This allows for rapid and low-cost alterations in parameters such as density, thickness, and yarn types, in order to refine their physical-mechanical properties and produce the artifact best suited for the individuals. II. Development of the State of the Art. This process generates parameters for the establishment of verification criteria (tensile and compression tests, liquid absorption tests, breathability tests, measurement of the friction coefficient, etc.).

4. Demonstration: the application of the artifact in a real or simulated context.

5. Evaluation: this is conducted according to pre-established verification criteria. I. Empirical Evaluation – the artifact is tested in a real or simulated context to validate its efficacy (or lack thereof). Empirical evaluation not only allows for questioning whether the technical findings enable the application of the mesh structures to the target group but also establishes perspectives for validating or rejecting the hypotheses and research questions. The evaluation process is primarily supported by the study's theoretical and epistemological methodological framework, which, therefore, addresses theories concerning comfort, materials, and health. Furthermore, the methodological choice – quantitative, qualitative, or a mixed-methods approach – plays a central role in guiding the study's findings. Within the DSR model, the demonstration and evaluation stages consist of presenting the structural construction and the design production process. The evaluation will be conducted from the perspective of identifying and illustrating the fundamental parameters for the development of knitted spacer fabrics, given that the research pertains to an "ongoing" project for the development of spacer mesh structures.

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6. Communication: a publication detailing the artifact's development process, along with its tests and results, plays a significant role in validating the findings and amplifying their reach within the scientific community.

5.1 Machinery Characterization

The machinery employed (Figure 10 – B) consists of an electronic straight bar knitting frame, equipped with Full Garment technology. The system operates with a single carriage incorporating three cam systems. The machine features a knitting width of 72 inches and is configured with 16 yarn feeders, which are actuated by a forward and reverse belt system. The equipment includes a main takedown and a secondary takedown system with 19 sections, each individually controlled by programmable stepper motors, along with a third takedown system, designated as a draw-down, composed of two panels (front and back) positioned below the primary takedown. The equipment used is a Mandarin brand, Full Garment model, series FG372 SYF (Smart Yarn Feeders).

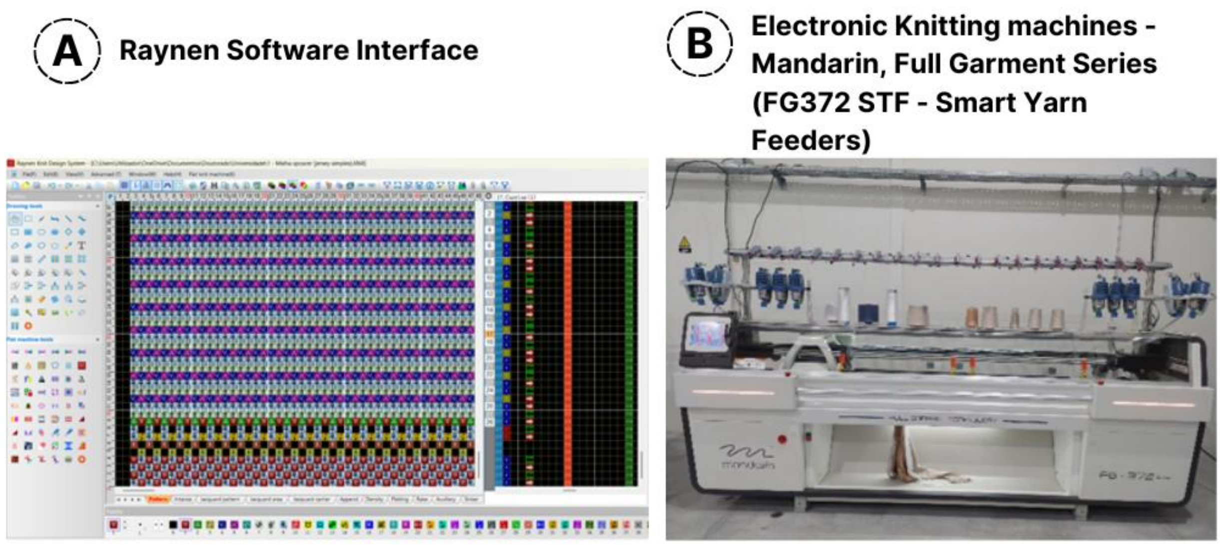

Figure 10. Software and machinery applied in the project and prototyping of weft-knitted spacer fabrics. ***A****. The interface of the Raynen system from Raynen Technology Co., Ltd.* ***B.*** *Mandarim electronic straight bar knitting frame, Full Garment model, series FG372 SYF.*

The software utilized for the development of the knit structures was developed by the Chinese company Raynen Technology Co. Ltd. The software constitutes a CAD system for the development of weft-knitted fabrics. Figure 10 - A illustrates the software interface.

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6 Results and Discussion

6.1 Development and Design of Weft-Knitted Fabrics

Textile structures have been gaining prominence in the production of wound dressings, with significant structural innovations emerging in this field. Certain products, such as Siltape® (Advancis, 2025), are employed as substitutes for conventional adhesive tape due to their properties: micro-adhesion, porosity, and straightforward application. Although used in conditions such as Epidermolysis Bullosa (EB), some studies indicate that they may provide a risk to neonates or individuals with highly fragile skin (Denyer; Pillay, 2012).

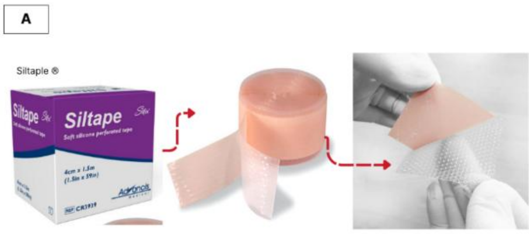

*Figura 11. **A**. Microporous tape for application in wound dressings*

The structure of Siltape® (Figure 11) is engineered to exhibit structural porosity, which confers breathability (enhancing ventilation and permitting the passage of moisture or vapor from the skin). The mesh structure developed in this project was based on parameters applied in wound dressings, as exemplified above (Figure 11). A spacer fabric structure in jersey knit was developed, as illustrated in Figure 12, which displays the fundamental aspects crucial for its development. In this instance, it serves as a control structure, without any modifications to the stitch architecture. It is important to emphasize that this structure lacks structural interventions and presents a cover factor "characteristic" of the jersey knit, devoid of raised textures or face-to-face integration (Figure 12). It should be noted that the jersey structure serves as the foundation for the development of other weft-knitted structures (jersey derivatives). It is composed of simple loops, aligned in the same direction horizontally (courses) or vertically (wales). In jersey knit, each stitch is formed when a new loop passes through the previously formed loop (Araújo, 1988).

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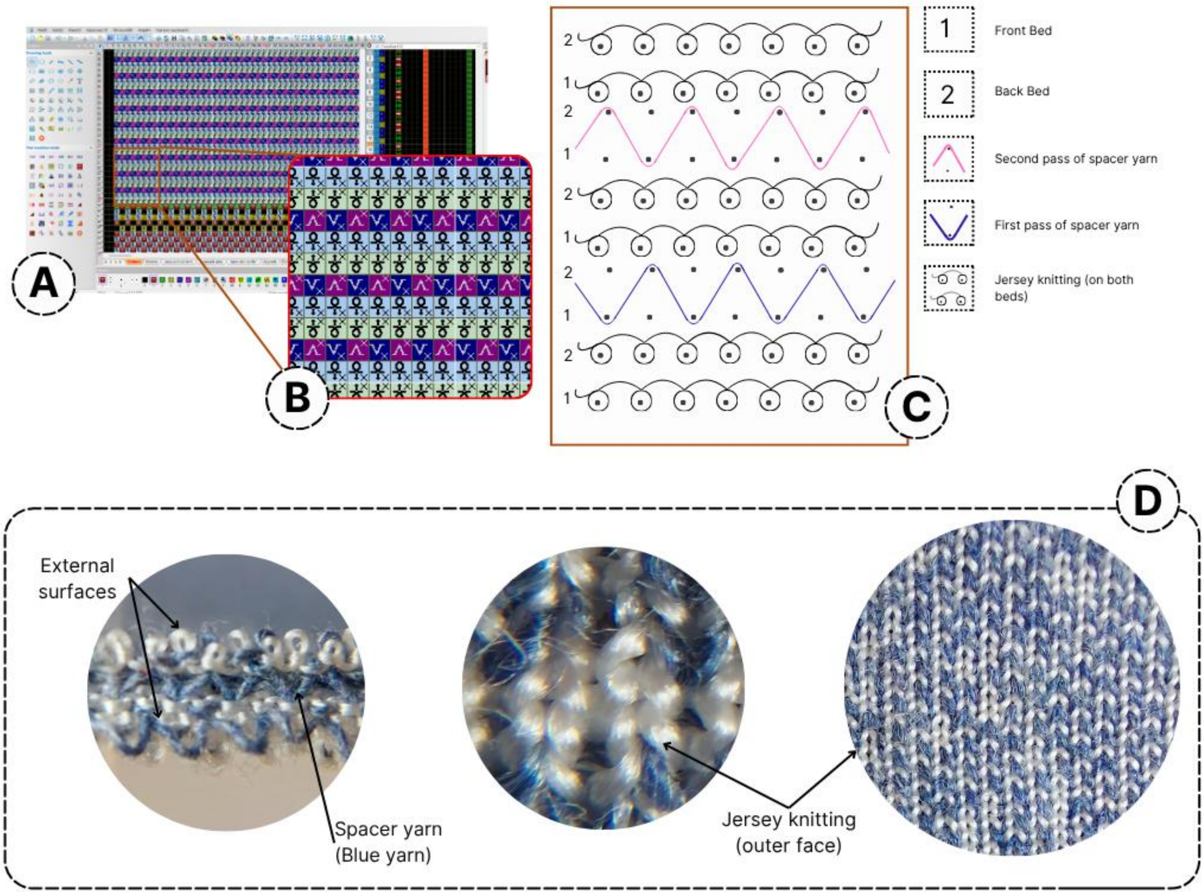

*Figure 12. Development process of a jersey spacer structure. **A**. Image of the Raynen software interface. **B**. Schematic structure of the knit construction within the software. **C**. Representation of the construction's stitch pattern. D. Fabric obtained after program execution: enlarged top view (central figure) and non-enlarged view (right), and a perpendicular view identifying the external faces (white loops) and the path of the spacer yarn (blue yarn). Source: Prepared by the authors.*

In the development of the second structure (Figure 13), the primary objective consisted of creating a fabric with textural elements and the presence of interstices at the junction between the faces, in addition to producing a surface relief on one of the external faces of the knit. These modifications necessitated the design of this specific stitch pattern, as observed in Figure 13 - B. Beyond the jersey stitches and the paths of the spacer yarns, the presence of programmed loop movements is evident: transferring loops to the back and subsequently to the front, repositioning the loop 1 needle to the left or right (symbols in pink and light beige, featuring the inscription "1P" and a symbol resembling a "twisted arrow pointing left and right").

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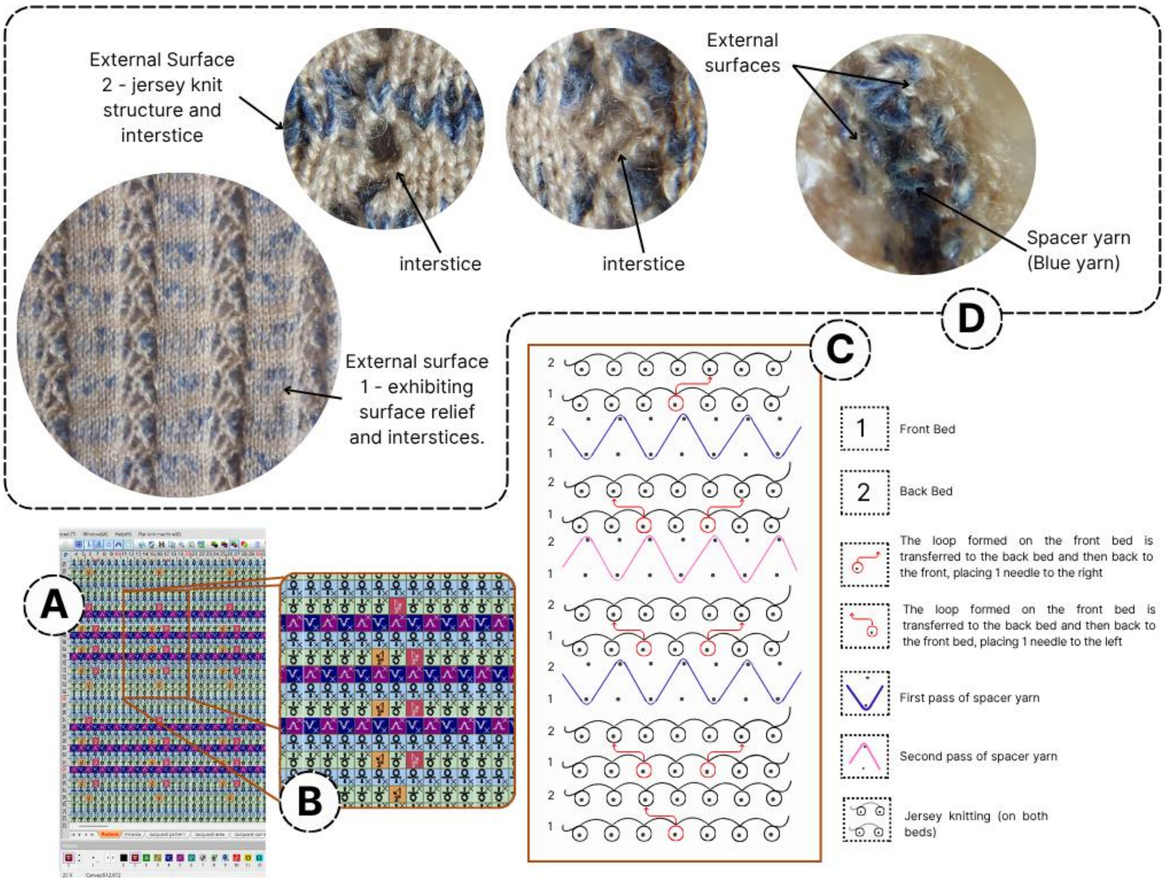

Figure 13. Development process of a spacer structure with interstices and surface relief (derived from jersey). ***A****. Raynen software interface image.* ***B****. Schematic structure of the knit construction in the software.* ***C****. Knitting stitch.* ***D****. Knit fabric obtained after program execution: the right side (larger figure) features relief columns and pore columns; enlarged pores (two central figures) and a perpendicular view (on the right) identify the external faces (white loops) and the path of the spacer yarn (blue yarn). Source: Prepared by the authors.*

The loop transfers demonstrated in Figure 13 – A, B and C provide the designer with the possibility of creating reliefs, textures, and shapes (Francis; Sparkes, 2011). In the context of texture creation, the action of loop transfers is particularly noteworthy, which, in this context, it will give rise to sections of the knit fabric with interstices.

The design project of a textile structure, when aiming for the structure to exhibit higher water vapor permeability (evaporation of sweat and skin gases), must take into account the following aspects: types of used fibers, fabric thickness, porosity, moisture absorption, structural design of the textile, and environmental conditions. Water vapor permeability involves two distinct mechanisms: the presence of a pore in the structure, which, in turn, can facilitate gaseous exchange, or through liquid absorption and subsequent evaporation from the surface (Barbari; Asayesh, 2025).

The architecture and behavior of spacers presents characteristics that promote

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breathability and comfort, which are important points in the design of medical textile structures. Furthermore, the customization of the structure plays a significant role in enhancing the comfort and functionality of spacers. Customization of the spacer layer (yarn diameter, yarn type, and layer dimension) alters thermal conductivity (Dejene; Gudayu, 2024).

When comparing the structures present in Figures 12 and 13, a modification in surface morphology is observed, presenting a structure with relief on one face and interstices. The interstices can facilitate permeability to air and water. It is important to emphasize that the airflow transits predominantly through the interstices and between the yarns, being directly influenced by the constructive characteristics of the knits, such as the cover factor. In this sense, such constructive characteristics stand out as a crucial point for the final performance of the knit fabric (Guru *et al.*, 2024).

6.2 Correlation between textile design education and the application of biomedical products

Teaching in design and textile design can be linked to project construction and the development of content, including the explanation of the technical dimension of knitting processes and their components for their development. Aguiar Souza e Kohan (2024) present the development of visual elements (3D simulations) in teaching the construction of complex textile structures for scaffold biomedical applications. This aligns with the DSR model through the integration of Visual Methods: technical representations, such as illustrations of the loop formation process, can facilitate teaching about the construction and application of these structures.

In a society that highly values the application of visual intelligence and communication through visual codes, teaching based on these principles can be an extremely effective mechanism, focusing on: I. the valorization of visual intelligence, prioritizing forms of communication that use visual elements (images, graphics, symbols, and video) to structure information (Dunlap; Lowenthal, 2016; Zhang; Zhao, 2023). II. visual codes as facilitators, as they can organize knowledge acquisition and retention, in addition to guiding learning (Fragou & Papadopoulou, 2020).

7 Conclusion

The primary objective of this research was to propose the development of weft-knitted spacer knitting structures, based on a methodology grounded in Design Science Research (DSR) and utilizing the DSR model by Pimentel, Filippo and Santos (2020). This approach aimed to systematize the construction of knitting structures intended for biomedical applications in clothing, especially for users with genodermatoses, as well as to structure and illustrate the steps of the production process.

The study presented a detailed explanation of knitting formation and weft and warp knitting machines. Furthermore, it detailed key parameters, including yarn type, density, inclination, tension, and manufacturing sequence. Additionally, it presented data generated using software (Raynen) for prototyping, which is essential for programming the structures, and concluded by demonstrating the process of creating the knitting structures and their execution on the machine

In summary, the study presented a contribution to the teaching of technical textile structures by correlating the development of a biomedical product – the spacer knitting structure for Epidermolysis Bullosa (EB) – with textile design, highlighting the importance of visual tools (images and illustrations) in teaching complex textile structures. To this end, it was based on the application of a guiding methodological model for the systematization of the development process of the structures addressed therein. The work highlighted the development and design of weft knitting structures, describing the creation of two prototypes: a spacer structure in jersey knit (Figure 12) and a structure derived from jersey with pores and surface reliefs (Figure 13), aimed at improving permeability and comfort.

The application of the DSR model allows for the integration of theory and practice, as advocated through creative cycles of development, testing, and evaluation. In the teaching process, the incorporation of visual elements in textile design education – such as images, illustrations, 3D simulations, among others – can enhance retention and improve learning, with the methodological model (Figures 8 and 9) serving as a guiding thread for theoretical-practical instruction. This research is configured as a translational project; the use of the proposed model enables the creation of theoretical-practical knowledge applied not only to textiles but also to the conversion of technologies to

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overcome the demands of individuals and societies. Through the development of the artifact, the study contributes both to the theory and practice of design and to the construction of specialized literature that addresses sciences in an integrated and complementary manner regarding their knowledge, techniques, and methodologies[7].

[7] Review conducted by Albertina Felisbino. Doctor of Letters, Federal University of Santa Catarina, 1996. lunnaf@uol.com.br

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Supplemental material

All data required to reproduce the results are contained within this article.

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