Research Article

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The role of standardized technical packages in ensuring consistency and accuracy in apparel product development

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Abstract: Tech pack is a comprehensive communication document that provides detailed instructions and specifications for apparel production. It serves as contracts between design sections, production sections, and clients, ensuring consistency, accuracy, and effective communication throughout the product development process. This study aims to identify and examine the specific components of tech packs. Through surveys, interviews, and analysis of existing tech packs, the study validates the importance of each component and its contribution to the overall effectiveness of tech packs. The methodology involves hypothesis generation, questionnaire development, data collection through surveys, and data analysis using statistical techniques. Confirmatory factor analysis (CFA) technique was used to prove the model statistically by using AMOS and SPSS software. Results were improved by several iterations, and they verified that the obtained components of tech packs are necessary to get the right information from customers. Finally, the study developed a conceptual model that describes the relations among all tech pack components and illustrates their interactions and benefits within the apparel sector in question. Furthermore, this study will contribute to the improvement and standardization of tech pack development, ultimately enhancing productivity and ensuring consistent and accurate apparel product development.

Keywords: tech pack; factor analysis; confirmatory factor analysis; production process

1 Introduction

The apparel industry is now globalized, with companies sourcing materials, resources, and production capabilities worldwide [1]. Global sourcing is the systematic procedure of recognizing, assessing, negotiating, and arranging supply chains spanning various regions to minimize expenses, enhance efficiency, and effectively handle potential risks [2]. Globalization resulted in the relocation of production and trade from local manufacturing to sourcing production offshore, followed by the outsourcing of fabrication and design [3]. It demands a detailed understanding of local market conditions, regulations, cultural norms, and other significant factors that affect production. In the realm of apparel production and global sourcing, specifications are critical for guiding workers and preventing mistakes. Written specifications ensure clear understanding of expectations among workers in the samples' chamber [4].

Design specifications should be concise and clear, ensuring clarity and minimizing confusion. They serve as contracts between the design section, production sections, and clients [5] Furthermore, the specification serves as a communication source between the design section and other production sections within the same clothing company, as well as with external clients. In the clothing industry, production agreements are generally written in English, which is the dominant language used to express technical and production details in apparel industry across the world [6] The communication document is commonly called a Technical Package, Tech Pack, Dossier, or Specification Sheet [7]–[9].

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A technical package or tech pack, according to Senanayake, is a “bid package” for price negotiation and contractor selection. It ensures error-free product development in the fast fashion industry with tight timelines [10]. A. Rita reported that, an accurate tech pack enables any global manufacturer to produce the exact product without further information [11]. Designers begin with a partial tech pack and add more details after the finalization of design and functionality elements. Sections include design sheet, fabric sheet, specification sheet or spec sheet, fabric specifications, and trim specifications. The design and fabric sheets are important for seamless projects while the other important details are recorded by spec and trims [12].

Tech packs play a significant role from a merchandiser’s perspective [11]. They serve as comprehensive blueprints that guide the manufacturing process from sampling to bulk production, containing all the necessary information to create a product. Tech packs enhance communication and prevent production issues by furnishing comprehensive instructions and specifications [13]. They act as contractual agreements between vendors and buyers, ensuring both parties are on the same page and facilitating efficient collaboration [14]. During the bulk production stage, merchandisers negotiate production costs and review vendor compliance according to the details provided in the tech pack [15]. Additionally, tech packs contribute to smoother operations by minimizing errors and defective samples, ultimately reducing costs and production time [1]. Furthermore, tech packs are useful for various departments, such as marketing, enabling pre-booking and advertising, and quality control, ensuring garments meet customer requirements [16]. Overall, the importance of tech packs cannot be overstated in streamlining and optimizing the manufacturing and ordering process.

Effective communication plays a pivotal role in the successful development of a product, ensuring the production of high-quality outcomes. In the early stages of global sourcing [17] observed challenges arising from non-editable written guidelines. However, the introduction of a hypermedia application marked a significant improvement, enabling editable digital guidelines. This innovation facilitated more accurate and clear communication, fostering collaboration, and enhancing the efficient review of process-related specifications. Kastanos [18] conducted a study focusing on various communication challenges inherent in product development. The findings emphasized that communication stands out as the most significant problem during the product development process.

In addition, Rita and Mahamud [1] explored the analysis of communication types across various apparel units. Their study illustrated differences in tools and emphasized the importance of technical packages. They explained that technical packages were commonly used, and that the specifics and formats depended on the size of the industry and how the information was communicated. Saeedi and Choudhury emphasised on tech pack errors as a cause of communication defects and job overload based on empirical error analysis in garments manufacturing. Garon [12] identifying communication and production processes; three case studies on smart textiles. The studies emphasized variations in tech pack formats and details, with Garon concluding that the complexity of the production process varied between in-house development and collaborative efforts involving multiple factories. He highlighted the challenges of potential errors and miscommunication in such collaborative settings.

The evolution of tech packs into communication tools connecting various departments within the apparel industry was discussed by [19]. While acknowledging their role, they cautioned that tech packs might sometimes increase confusion rather than alleviate problems. The escalating workload and communication challenges resulting from globalization prompted the creation of a mobile app, significantly reducing both time and costs in the product development process. A study conducted by [18] delved into the root causes of differences between expected prototypes and constructed prototypes. The study concluded that clear communication, meticulous order of operations, and detailed tech packs are crucial in garment manufacturing, especially in factories dealing with language barriers and time zone differences. The skills of the tech pack creator were also identified as vital components in creating effective tech packs.

Petersburg et al. [20] emphasized the importance of enhancing technical skills and utilizing effective tech packs for the growth and competitiveness of the apparel industry. Their insights underscored the critical role of technical proficiency in navigating the intricacies of the product development process. The textile industry highlighted examples of various terms used by designers and knitting technicians, emphasizing the potential for communication gaps. Senanayake [10] studied the product development process of apparel products, arguing that designers need knowledge in various areas, including commercialization, production processes, problem-solving, fabric, CAD, grading, and collaboration to enhance clothing development.

Innovation-driven products can be developed through various approaches, as demonstrated by companies like TZMO, Filter Service, Corin, and Knittex, each achieving significant market positions Czajkowski and Woźniak-Malczewska [2]. Observing market leaders offers valuable insights into innovative methods for generating new product ideas, ultimately leading to competitive advantage and potential breakthroughs.

The unique product development process in the apparel industry requires close coordination and detailed tech packs. Sayed and Assistant [7] analyzed [21] students' skills in creating tech packs, proposing a training program to enhance technical skills. The results indicated improved grades and skill development among the students. Jhanji [22] highlighted the role of CAD technology, including software like Photoshop, Illustrator, Gerber, and Pointcare, in enhancing automation, precision, and productivity in the textile industry. Meanwhile, in 2022 [23] reported on the need for tech pack standardization and sustainability requirements in the garment industry, emphasizing the importance of standardization in the development process.

Table 1 compiles recent research endeavors that have leveraged tech packs to address various research problems. The literature review establishes that authors have incorporated distinct components of tech packs in their respective studies. However, upon closer examination of the table, it becomes evident that none of the researchers have comprehensively employed all the components or endeavored to investigate them collectively in a single study.

A consensus among many researchers is the acknowledgment that even a minor alteration or misinformation in a tech pack can result in significant losses, costs, and time wastage. Nevertheless, individual organizations tend to manage communication and processes in their unique ways, often leading to incomplete tech packs and technical details being left for technicians to create and record [32]. Recognizing this research gap, the current study aims to address this area by encompassing and exploring all components of the tech pack.

By examining these components, the research aims to uncover insights into their significance and contribution to the overall effectiveness of tech packs. This comprehensive approach aims to shed light on the holistic utilization of tech packs, a departure from the fragmented use observed in prior research efforts. Therefore, this research proposes the following questions:

– Which components of a tech pack are essential for successfully constructing an apparel product?
– How can the statistical significance of these components be established?

In the context of the literature presented, this study proposes the following hypotheses to address specific research gaps:

Hypothesis No. 1 (H1): The inclusion of a comprehensive design sheet and its components in a tech pack is necessary to create a defectless product.

Hypothesis No. 2 (H2): Providing detailed color specifications for all product constructs in a tech pack will streamline the manufacturing process.

Hypothesis No. 3 (H3): The presence of a spec sheet with detailed illustrations is a critical factor in the effectiveness of a tech pack.

Table 1: Comparison of the suggested study plan with the past research.

	Design sheet/ cover page	Color specifications	Fabric specifications	Points of measurement	Spec sheet	Artwork details	Tag/label specifications	Packing details	Trims details
Senanayake [10]	*	*	*	*	*	*		*	*
Rita and Mahamud [1]	*	*	*	*	*	*	*	*	
Jaeil Lee and Camille Steen [24]	*	*	*		*	*	*	*	
Myers-McDevitt [25]	*		*	*	*		*	*	
Gopura et al. [26]	*		*		*	*		*	*
Sayed and Assistant [7]	*	*	*		*	*	*	*	
Pirzada Gouhar [13]		*		*	*	*	*		*
Mohibullah et al. [27]		*		*	*	*			*
Petersburg et al. [20]	*				*				
Gorea et al. [28]	*		*		*				*
Shafiq [29]			*		*		*	*	
Tiwari [16]	*	*	*		*			*	
R. Rathinamoorthy and R. Surjit [30]	*		*		*	*		*	
Garon [12]	*						*	*	*
Akash Rajiv Mehta and Manisha Barla		*	*	*	*	*		*	
Srishti, Garbyal			*		*				
Ghalachyan [31]	*			*	*				
Current research	*	*	*	*	*	*	*	*	*

Hypothesis No. 4 (H4): Inclusion of comprehensive trims details in a tech pack facilitates the communication process between vendors and buyers.

Hypothesis No. 5 (H5): Detailed construction details are essential components for creating a product that meets the seller's requirements.

Hypothesis No. 6 (H6): A comprehensive explanation of artwork on the product within a tech pack reduces the chances of product rejection.

Hypothesis No. 7 (H7): Including label and tag details with all the necessary constructs in a tech pack helps minimize errors during production.

Hypothesis No. 8 (H8): The inclusion of packing details is a crucial element that holds significant importance in a tech pack, ensuring efficient packaging processes.

2 Methodology

A comprehensive study was conducted to analyze the components of a tech pack. The data collection process employed a survey method utilizing a self-administered questionnaire created from the conceptual model. The theoretical framework of the study drew upon research papers and articles that explored different constructs of tech pack, as shown in Figure 1.

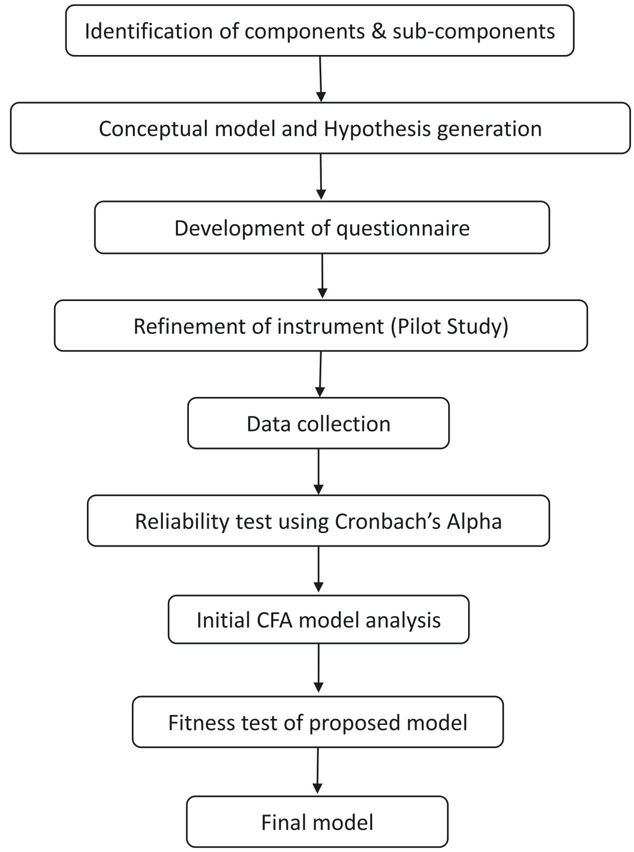

Figure 1: Methodology flow chart for the research.

2.1 Data collection

To gather data and test these hypotheses, a well-structured questionnaire was carefully designed. The questionnaire was specifically tailored to collect data from the apparel industries, focusing on capturing relevant information to substantiate the formulated hypotheses.

To ensure the effectiveness and reliability of the questionnaire, a pilot study was conducted. Structured interview method was used in order to conduct pilot study. Fifteen experts from different sectors of apparel participated in pilot study. The pilot study served the purpose of testing the questionnaire on a small sample size, allowing for necessary adjustments and refinements to be made based on the feedback received. This iterative process led to the finalization of the questionnaire, ensuring its appropriateness and accuracy for the subsequent data collection phase. Following the finalization of the questionnaire, data collection commenced. Electronic surveys were selected as the preferred method due to their capacity to enhance data integrity, facilitate rapid response rates, and reduce research expenses [33], [34]. To improve the rate of response, diverse apparel (knitted, woven and denim etc.) industries were contacted, and the e-form link was distributed to specific departments. Demographic information is given in Table 2.

2.1.1 Sample size

A total of 250 questionnaires were distributed to companies that expressed interest in supporting our research objectives. These questionnaires were then shared with apparel professionals within each organization. The risk of selection bias is minimized, as we neither self-selected nor

Table 2: Demographic information of respondents.

Characteristic	Category	Frequency	Percentage
Sector	Woven	76	40.8
	Knitting	107	57.5
	Others	3	1.6
Education	Graduation	107	57.5
	Masters	79	42.5
Experience	0–3 years	82	44.1
	4–6 years	51	27.4
	7-above years	53	28.5

intentionally targeted specific respondents. Out of the 250 questionnaires sent, 200 were returned, with 186 valid responses included in the analysis, resulting in a response rate of 74.4 %. This response rate is considered reasonable, based on similar studies published by Chen et al. [35] and Xiong et al. [36].

2.1.2 Sector

This study includes the data from 186 respondents from different industries. 40.8 % of the respondents were from the woven department, 57.5 % were from knitting department while 1.6 % were from other than these two departments of apparel industry.

2.1.3 Education

According to the collected data, 57.5 % respondents were having graduation degree and 42.5 % were holding master's degree.

2.1.4 Experience

In terms of experience, participants were divided into three groups based on the number of years: 0–3 years, 4–6 years, and 7 years and above. The highest number of participants fell within the 0–3 years category 44.1 %, followed by 7 years and above 28.5 %, and then the 4–6 years category 27.4 %.

2.2 Data analysis

After the data was collected, it was analyzed with multivariate techniques in SPSS (version 25) and AMOS (version 24). Procedures included data editing, cleaning, and analysis as well as descriptive statistics, reliability testing, and confirmatory factor analysis (CFA). CFA was important in this study because it verifies the measurement scales that were used for the different components of tech packs. CFA checks whether the survey items fully measure the proposed concepts by analyzing the correspondence between the extracted data and the theoretical model consisting of the components of the tech pack. It's most basic role is to substantiate that the survey items are representative of the complex parts of the tech packs. In addition, CFA aids in establishing the credibility of the measurement scales by demonstrating their claimed level of internal consistency. This fusion approach is indispensable to give credence and authenticity to the research results about components of tech packs, thus improving the granularity of the study. Cronbach's alpha coefficient was used to assess the reliability of the measurement instrument and CFA was used to test the ability of the conceptual model and the proposed relationships within its constructs. Consequently, CFA performed as the primary statistical method for calculating the validity and reliability of the proposed conceptual model, as well as relevance of the testable hypotheses.

2.3 Conceptual model

Based on the literature review, eight components and their subcomponents were selected for the development of tech pack. It was observed that these variables were responsible for getting the right information from tech packs. The conceptual model is developed using selected components as shown in Figure 2.

2.4 Components and corresponding observed variable

After thorough literature review, several observed variables were identified against each component to measure the identified constructs. The details of each component and subcomponents are summarized in Table 3.

2.5 Refinement and development of instrument

In this study, a survey instrument was created to collect data on the components and subcomponents of tech pack, based on the guidelines by Dillman [6]. The instrument was divided into three main sections: the first section focusing on demographic information of the respondents, the second section gathering data on the main components of tech pack, and the third section based on data collection of the subcomponents. Each sub-section contained succinct and to-the-point questions addressing one topic at a time, based on the observed factors indicated in Table 3.

Two subjective approaches were utilized to validate the reliability of constructs and the equitable classification of observable variables: content validity and reliability testing. Content validity was established by engaging in brainstorming sessions with managers/experts hailing from various sectors of the apparel industry. Their valuable input was used to refine the survey instrument to enhance its clarity among the respondents. Reliability was tested using Cronbach's alpha test, computed later in the procedures. Respondents were asked to rate the extent to which they believed each observed variable on a five-point Likert scale.

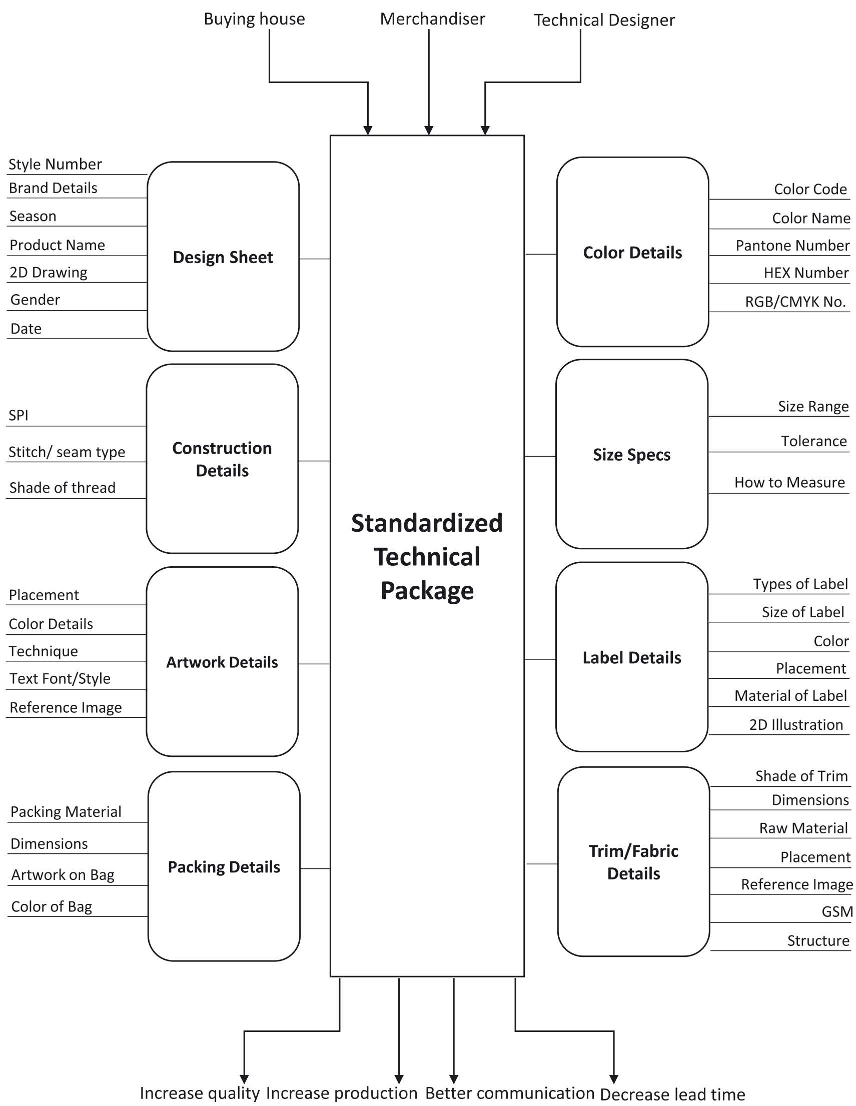

Figure 2: Conceptual model for tech pack components.

These measures were taken to ensure the validity and reliability of the survey instrument and to collect accurate and meaningful data on the components and subcomponents of the tech pack.

2.6 Descriptive statistics

Data was gathered from the garment industry in Pakistan, focusing on key industrial cities such as Faisalabad, Karachi, Lahore, and Sialkot. The study delves into the demographic distribution of participants, considering factors such as sectors, educational backgrounds, and levels of experience. In terms of sectors, the study found representation in woven, knitting, and other sectors. The knitting sector had the highest frequency (57.5 %), followed by woven sectors (40.8 %). Participant's educational qualifications were categorized into graduation and master's, with a relatively equal distribution between the two categories. In terms of experience, participants were divided into three groups based on the number of years: 0–3 years, 4–6 years, and 7 years and above. The highest number of participants fell within the 0–3 years category (44.1 %), followed by 7 years and above (28.5), and then the 4–6 years category (27.4 %).

3 Results

3.1 Reliability and validity test

The reliability score was derived using Cronbach's alpha for every construct in the model, which included cover page, colour specification, detail of fabric, artwork and label, as well as packing details. A Cronbach's alpha of 0.70 or

Table 3: Latent variables with observed variables for initial model.

Latent Variable	Observed Variables	Abbreviation
Design sheet (DS)	Style number	A1
Gopura et al. [26]; Senanayake	Brand name and Logo	A2
[10]	Season	A3
	Product name	A4
	2D drawing	A5
	Gender of product	A6
	Date	A7
Color specifications (CS)	Color code	B1
Senanayake [10];	Color name	B2
Rita and Mahamud [1]	Pantone no.	B3
	HEX no.	B4
	RGB/CMYK no.	B5
Construction details (CD)	Stitches per inch	C1
Senanayake [10] Gorea et al.	Drawing of shade/seam	C2
[28]	Shade of thread	C3
Size specs (SS)	Size range	D1
Tiwari [16]; Senanayake [10];	Tolerance	D2
Rita and Mahamud [1]	"How to measure" drawing	D3
Artwork details (AD)	Placement	E1
Senanayake [10];	Color details	E2
Rita and Mahamud [1]	Technique	E3
	Text style/font	E4
	Reference image/sketch	E5
Tag/Label details (LD)	Type of label	F1
Myers-McDevitt [25];	Size of label	F2
Rita and Mahamud [1]	Color	F3
	Placement	F4
	Material of label	F5
	2D illustration of label	F6
Packing details (PD)	Packing material	G1
(Rita and Mahamud [1])	Packing Bag dimensions	G2
	Drawing of artwork on bag	G3
	Color of packing bag	G4
Fabric/Trim details (TD)	Shade of shell fabric/trims	H1
Garon [12]; Senanayake [10]	Dimensions	H2
	Raw material	H3
	Placement	H4
	Reference image/sketch	H5
	GSM	H6
	Structure	H7

higher is recognized as a sign of scale reliability [37]. Table 4 presents the results of the test above, along with the corresponding coefficients for the tech pack components, as labeled in the table. These coefficients, ranging from 0.776 to 0.897, suggest that the constructs theoretically engaged in the study are highly reliable and consistent. The KMO values are 0.879 which is considered to be good and validates the use of factor analysis [38]. Convergent validity was evaluated based on the standardized factor loadings given. The relevance of the standard regression weight confirms the relevance and embodying nature of the indicator variables in question to their underlying latent variables. The factor loadings for all observed variables fell within the range of 0.53–0.88, thus satisfying the criteria for convergent validity.

Table 4: Reliability and validity test summary.

Construct	Number of observed variables	AVE	CR	Value of Cronbach's alpha (α)
Cover page	7	0.522	0.883	0.877
Color specifications	5	0.520	0.835	0.853
Construction details	3	0.530	0.773	0.732
Size specifications	3	0.611	0.825	0.824
Artwork details	5	0.581	0.871	0.868
Tag/label details	6	0.608	0.902	0.897
Packing details	4	0.566	0.838	0.835
Trim details	7	0.501	0.717	0.844

To establish convergent validity, it is recommended by Hair, Anderson, Babin, and Black [39], [40] that the composite reliability (CR) should be greater than 0.7, CR should be greater than the average variance extracted (AVE), and AVE should be greater than 0.5. The construct in this study meets these standards for both convergent validity and discriminant validity, as shown in Table 4.

3.2 Model specifications and refinement

The initial model was analyzed with CFA using SPSS-AMOS-24. The initial model contained eight constructs and 39 sub constructs and is shown in Figure 3. CFA provides information on the validation of the measurement model which is reflected in the given set of factors. Its relationship has been assumed by Goodness of Fit (GOF) as well as RMSEA, CFI, TLI and PGFI and PNFI. All indicators' variables are expressed by their latent construct with higher degree of regression.

The degree of variance is assessed using squared factor loadings. The squared factor loading for each observed variable determines its level of explanatory power. If the squared factor loading exceeds 0.70, the observed variable

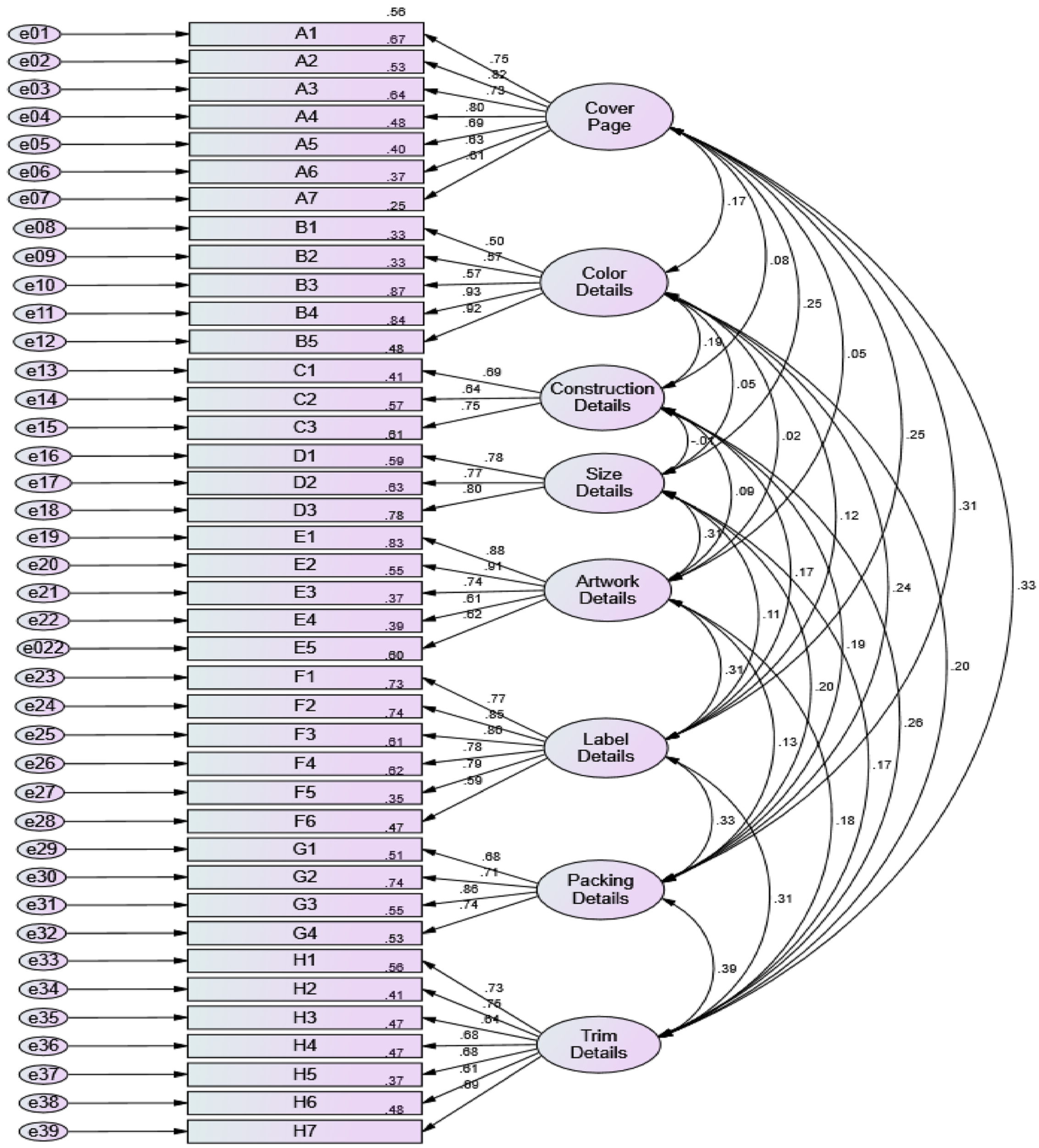

Figure 3: Initial model of path analysis.

has a high degree of explanatory power. The explanatory power is considered moderate if it falls between 0.50 and 0.60. However, the explanatory power is deemed poor if the squared factor loading is below 0.50. To enhance the goodness-of-fit (GOF) of the final model with a high degree of explanatory power, sub-constructs with lower values than 0.7 were systematically eliminated from the initial model. Variables with lower values were sequentially removed until the desired GOF values were attained. The excluded sub-constructs are detailed in Table 5. Care was taken to ensure that none of the essential sub-constructs, crucial for acquiring information and covered by another factor, were inadvertently removed.

4 Discussion

Figure 4 depicts the proposed model derived from this research. The path coefficient connecting each construct to its observed variables represents the factor loading. The results indicate that the observed variables significantly impact the structure of the tech pack and effectively measure

Table 5: Removed sub-components amid lower square factor loading.

Main construct	Sub-constructs	Square factor loading
Cover page	Date	0.51
Color details	Color name	0.50
	Color shade	0.51
Artwork details	Text style	0.6
Trim and fabric details	Shade of shell fabric/trims	0.51
	Dimensions	0.59

their respective constructs. In this study, the threshold value for the constructs was set at 0.5 [41], [42]. Any values with a regression weight below 0.5 were excluded from the final model. Therefore, all standardized regression weights in the range of 0.55–0.95 suggest a strong relationship between the constructs and the latent constructs.

Table 6 compares the values of initial and final model. Values according to the recommended GOF values were attained after several iteration attempts. The final model of this study provides evidence to support and validate all the

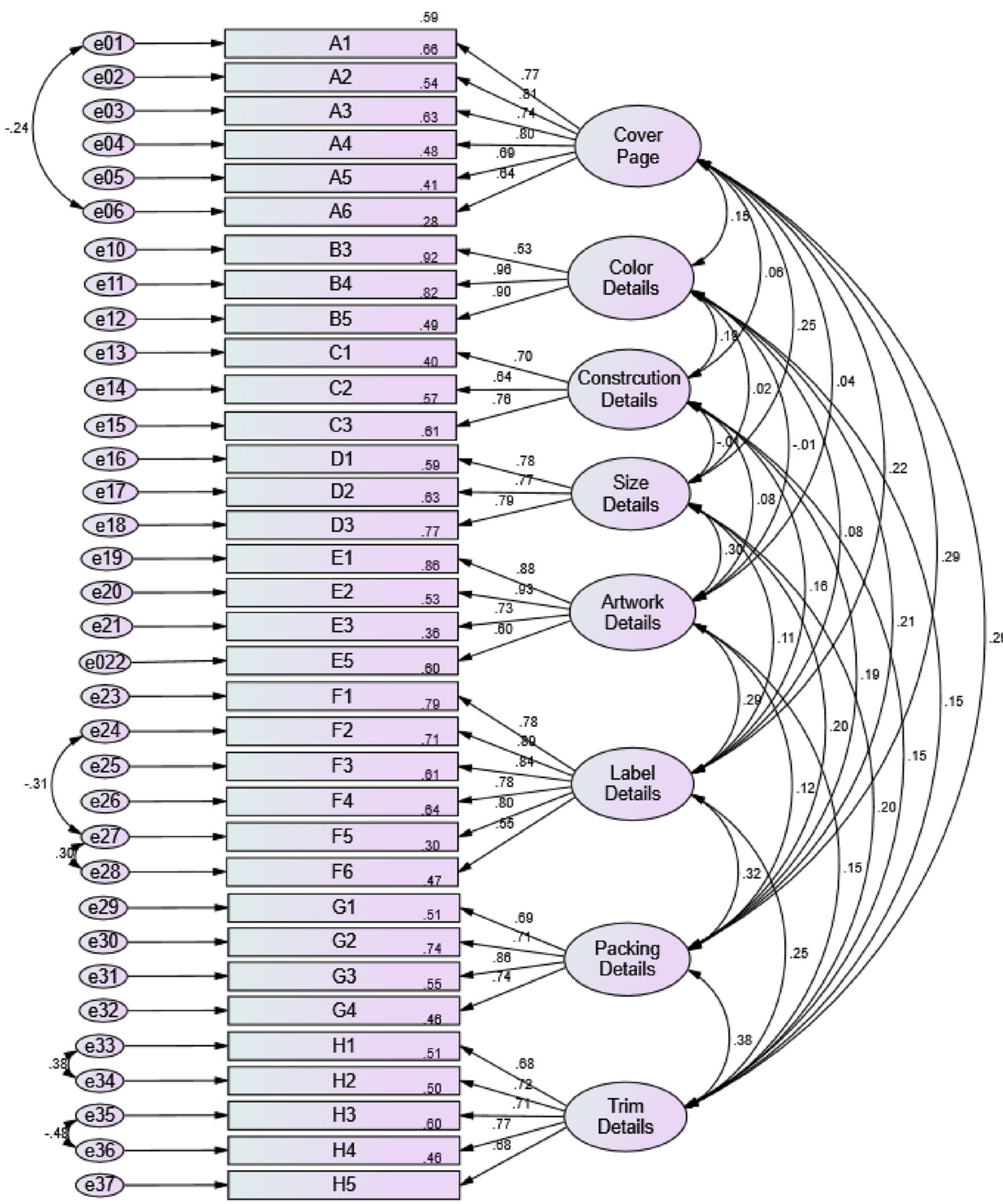

Figure 4: Final proposed model of the research.

Table 6: Comparison between initial and final model values.

	Recommended level of GOF	Initial model	Final model
Goodness of fit measure			
CMIN/df	<3	1.856	1.532
Absolute fit			
RMSEA	<0.10	0.068	0.054
Incremental fit			
Comparative fit index (CFI)	0 (no fit) to 1 (perfect fit)	0.843	0.917
Tucker-Lewis index (TLI)	0 (no fit) to 1 (perfect fit)	0.828	0.906
Parsimonious fit			
Parsimonious goodness of fit (PGFI)	>0.5	0.635	0.677
Parsimonious normal-fit index (PNFI)	>0.5	0.654	0.702

Table 7: Results of proposed hypothesis.

#	Hypothesis statement	Results
1	The inclusion of a comprehensive design sheet and its components in a tech pack is necessary to create a defect-free product.	Approved
2	Providing detailed color specifications for all product constructs in a tech pack will streamline the manufacturing process.	Approved
3	The presence of a spec sheet with detailed illustrations is a critical factor in the effectiveness of a tech pack.	Approved
4	Inclusion of comprehensive trims details in a tech pack facilitates the communication process between vendors and buyers.	Approved
5	A comprehensive explanation of artwork on the product within a tech pack reduces the chances of product rejection.	Approved
6	Detailed construction details are essential components for creating a product that meets the seller's requirements.	Approved
7	Including label and tag details with all the necessary constructs in a tech pack helps minimize errors during production.	Approved
8	The inclusion of packing details is a crucial element that holds significant importance in a tech pack, ensuring efficient packaging processes.	Approved

hypotheses put forth in the conceptual model. In the Cover page construct, the variable "date" was eliminated from consideration due to its low regression weight. Within the color details construct, it was suggested that the utilization of color codes such as pantone number, RGB/CMYK number, or HEX numbers is adequate for achieving accurate product colors. Regarding the Artwork construct, the variable "text style" was found to be inconsequential for product manufacturing, and both the GSM (grams per square meter) and the structure of trims were deemed insignificant as well.

The final and initial values of the model prove that the proposed hypotheses are true. Table 7 provides an overall summary of the research hypotheses and their collective results. All eight hypotheses were approved, indicating their significant importance in tech packs and apparel product development. These findings collectively underscore the crucial role of various tech pack components in ensuring product quality, effective communication, and streamlined manufacturing processes within the apparel industry.

Figure 5 illustrates the proposed Tech pack model and its utilization across various stages of apparel manufacturing. The model posits that comprehensive inclusion of all necessary details is essential before initiating the manufacturing process for any apparel product within the industry. Its primary objective is to serve as a communication template, informing designers, buyers, and manufacturers about the specific information required throughout the development of an apparel product. The design sheet, the blueprint for the entire production process, initiates collaborative discussions between designers and manufacturers. These conversations are essential to clarify any ambiguities, verify design elements, and establish a shared understanding of the product's visual representation. Regular communication ensures that the manufacturer accurately interprets the designer's vision, minimizing the risk of misunderstandings and facilitating a more efficient production process.

Color specifications, a critical aspect of the tech pack, warrant in-depth discussions between designers and manufacturers. The precision of color codes, Pantone numbers, and RGB/CMYK references is paramount for maintaining brand consistency. Continuous dialogue during this phase aids in addressing any challenges related to color reproduction, ensuring that the final product aligns seamlessly with the intended brand aesthetic. Collaborative problem-solving between both parties is key to overcoming potential hurdles and achieving the desired color outcomes. On the other hand, construction details, encompassing stitch per inch, seam types, and thread colors, involve technical discussions that are integral to the garment's quality and durability. Engaging in open communication on construction details allows manufacturers to seek clarifications, provide insights, and make suggestions based on their expertise. This collaborative exchange not only enhances the precision of the tech pack but also fosters a partnership where both designers and manufacturers contribute to the optimization of the production process.

Trim details, specifying raw materials, shades, dimensions, and placement, require thorough discussion to ensure the availability of the correct materials and accurate execution of design elements. Regular updates and clarifications during this phase minimize the chances of errors,

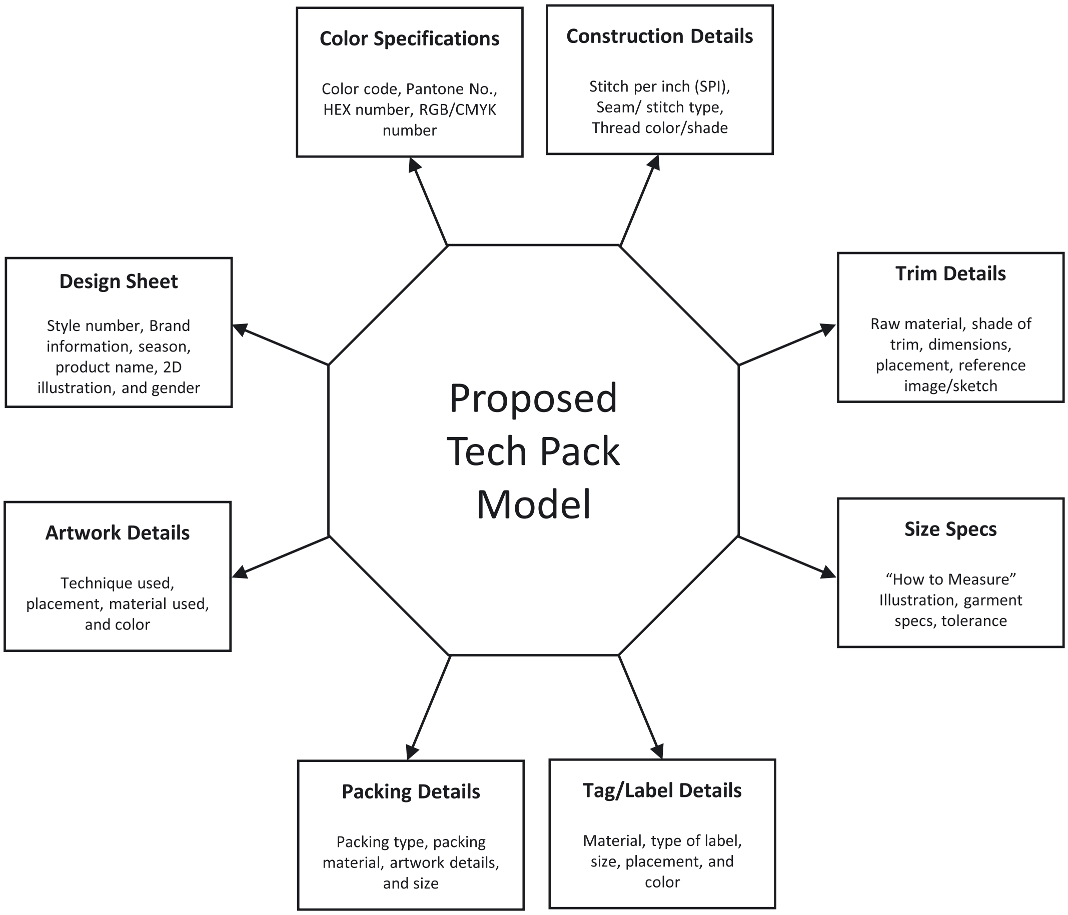

Figure 5: Proposed tech pack model.

resulting in a more streamlined production process. Whereas, the size specs, communicated through a "How to Measure" guide, demand detailed discussions to achieve consistency across sizes and minimize errors during production. Manufacturers' input on the practical aspects of size specifications can prove invaluable, and collaborative discussions help refine these details for optimal outcomes.

Implementing the proposed tech pack model is vital to enhance visibility into the intricate design aspects of producing an apparel product. This visibility facilitates effective coordination and collaboration with stakeholders, ensuring a streamlined and efficient manufacturing process. The model serves as a comprehensive guide, encompassing critical components such as technical specifications, measurements, material requirements, construction details, and any other pertinent information necessary for the successful realization of the product.

Furthermore, the proposed model helps minimize errors, ambiguities, and misinterpretations that may occur during manufacturing. It is a reliable reference point for all stakeholders, enabling them to align their efforts and ensure adherence to the specified design requirements. The proposed tech pack model promotes clarity, consistency, and accuracy throughout the apparel manufacturing supply chain by establishing a standardized framework for exchanging information. It offers a comprehensive and standardized approach to effectively communicate and document the essential details required for developing and producing apparel products. Its industrial implementation is inevitable to improve collaboration, minimize errors, and enhance overall efficiency within the industry.

5 Conclusion and future work

This study set out to understand the various elements of tech packs in apparel manufacturing and assess their relevance to ensure proper consistency and precision in product development processes. It answers the research question based on the findings from surveys and an existing tech pack analysis, where every component of the tech pack was found to be relevant and effective. The construction of tech packs has a significant impact on the execution of a tech pack and its effectiveness on product development and subsequent manipulation of the design features of the tech pack. In particular, the design sheet, color specification, fabric specification, size specification, artwork specification, tag/label specification, packing specification, trim specification are critical elements that substantially impact the product development process. All the relevant literature highlighted that while previous research studies had considered some components of tech packs, none had attempted to investigate all tech pack components together in a single study. As pointed out earlier in introduction section, such contribution by literature provides us a problem to solve and this was the essence of this research. Correspondingly, the study developed a conceptual model that describes the relations among all tech pack components and illustrates their interactions and benefits within the apparel sector in question.

Although this study effectively confirms a uniform conceptual model for tech pack development, future research should consider several limitations. First, the study's conclusions may not be as applicable to other international markets with distinct operational frameworks and regulatory needs because it was carried out using data from Pakistani clothing companies. Additionally, although the sample included respondents from diverse organizational roles and multiple apparel sectors, the study did not conduct a comparative analysis across company sizes or between domestic and export-oriented units. Another limitation lies in the scope of analysis; this study focused on measurement validation using Confirmatory Factor Analysis (CFA) and did not extend to structural modeling of relationships among tech pack components and broader performance outcomes. Subsequent studies should employ full SEM techniques to investigate how standardized tech pack practices impact production efficiency, cost optimization, and customer satisfaction. Finally, although this research highlights the need for digital integration, no formal feasibility study was undertaken to develop an intuitive tech pack application. Addressing these areas will extend the practical and theoretical contributions of this research and strengthen its application across global apparel supply chains.

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