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# Conceptual design methodology for knitted fabrics

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**Abstract.** This paper proposes operational systematics for the design phase, specifically the conceptual design, considering integration with manufacturing variables, promoting the concurrent engineering in the knitted industry. The bibliographic references are analyzed to compose a theoretical framework about models for the product development process (PDP). In order to understand the PDP practiced in the knitting industries, field research was conducted in four large companies located in Brazil. The PDP models identified were compared with the theoretical frameworks for generic products. Based on this analysis and the contribution of three specialists in knitting development, a methodology is proposed to support the conceptual knitting design, considering manufacturing aspects and including some tools. This methodology is evaluated through a simulation, where two groups use the proposed methodology, and the indicators are compared with the third group with a high experience that does not use it to develop a conceptual knitting project. Among the results, the article proposes and evaluates a systematization, adapted to the Brazilian local reality and needs, considering the integration between product design and manufacturing phases.

**Keywords:** Product Development, Conceptual Design, Methodology, Textile, Knitted Fabric.

## 1 Introduction

The textile industry has great importance in the Brazilian economy, since Brazil is among the largest producers in the world [1]. In order to continue making progress, the textile industry needs to produce differentiated and greater value-added articles, nearing the market needs. However, it observes a shortage of qualified staff and development sectors with appropriate methodology, using a development process based on trial and error, supported by the experience of experts [2,3]. Still in 2021, [4] discuss about needs for knowledge transfer in conservative production processes such as the textile industry. This kind of process still rely heavily on implicitly available experience-based (tacit) knowledge, make the process vulnerable. There is not design models with manufacture parameters in details and explicit. To help in this task, they suggest the “Internet of Production (IoP)”, aiming to provide a framework to be incorporated within the textile industry.

Despite the numerous approaches to product design, providing many theoretical frameworks [5], the publications related to this specific problem are rare [6]. A brief search with some keywords was conducted in order to identify some contributions in literature, related to the subject in question, without restriction of periods. This research considered peer reviewed articles, in the engineering area and published in English, taking into account the main academic databases. The key words are "integrated", "conceptual design", "method", "textile industry", "and manufacturing". This search has resulted in 28 articles. However, analyzing the title and the abstract of these articles, only four presented a similar focus.

[7] comment that the literature clearly documents the importance of new product development to success of a manufacturing firm. Many examples of generic models of the process can be found, including sequential, concurrent, and multiple convergent models. However, these models have insufficient details to provide an adequate foundation for redesigning the development process of apparel products. This article proposes an operational systematics for conducting the project, although focused on clothing, and not on knitted fabric.

[8] analyzes the potential for developing novel methods of generating material and for creating new fabrics, useful for both fashion and decorative art, as well as exploring the potential uses of the newly generated fabrics. This study demonstrates the possibility of approaching artistic fashion by manipulating overstretching and the feasibility of conducting a fashion design process in which product aesthetics is generated from yarn texture, fabric structure, and garment construction. However, this article does not suggest a structured design methodology in order to create the fabric; it rather extrapolates creative solutions, through differentiated combinations of thread interlacing, aiming at creating innovative aesthetic solutions.

[9] use interviews, direct observation methodology, and theoretical argumentation to obtain the expert's knowledge on describing the problems in the garment design process. The purpose is to generate a methodology so that the expert in this field will become highly specialized, supporting them with the TI methodology and the design management model. It is a generic methodology, whose production knowledge prevails as a knowledge representation technique, making possible to acquire knowledge domain in complex problems such as in the garment industry. The proposal is based on the mapping of problems during the garment design, aiming to identify its origin, reducing the situation complexity. In other words, it is not a methodology for the garment creation, and has not been applied to fabric design before.

[10] reviewed the design processes used in the fields of architecture, engineering, industrial product design and clothing, and translated these methodologies in three major steps: (a) problem definition and research, (b) creative exploration, and (c) implementation. Based on these steps, a design process was proposed and tested to facilitate a cooperative industry-university project in the redesign of an athletic ankle brace. However, the method does not address the design parameters of the fabric that makes up the product, and it was not tested for this purpose.

Some studies show the importance of the phases of a fabric design in containing the functional description of the product [11]. Others show the project planning, starting

from a market research, including computational tools to support the development of the fabric design [12,6].

[13] present a review about the evolution of Engineering Design, in the Industry 4.0 context, considering smart and connected products, end-to-end digital integration, customization and personalization, data-driven design, and intelligent design automation. The digital innovations allow improvements in product design because promote data collection from the field to feed new designs. The creation of these engineered systems must consider management systems that makes it possible to store, share, and use data collected in the field and ensure proper information throughout the PLM.

[14] reviews recent articles about digital technologies in textile manufacturing, concluding that these technologies could optimize production, reducing cost, and increasing profitability. However, its application is not common yet in textile manufacturing. The author suggests an example with an automatic model of knit fabric defect detection based on image classification and neural network that could refeed and improve the design phase. However, there is still the need of initial design model to start this process of improvement.

The researches show a lack of models that detail how to execute a design including all phases of knitting development, considering all aspects of manufacturing parameters. This is also true when analyzing the generic bibliography of the product development; the methodological focus for its management deals with isolated phases, not presenting a systemic integration of the development process, which directly relates the design to the manufacturing [15,16,5].

The purpose of this work is to develop a systematization in order to operationalize the conceptual design phase of the knitting fabric, taking into account the manufacturing aspects, promoting the concurrent engineering. To this end, a bibliographic review on the product development process (PDP) is presented, as well as its integration and systematic approaches to conduct it effectively. Next, a survey is conducted in four large-scale knitting companies located in Brazil, aiming to identify the methodologies applied in the development of their products. This result is compared with the design methodologies suggested in the literature, aiming at diagnosing the deficiencies of the industrial practices. Based on these deficiencies, a systematization is suggested, with the purpose of supporting and guiding the knitting developers in the conceptual design phase. In order to compose this systematization, the particularities of the textile industries were considered, aiming at identifying the best methods and tools to perform each design activity, also considering the manufacturing aspects involved in the knitting production. This methodology was evaluated through an empirical simulation and an evaluation simulated by experts in the industrial knitting area.

## **2 Material and methods**

In order to achieve this study's objective, it started with an understanding of the subject and a data collection in an industrial field, aiming to understand the way the product

development occurred and its integration with the production, in a general manner, and in the knitting manufacturing industry, in a specific way.

The bibliographic review addressed the product development, its integration and systematic approaches on how to conduct it. The review structure is based on the approach developed by [17].

Despite the numerous approaches to product design, providing many theoretical frameworks [5], the publications related to this specific problem are rare [6]. A brief search with some keywords was conducted in order to identify some contributions in literature, related to the subject in question, without restriction of periods. This research considered peer reviewed articles, in the engineering area and published in English, taking into account the main academic databases. The key words are "integrated", "conceptual design", "method", "textile industry", "and manufacturing". This search has resulted in 28 articles. However, analyzing the title and the abstract of these articles, only four presented a similar focus.

The search was performed with the following keywords, considering the "industrial engineering" area: "product development model"; "Integrated model of product development"; and "integrated product development process". The articles found were selected from the reading of the title, keywords and abstract, according to the topic relevance.

Considering the rating of 27 selected papers, 48% of which correspond to books, 15% to MPhil thesis, 11% to PhD thesis and 26% to articles with SJR (Scientific Journal Rankings) – the latter have relevance of Q1 (86%) and Q3 (14%).

After the analysis of the bibliographic references and selection according to the affinity of the topic discussed, a study was conducted in four large companies, aiming to understand the practices used during the development of the knitting product. These companies were chosen for having a specific department of knitting development. They are located in the southern region of Brazil, in the State of Santa Catarina, known as a producer of knitwear.

In order to collect data, this study used a questionnaire with 26 questions, containing: (1) 4 questions to identify the company and interviewee characteristics; (2) 18 questions to understand the different phases of this process and how they occur — among these, 6 questions on informational design, 5 questions on conceptual design, 4 questions on preliminary design and 3 questions on detailed design, considering the methodology of [16]; (3) and finally, 4 questions related to rework during the PDP process and its causes. The interviewees have more than ten years of experience in knitting development and are responsible for the PDP management.

With the aim of analyzing the previous collection and obtaining a diagnosis of the industrial situation, the data collected in the industrial field were compare with the design methodologies studied, identifying the inefficiencies of the processes conducted by the industries.

The creation of the model considered the points of failure previously identified, aiming at establishing a model that would address these failures with literature proposals, including methods and tools identified as potential to operationalize some activities and considering the integration of manufacturing data. The model focused on the conceptual design step of fabric knitting and considered the interface to manufacturing. In

order to construct the model and considering the best alternatives for the actual industrial situation, three instructors from the Technical Knitting Course of the Santa Catarina Federal Institute of Education, Science and Technology – IFSC were consulted, bringing their knowledge about the features of the knitting design. Aiming to present the model concept in a clearer way, this study presents an application simulation, whose preparation was based on the experience from one of the authors of this work who, besides acting in the academic area, has more than 10 years of experience in knitting projects.

In order to evaluate the performance of the proposed model, this study conducted an experiment with six technicians in knitting development (four with more than 10 years in this area and two with less experience) and divided into three groups: G1 (2 experienced technicians), G2 (2 technicians with little experience) and G3 (2 experienced technicians as a control group). The G1 and design G2 groups had a training whose purpose was to present the theory of the product development, the proposed model and its use. The G3 group did not receive this training because, as a control group, it was responsible for being a reference for the other groups. The proposal was to compare the conceptual design elaborated intuitively by the G3 group with the conceptual design developed with the methodology proposed and passed on to groups G1 and G2. In order to evaluate the performance of the groups that used the proposed methodology, the results obtained and the execution time between (G1 and G2) and G3 were compared. The evaluation considered as a key performance indicator (KPI) the design performance, considering the number of principles of solutions, the number of conceptions (as it is associated to product differentiation), and the quality of the records in the design step.

### **3 PDP and Product Design**

The PDP process involves the design of systematic products and processes, integrating approaches in order to minimize costs and maximize the quality and performance of the development and the final product [15,18-20]. The evolution of the PDP management, some approaches and the main characteristics are: Sequential product development, Integrated development of products (Simultaneous engineering, Stage gate, Funnel model) and new approaches to improve and integrate product development process (Lean Manufacturing, Design for Six Sigma, Maturity models, Management of product lifecycle).

For [21], the integrated development of products has determinants at the strategic and design levels. At the design level, it includes the overall process of product development, the design structure, the cooperation between departments and the involvement of suppliers and customers in the product development. In addition, it also uses multidisciplinary teams to share knowledge, aiming to facilitate problem solving and reduce failures [22,23]. Considering its complexity, the companies need a reference model, from which they can guide the activities and decisions taken during product development.

### 3.1 PDP models

[24] define a reference model as the union of the best practices related to a particular development process, these practices being clearly represented to any user of this process.

The models include the key decisions, activities and tasks required to the product development, providing a framework from which the companies can conduct, control and assess their PDP process. For [24], the models also facilitate the understanding and communication between the product design coordinators, helping in their planning and organization, and generating a unique view of the PDP process, as well as serving as reference for companies and professionals to develop products according to an established standard.

Several approaches or strategies can be adopted in the PDP process, whose characteristics make up different types of models; some of them are limited to the design process, while others address the integrated PDP as a business process, moving beyond the technical specifications of the product [25, 26, 51, 52]. For example, the models with a simultaneous approach address some elements such as: parallel activities, information flow between activities, integrated development with several areas of the company, use of supporting tools, multidisciplinary teams, product life cycle and management of product development [5]. The involvement of work teams from all areas included in the process contributes to a more holistic view of the product [25, 26].

The PDP process must be adapted in accordance with the environment influence and the market pressure to which it is subject. These factors determine the degree of success, the market recognition, and competitive advantage achieved by new products. This way, the PDP process must be cost-effective and aligned with the clients' needs [27]. One possibility to address this challenge is to incorporate a strategy that integrates the production technologies and manufacturing characteristics into the early phases of the project, as these phases are essential for the efficiency of the PDP process and product innovation level. This enables the generation of optimized products, with functional benefits, and reduces the complexity of the parts [28]. According to [29], this integration demands new skills from the product engineers, covering both design and manufacturability issues. It also demands technical skills related to product design and the analysis of its manufacture, as well as behavioral skills such as teamwork and communication between different areas.

However, there are still gaps when dealing with design and manufacturing; the PDP process uses the construction of a system and the function of the product, while production uses the process, operation and tools. In addition, it is necessary to form both models in such a way that the relationships between them can be expressed even in different domains [30]. [31] have identified significant differences between manufacturing and design operations. While sequential processes, executed several times in similar ways, characterize manufacturing operations, the design operations are not linear; tasks such as design, testing and redesign are performed cyclically and interconnected through functions at different hierarchical levels. In addition, the authors identified other barriers to integration and cooperation between design and manufacturing: manufacturing has a shorter time horizon than design and, in contrast to manufacturing



tasks — these are well defined —, design tasks are often abstract. Additionally, there is a lack of knowledge about the operations of other functions, as well as the difficulty in allocating resources and predicting costs, even in the initial phases of the project.

Thus, to better understand this operational dynamic, it will be presented some reference models for the PDP process. According to [32], the models emphasize the process systematization and are oriented through phases, ranging from generation of ideas or identification of needs to the detailing of the proposal, new product development, its production, launching and product monitoring on the market, until its withdrawal. For the author, many of these phases are repeated in the models, with differences only in their terminology, since each author has his own point of view of the PDP interpretation, considering a particular application.

After reading 27 papers found in the bibliographic review about PDP models, this study developed a chronological structure in accordance with several authors, considering the complete life cycle of the product, which includes the pre-development, development and post-development.

Some authors attribute different qualifications to these steps but, when analyzing the operational activities, it can be observed only different forms of grouping. It seems to be the case of [15], who did not mention the expression "preliminary design" in his model; however, the author considers these step activities together with the "detailed design" activities, both under this same step.

An analysis of some works read allows to identify that most of them do not consider the complete product development cycle, including the product launch and its maintenance in the market. The implementation of the discontinuity phase is very important for the company's competitiveness, since it takes into account the end of the product life cycle, such as recycling, reuse, among others, making the company more sustainable. This phase was identified in a few studies and requires more elaborate studies. Some papers describe the production preparation, but do not align it with specific projects for the production itself, which is a relevant sector to maintain the designed requirements and specifications for the final product. In the last decades, the traditional approaches that include and integrate the final activities of the product life cycle in the PDP process define the assembly sequences after the detailed design phase [33]. Most of the works focus on the design steps and present their final phases in a fragmented way.

After the reading and analysis, this study selected 17 works, which were chosen as they approached the model in more detail and included the last phases of the PDP process. The 17 papers selected were: [4,5,13-16,32,34-43]. Of these, some use life cycle approaches, integrated development of products and stage gate, simultaneous engineering approach, and the newest ones, suggest inserting technological tools like artificial intelligence, to collect and improve data, and other to make the process more autonomous. Only the studies presented by [32] and [15] use all approaches in their models; the other authors use them partially. All authors integrate the manufacturing process at some stage of design, but not the complete product life cycle, and the most connected phases are the preliminary, conceptual and production design phases. Only three authors do not mention the connection between manufacturing and another specific phase. In spite of this, there is still no consensus on how to integrate manufacturing with the prior and subsequent production phases, considering a complete and operational life cycle.

In an analysis of selected papers, the models defined by [34] are very similar and use the production and consumption cycle to describe the model phases, differing only in the nomenclatures and in the form of presentation. However, they do not use approaches like concurrent engineering and stage gate because these are works developed before the popularization of these approaches or are very recent. The three models are related to the production and consumption phases and with the withdrawal options of the product from the market, but in a simple way, without using any tools or approaches.

The models presented by [36,16,35,41] conclude the development cycle in the detailed design, production preparation or product launch on the market. The focus of these works is on product design, not addressing the production and post-development phases (product monitoring on the market and discontinuity). [37] also complete their model in the launch phase, presenting a step called "supply chain design" that addresses the type of process to assemble the product; however, they do not describe this topic at the production phase. [5,38-40] conclude their models in the market-monitoring phase; however, [39] does not present a phase for this step; these decisions are taken at a phase prior to the production preparation.

[32,15] present models for the complete PDP cycle, including the company's strategy, development projects and product discontinuity. Their models address integrated development of products, concurrent engineering, stage gates, and some decision-making methods. It is important to highlight that, from the 17 papers selected, most suggest a model applicable to a generic product.

Considering that this study's focus is the operational systematization for the knitting design, the way the product design step occurs in the textile industry will be analyzed.

### **3.2 Textile product design**

In order to plan a textile product, various design methodologies could be adapted and used. However, among the most widespread methodologies in Brazil, there are those defined by [16,15,5], which are very similar in their descriptions and objectives. The phases are:

1. Task planning and clarification/Information design: it aims at understanding what is required by consumers and transforms this information into technical specifications;
2. Conceptual design: it proposes solutions from a functional structure of the product, evaluating the principles of solutions generated and composing several solutions for the same problem. The best design is compared and selected in order to meet consumer expectations;
3. Preliminary design: from the concepts generated, the constructive structure of a system is determined according to the technical and economic criteria;
4. Detailed design: it deals with the documentation for the production, with detailed drawings, parts lists, instructions for the production and assembly.

Of all the phases previously mentioned, the conceptual design is the phase where the product concepts are developed, and it is of vital importance for the creation of an innovative product. After all, it is at this phase that you have the opportunity to find innovative solutions, aiming at a better solution for the problem. However, some researchers conducted in Brazil show that it is the conceptual design phase in which the

companies that develop knitwear have greater vulnerability [3]. The activities of the conceptual project, as well as the methods for accomplishing them, was based on [15,3, 16,5]. They are: Function structure (Describe the global function that the product must perform and all its subfunctions, including the connections between them - Method: Functional synthesis); Alternative conceptions (Generate alternative solutions for previously defined functions - Method: Brainstorming, Attribute Listing, Morphological matrix, 635 method, Triz, The Delphi technique, Synthetic Method); Selection of conceptions (the choice of solutions previously generated, to identify which are the ones that better meet the general qualitative criteria - Method: Compliance with the functions, Pugh's Method); Assessment of the selected conceptions (The evaluation must follow a technical and economic nature, verifying the production flows required by the design and its costs - Method: Pugh's Method).

With the purpose of observing the industrial reality, in order to contrast with the analyzed theory, the study starts by exploring information in the field; however, it has with a product focus: the knitting development.

#### **4 Model for conducting the conceptual knitting design**

In order to analyze the systematic that has been applied by the knitting industries in their product designs, a study was conducted in four large knitting producers (called A, B, C and D) that presented a knitting development department (design). The collection used a questionnaire, filled via interviews with workers with more than ten years of experience, responsible for managing the knitting developments.

The questionnaire has 26 questions, containing: (1) 4 questions to identify the company and interviewee characteristics; (2) 18 questions to understand the different phases of this process and how they occur — among these, 6 questions on informational design, 5 questions on conceptual design, 4 questions on preliminary design and 3 questions on detailed design; (3) and 4 questions related to rework during the process and its causes. The objective was to understand how the "Design step" is developed; this step is composed by the "informational, conceptual, preliminary and detailed design", belonging to the Macro phase "Development". Subsequently, the goal was to identify the most critical phase of the project, considering the systematization used in the industry, even without a structured model or script. A detail of this collection is shown in [3]. Analyzing the answers, it was verified that the development of alternatives and their formalization were the most critical steps, because they were not verified in any of the companies. This finding indicated that the conceptual design phase was neglected in the four companies analyzed. A detail of this collection is shown in [3]. Analyzing the answers, it was verified that the development of alternatives and their formalization were the most critical steps, because they were not verified in any of the companies. This finding indicated that the conceptual design phase was neglected in the four companies analyzed. Based on this observation, the systematization for the conceptual phase of the knitting design started, following the previously steps described. In addition to biblio-graphical references and deficiencies found in the analyzed industries, two instructors working in this area contributed to indicate which resources (methods and tools) could contribute to the execution of the activities.

Considering the specific knitting development, the generic model was adapted, taking into account the real needs of the industry. This adaptation is described in the operationalization of each activity that make up the conceptual design, as can be seen in the description below:

- List of requirements: originated from the informational design, it contains the necessary requirements for the product to meet the customer's needs and have a good performance. In the industries that produces clothing knitting, some functional requirements such as protection, comfort, thermal comfort, among others, are already intrinsic to all products. The list of requirements for knitting development should be more technical, preferably indicating units of measurement, thus providing greater assertiveness in development.
- Functional structure: it determines the functions that the product must present, identifying which functions and sub-functions the product must implement to achieve the product requirements defined in the previous activity. Depending on the affinity of these requirements, a function may be sourced from more than one requirement. For knitting developments intended for clothing, it is not necessary to define intrinsic functions, such as, protect the body, accommodate the shape or provide comfort — these are obvious functions. The functions established at this stage may contain indications of raw material or industrial processes in a generic way. The functions for knitting are usually independent, leading to a set of functions to meet a single product. After defining the product functions and sub-functions, the process evolves to determine the principles of solutions.
- Generation of alternatives: This activity can use the "morphological matrix" method to help in the exploration of solutions for each sub-function previously identified, allowing a systematic examination of all the combinations among the different solutions, creating some solutions that meet the global function of the product. This way, the mental processes of a knitting developer are implemented and improved. In the case of knitting development, the principles of solution should be used in the form of a verbal description. In order to generate conceptions of viable products from the morphological matrix, the combination of the different principles of solutions must respect two criteria, called filters. These filters are described below:
  - a. Technical compatibility between the principles of solution;
  - b. Meet the technical requirements.
- Evaluation and selection of conceptions: The selection of the best conceptions is conducted by using the Pugh's method [44]. In this selection, the conception considered more usual in the knitting shops is used as a reference for the comparison of the other solutions. The following criteria are evaluated:
  - a. Compliance with the requirements: the number of product requirements met by the design under analysis is verified, comparing it with the referential design. If the number of requirements met exceeds that of the reference, the symbol (+) is assigned; if it is equal, there is the number (0) and if it is lower, the symbol (-) is assigned;
  - b. Estimated cost: the estimated cost of the design under analysis is verified, comparing it with the referential design. If the cost is higher than the reference, the symbol (-) is assigned; if it is equal, there is the number (0) and if it is lower, the symbol (+) is assigned;

c. Reliability: it is related to the good performance of the product during a certain time. In this criterion, the useful life of the design under analysis is compared to the reference design. If the useful life is higher than the reference value, the symbol (-) is assigned; if it is equal, there is the number (0) and if it is lower, the symbol (+) is assigned;

d. Appearance: it is related to the visual quality of the product. In this criterion, it was comparing the good image of the conception under analysis to the referential conception. If, according to the evaluators, the characteristics of the design evaluated generate a visual quality superior to that of the reference, the symbol (-) is assigned; if it is equal, there is the number (0) and if it is lower, the symbol (+) is assigned.

- Technical and economic evaluation: The best design previously defined receives a refined technical assessment, taking into account its manufacturing feasibility. Considering the projection of volume to be produced, the productive capacity of the company is verified and, if any process demands outsourcing, it is necessary to verify if other companies are able to meet this demand. The raw material supplier and its delivery capacity is also verified. The costs involved are detailed, in order to verify if it meets the "end product cost" requirement. Since the detailed product design is not yet available, the values established in this phase are subject to variations, for the knitwear is established only at the conceptual level.

This study presents a practical simulation in [3]. The process begins with the list of product requirements, including the "cost" requirement, which is the most responsible for rework. From this list, it is determined the functions of the product. The development team should analyze these functions, and then the group proposes some principles of solution for each function. For each function, different principles of solutions were described, generating a matrix of concepts. These solution combinations of the product, respecting the restrictions of compatibility and the compliance with the requirements, which are: Synthetic and elastomeric fibers are not mercerized; The resin application increases the grammage, and does not meet the initial requirements; Mercerization does not provide elasticity; The high degree of tightness decreases the elasticity. From the matrix of concept generation and taking into account the restrictions previously described, it was defining the possible product conceptions.

In order to define the best conception, one of them is defined as a reference (probably, the winner) and compared with the others, in order to identify if other possibilities are better than the one chosen by the group of designers. The best conceptions undergo a technical and financial evaluation, identifying the winning solution and verifying its real manufacturing viability.

With the purpose of testing the systematization in the field, 6 technicians used it in simulated projects, in order to verify the functionality of the proposal [3]. This study verified that all participants found a significant number of functions and principles of solution, indicating that the systematization provides the generation of functions and their respective principles of solution, independent of any experience. However, although the tool conducts the process, the user experience influences the generation of principles of solutions when more skill and knowledge in the area is required. Still, all groups have achieved very close product design results. This way, it can infer the systematization efficiency, by allowing inexperienced technicians to have results similar to those of very high experienced professionals. One group provided a list of raw

material data, machine settings and process flows, using approximately 1.5 hours to perform the experiment, that is, they did not explore or present principles of previous solutions. This proves that the conceptual step has been neglected in the knitting industries, trying to reach final solutions without exploiting other opportunities. Starting from the product requirements, the developers migrate directly to the detailed project, mentally evaluating alternatives, without producing records. This makes it difficult to transfer experience to new designers, as it can compromise the technical detailing of a given knitwear when a technician, who possesses this knowledge, leaves the company. In any case, the model shows that, in addition to assisting designers with little experience of the conceptual knitting design, it also helps to keep records of the conception evolution and the technical details associated.

## 5 Conclusion

The review presented about PDP process found that there is little operational systematization to integrate design data with manufacturing process, considering the whole development life cycle. The papers address integration only within specific steps or suggest the use of new technologies to improve design from manufacturing data. There is a lack of methodologies to operationalize the conceptual and preliminary design phases, integrating manufacturing aspects, especially in knitting fabric design [45,46,47]. So far, knitwear companies continue to rely on the tacit knowledge of some experienced technicians. Recent reviews point to the tendency of incorporate tools of industry 4.0, which could contribute to operationalize the PLM. After all, the data collected in the field could feed and improve mesh designs, contributing to making these data explicit and shared, reinforcing the aims of the PLM proposal [48,49,50]. Despite this, it was found that few industries in the sector adopt technologies from industry 4.0 and the designs follow dependent from the experience of some employees, without sharing information and without formalizing its development. Based on the field research with four large knitting industries, this study found that the conceptual design phase is ignored in knitting development and that there is no systematics for the PDP process, involving the entire development cycle. This work proposed a systematic for knitting conceptual design, integrating manufacturing aspects. The proposal could use to initiate the design parameters and, in the future, with news technologies, could be improved with manufacturing data, improving the PLM. Through an empirical simulation conducted by a specialist in knitwear development and an assessment simulated by specialists in the knitwear sector, it was found that the proposal allows to generate products with a greater degree of assertiveness when compared without use of the methodology, meeting the customers' needs and reducing manufacturing reworkings. Both experienced specialists and novices were able to obtain satisfactory results following the methodology. However, in a first moment, the model demands a seek for information on raw materials and textile manufacturing processes with experts in these areas. Due to the peculiarity of the textile sector, the same systematization could be adapted for the development of woven fabric, non-woven textile, and yarn, remaining as a suggestion for future studies.

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