A Systematic Review of Green Apparel Manufacturing

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The purpose of this paper is to conduct a systematic review of the literature on green manufacturing practices in the apparel industry to map green practices across various apparel manufacturing departments. The review includes academic journal articles that were retrieved between March 2013 and March 2023 from several different databases. As part of a comprehensive literature assessment, content analysis was applied to 138 publications that were published in peer-reviewed journals over ten years. Green practices in garment manufacturing process are covered, including product design, raw material procurement, fabric spreading, cutting, sewing and assembly, washing, printing and embroidery, finishing, and packing. The review of eco-friendly production practices at each phase of the production process shows the variety and complexity of green practices in apparel production companies. However, there is a lack of research on the conditions of developing countries, where the majority of apparel production takes place, as well as on the methods used in the manufacture of garments. The study is distinct in that it focuses solely on the garment manufacturing industry, and will not include textiles because the production processes for textiles and clothing are fundamentally different. This study assists managers in building a company's sustainability competency by outlining best practices at various phases of production. It also provides scholars with a uniform representation of environmentally sustainable practices to spur additional scholarly investigation.

Keywords: e-supply chain management, green practices, sustainable, cutting department and sewing department.

Introduction

The fashion industry's supply chain is intricate and plagued by numerous social (Stotz and Kane, 2015) and environmental problems, which include considerable emissions, excessive energy, and water use, and widespread contamination. India, the second-largest producer of textiles and apparel in the world, employs 45 million people and contributes 13% of industrial production, 2.3% of GDP, and 12% of exports (IBEF, 2022). However, the fashion sector contributes 10% of the world's carbon emissions and is the second most polluting business behind the oil sector in terms of environmental damage (Muthukumarana et al., 2018). Mul-

tiple operations, including sewing, embroidery, printing, washing, finishing, and packing, have a significant negative influence on the environment (Resta et al., 2016). Implementing sustainable practices can provide businesses with an edge over their competitors (Li et al., 2016), manage resource shortages (Desore and Narula, 2018), and assist the long-term growth of textile and apparel companies (Todeschini et al., 2017).

Given their worldwide worth, consumption, and relevance, garment manufacturers have an increased need as well as urgency to adopt sustainable practices (Abdul-Rashid et al., 2017). Yet, a lot of those involved in the apparel manufacturing process are unaware of the extent to which the ecosystem is affected by the various phases of the product life cycle (Khan and Islam, 2013). Even though many studies have significantly advanced in Sustainable Development in the Textile and Apparel Industry (SDTAI), they do not offer a comprehensive or systematic perspective as they focus primarily on the textile and apparel industry combined. The textile and apparel industry is very different from each other. Mostly the company's manufacturing textiles do not produce apparel and vice versa, as the setup required is completely different for both, unless and until it is a vertically integrated unit. There is a substantial environmental effect, and there is a need for extensive studies on comprehensive literature in the apparel manufacturing sector. Therefore, it is important and relevant from both an academic and practical standpoint to conduct a systematic and thorough evaluation of the academic literature on sustainable production techniques in the apparel industry. Additionally, this study would assist many Indian garment manufacturing companies in discovering green apparel production techniques.

The following are the objectives driven by important literature study and analysis:

1 to determine, via content analysis, the extent and scope of academic research on green practices in the garment manufacturing sector;

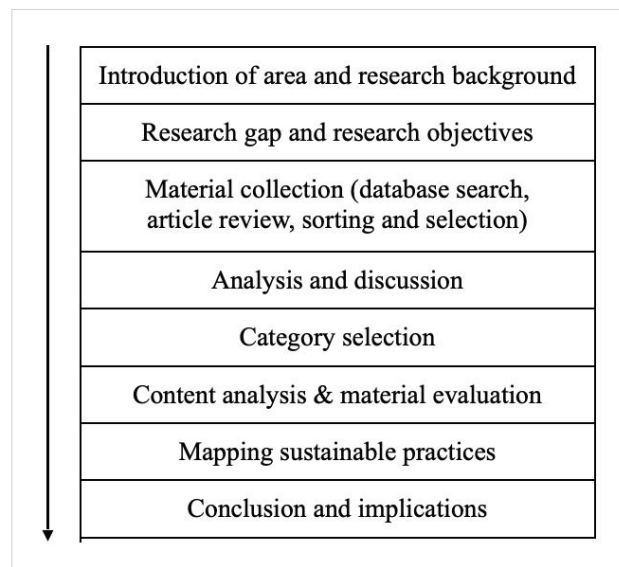2 to map the green practices used in the garment industry department-wise.

The rest of the paper is divided into the following sections. The methodology is initially presented, followed by a comprehensive mapping of practices derived from a meticulous content study of the existing literature. In conclusion, this section provides a concise overview of the study's implications, limitations, and potential avenues for further research.

Methods

A type of secondary study known as systematic literature review and analysis (Koberg and Longoni, 2019) involves finding, analyzing, and interpreting research that is pertinent to a certain topic or phenomenon of interest. According to Denyer and Tranfield (2006) and Karaosman et al. (2016), the essential components of the process include planning, carrying out the review, analyzing the results, and reporting them. *Fig. 1* shows an overview of the systematic review's approach.

Before starting to collect information and resources, the research first examined and established the article inclusion and exclusion criteria. The choice of March 2013 to March 2023 as the study's timeframe was supported by the substantial volume of scholarly material on the subject that was published during this period. Peer review assures a particular standard of quality, and academic journal articles offer rich data with a variety of themes suitable for attaining the study goals. Aside from that, the literature was chosen from journal papers written in English. The articles were found by searching for terms like "fashion", "apparel", "garment", and "clothing", among others. To assure a comprehensive coverage of pertinent articles for inclusion, logical operators (such as OR, AND), wildcards (such as *), and synonyms of terms were utilized. Each entry in a bibliography includes a list of authors, a title, an abstract, keywords, and references. The initial author's name, publication year, origin type, volume number, and DOI reference

Fig. 1. *Overview of research methodology*

| Introduction of area and research background |
| Research gap and research objectives |
| Material collection (database search, article review, sorting and selection) |
| Analysis and discussion |
| Category selection |
| Content analysis & material evaluation |
| Mapping sustainable practices |
| Conclusion and implications |

are all included in each reference. The search produced published papers based on the aforementioned retrieval criteria from Scopus, Web of Science, Science Direct, MDPI, Emerald Insight, and Springer Link, yielding a preliminary sample of 10 225 articles. Garment/apparel/clothing was searched in the title to focus the study, and 338 results were found. Following the additional screening, the study's selection was made up of 212 peer-reviewed complete texts that were published in scholarly journals in English over the previous ten years.

The publications were then extensively evaluated by Denyer and Tranfield's (2006) criteria (replicable, exclusive, aggregative and algorithmic) to determine the conformity with the study's scope after carefully reading their titles and abstracts. Previous studies in the field (Barnett and Thomas, 2009; Yang et al., 2017) served as a guide for evaluating internal validity. The inclusion and exclusion criteria for the publication were carefully reviewed by the authors and other peer researchers to settle any differences of opinion, improve possible significance and quality, eliminate bias, and guarantee intercoder reliability. Based on adequate reasoning and acceptable arguments (such as not within the purview of the study, falling short of established quality standards, not relevant to the garment sectors, and not completely accessible), duplicates and irrelevant articles were removed. Following this procedure, 138 highly pertinent papers were ultimately chosen for examination. Selected articles were saved in the Mendeley reference management program to simplify data management. For data extraction and sorting, references from previous literature reviews (Islam et al., 2021; Wu et al., 2022) were used as a reference model. Following a comprehensive examination of sustainable practices employed within the garment manufacturing business and a thorough analysis of relevant cases, a systematic categorization of sustainable practices was conducted. This categorization was based on various stages involved in clothing manufacture, including inspection, spreading and cutting, assembly, washing, and packing.

Results and Discussion

Cay (2018) asserts that the implementation of environmentally conscious or sustainable manufacturing methods is crucial for achieving sustainable production. The prevalence of green production in the fashion sector has increased, as indicated by previous research findings. Several studies have conducted a comprehensive evaluation of the relevant scholarly literature pertaining to green or sustainable manufacturing (*Table1*).

Structural dimension and analysis

The structural dimensions were discovered to examine the subject and potential avenues for further research. Subsequently, analytical categories were employed to further classify the constituents inside each dimension.

Distribution and evolution of papers. *Fig. 2* displays the results of the examination of articles' distributions and publications between March 2013 and March 2023. As academic knowledge and interest in the subject have grown, there has been a gradual increase in research on the sustainability in the clothing manufacturing industry from 2013 to 2016 and an acceleration from 2017. Since there are still many unanswered research questions, a continued growing research trend may be projected.

Table 1. *Literature review on textile and apparel industry*

Author	Area of Review
Luo et al. (2021)	Strategies used to measure environmental sustainability in the textile and apparel industry (TAI) and highlights of the limitations associated with these approaches.
Islam et al. (2021)	A variety of TAI manufacturing processes use environmentally friendly production techniques, and they developed a conceptual framework to provide sustainable practice guidelines.
Mukendi et al. (2020)	The management methods employed in the context of sustainable fashion and the societal ramifications associated with these approaches. Additionally, potential areas for further research are identified.
Jia et al. (2020)	The drivers, challenges, practices, and indicators pertaining to the implementation of a circular economy in the TAI.
Thorisdottir and Johannsdottir (2020)	Effect of corporate social responsibility (CSR) on the industry of sustainable fashion.
Koberg and Longoni (2019)	The study employs a systematic review methodology to examine existing literature related to sustainable SCM practices.
Tey et al. (2018)	The key drivers that influence consumers' inclination to spend a higher price for sustainable clothing products.
Koksal et al. (2017)	Social sustainable SCM in TAI – a literature review.

Area of research. The distribution of papers across several area of research, such as drivers/barriers, carbon emissions, circular manufacturing, textile and clothing, green design and innovation, sewing, apparel green supply chain management (GSCM), green manufacturing and literature reviews is shown in *Fig. 3*. Some articles covered both garments and textiles, perhaps unsurprisingly, as the field stands out for having the most publications with articles focusing on integrated textile and apparel research.

Research journals. Fig. 4 displays the division of articles demonstrating the contribution of prestigious journals to the subject between March 2013 and March 2023.

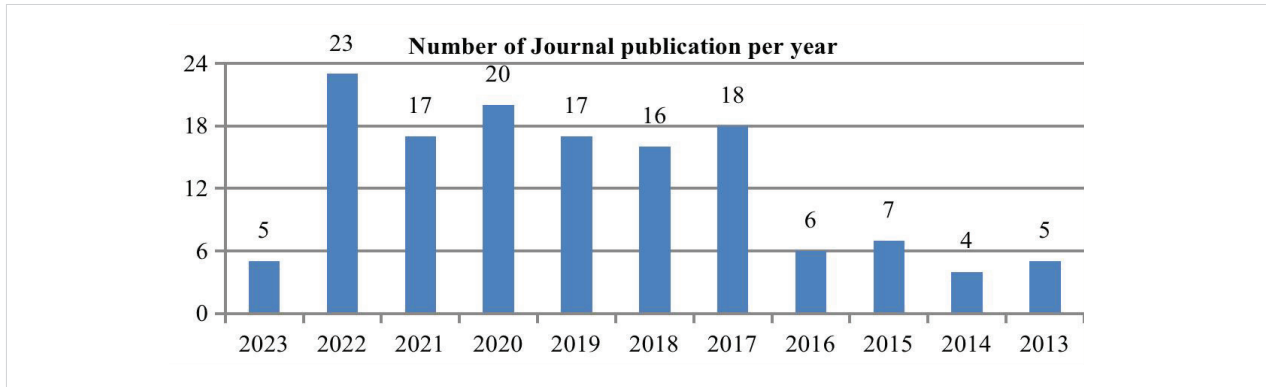**Fig. 2.** *Number of journal publications in a year on green apparel manufacturing*

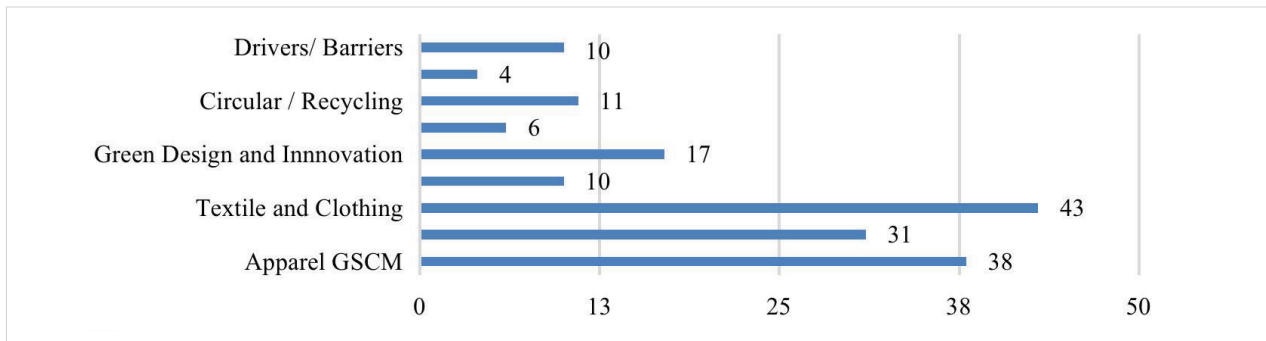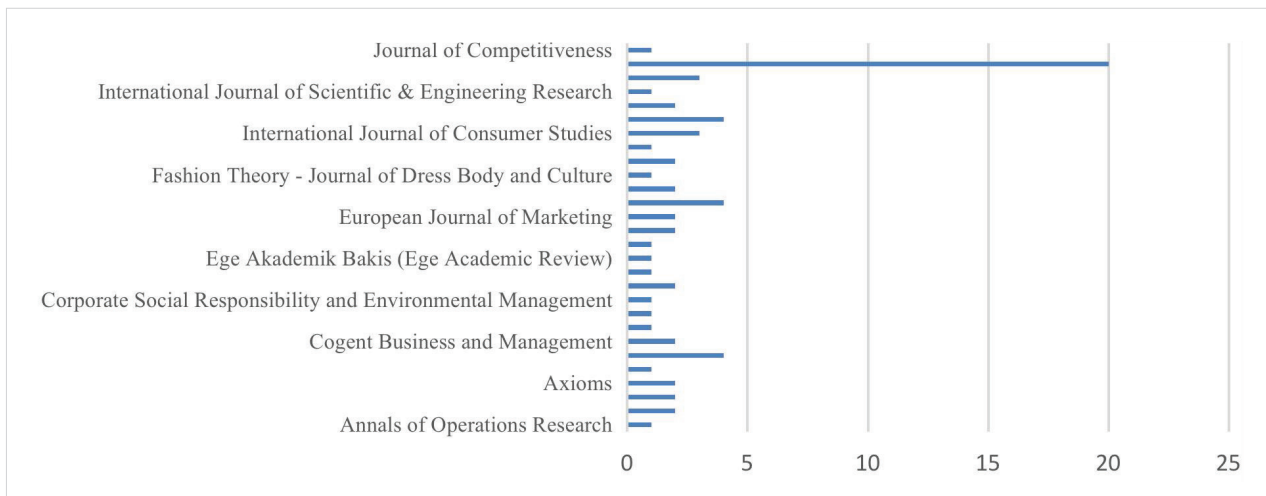**Fig. 3.** *Number of paper publications in journals in research areas*

Fig. 4. *Number of paper publications in journals on green apparel manufacturing*

Green practices across specific manufacturing processes. Later, several publications were examined in terms of the various production procedures involved in environmentally friendly apparel or garment manufacture. It was concluded that ensuring green at every level of the clothing manufacturing process is crucial for environmentally friendly production. Niinimaki et al. (2020) assert that the manufacturing of garments leads to the generation of considerable quantities of pre-consumer textile waste, accounting for less than 10% to 30% of the total waste. This waste is influenced by various factors, such as the kind of garment, fabric, design, pattern placement, and assembly. In the study of fabric waste in the Bangladesh knit manufacturing sector, Rahman and Haque (2016) studied knit T-shirt types with production steps, such as cutting, panel checking, sewing, and finishing. It was found that, on average, more than 26.5% of waste is produced at various phases, with 13.57% of the waste being unavoidable in the cutting area, 6.91% in the panel checking, 4.31% in the sewing section, and 1.72% in the finishing part. Green practices in the garment manufacturing process are covered, including product design, raw material procurement, fabric spreading, cutting, sewing and assembly, washing, printing and embroidery, finishing, and packing (*Fig. 5*).

Product design. The implementation of green manufacturing in the garment industry depends on designers (Kozlowski et al., 2019). When creating goods with a smaller impact on the environment in mind, designers can consider a variety of techniques, strategies materials, creative processes, and methodologies. The slow fashion, longevity design (Connor-Crabb et al., 2016), cradle-to-cradle design (Michel and Lee, 2017), and upgrade recycling and remanufacturing design (Han et al., 2017) are some strategies that have been suggested for designers to use to achieve sustainability. Innovations in products and processes have been created to produce better manufacturing methods that reduce harmful environmental consequences. Karell and Niinimaki (2020) showed that while designers do prioritize lifespan and material choice in their sustainable practices, their effect on decision-making is minimal in comparison with other elements like corporate strategy and employee mentality. Furthermore, designers exhibit a lack of awareness of industry norms pertaining to materials, recycling protocols, and optimal methodologies. According to study (Cimatti et al., 2017; Kozlowski et al., 2018), partnerships between RandD teams, designers, material suppliers, marketing departments, distributors, and recyclers are important for eco-design to reduce environmental consequences across the stages of a product's life cycle. Researchers are required to guarantee that advances in product or process design are both financially and environmentally viable (Bertola and Teunissen, 2018). The organization benefits from research and development of new goods, product differentiation, quality, and procedures, which enhance market positioning and raise the firm's worth (Shim et al., 2016).

Raw material sourcing. One of the numerous ways that designers can have a big influence on how clothing is produced, used, and disposed of is through the choice of materials, the use of energy and water, manufacturing techniques, and consumer purchases, use and recycling of the garments (Kozlowski et al., 2019). Guo et al. (2017) discusses the assessment and selection of green suppliers using a fuzzy multi-criteria decision-making (MCDM) framework and the triple-bottom-line approach. Research also recommends that Western fashion firms work with suppliers to improve environmentally friendly practices and lessen their ecological impact (Koksal et al., 2017). Businesses like Levi Strauss and Evrnu create their goods while taking into account environmental sustainability principles, employing certified and recycled materials, and doing life cycle assessments.

Fabric spreading and cutting. Rahman and Haque (2016) have conducted a study on fabric waste in the knitted garment production industry in Bangladesh. Their findings revealed that waste generation occurred at many stages, with around 26.5% of trash being produced overall. Specifically, 13.6% of waste was attributed to the cutting phase, while 6.9% was associated with checking panels. They also proposed that waste may be effectively managed by utilizing computer aided design / computer aided manufacturing (CAD/CAM) technology, automating the process, highly trained workers, and careful management. According to Bizuneh and Tadesse (2022), fabric accounts for an average of 28.55% of cut-and-sew waste. Zero waste patterning provides a solution that guarantees that there are no remaining scraps after the garment is done by using the entire yardage of fabric (Carrico and Kim, 2014). Research by McQuillan (2019) studies ways to reduce textile waste by applying zero-waste pattern cutting to increase the results that may be achieved through composite garment weaving. The core of the product development process is sampling, where there is potential to lessen environmental impact, which might result in competitive advantages

Fig. 5. *Mapping sustainable practices in garment manufacturing*
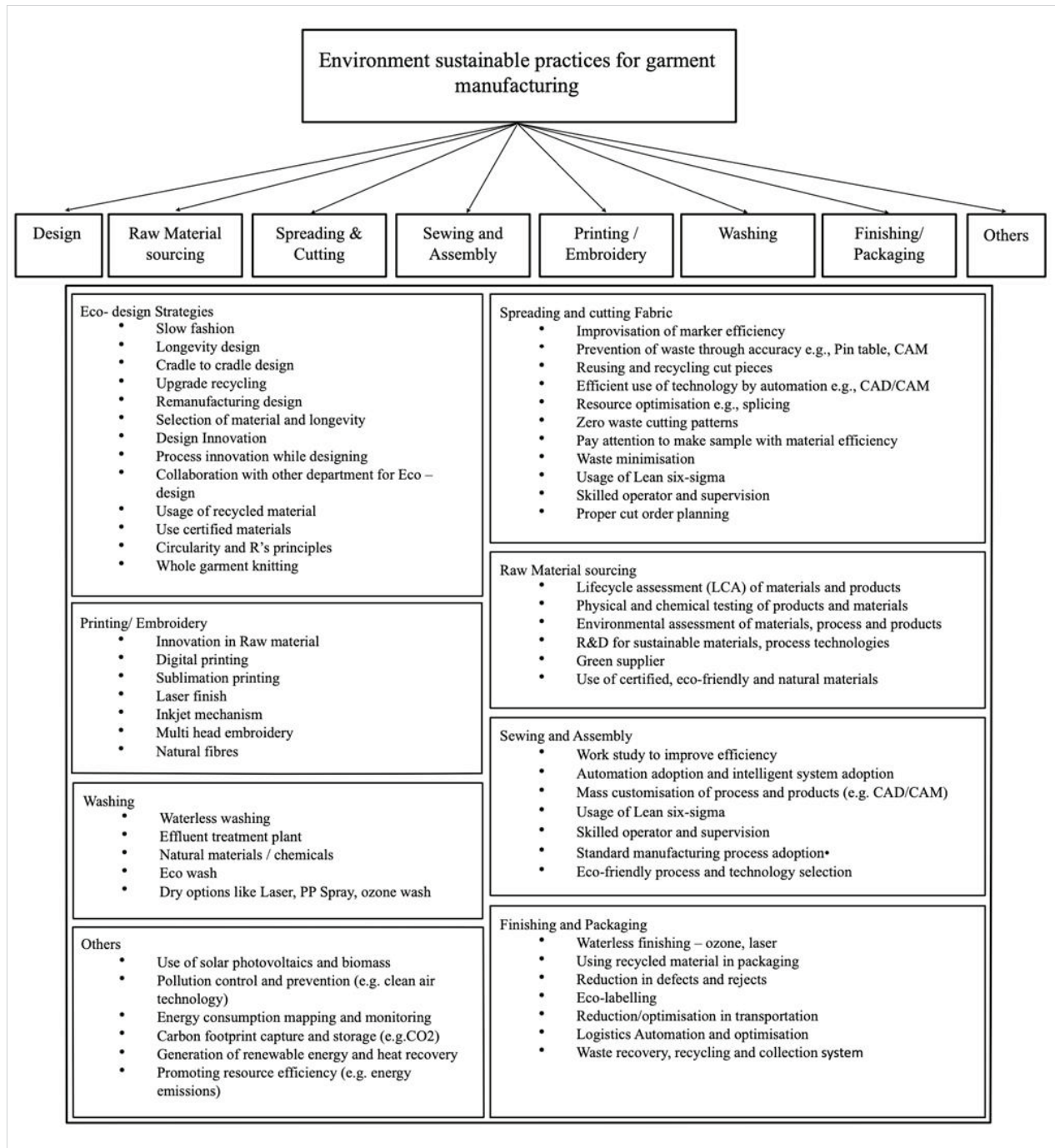
if handled efficiently through the optimum utilization of technology and management (Grieco et al., 2017). However, the majority of clothing manufacturers give samples less consideration, which raises prices during mass production, uses more material, and creates waste (Todeschini et al., 2017).

Sewing and assembly. According to Barbary (2018), "green manufacturing" may be brought into a sewing room in medium garment factories by using Lean Six Sigma and reevaluating the work of the phases that precede the production process. According to Bertola and Teunissen (2018), the Industry 4.0 paradigm has

resulted in the development of several technologies and management strategies that have the potential to transform production processes and enable a smart factory. Khedher and Jaouachi (2015) make contributions by simulating sewing thread consumption while wearing traditional denim trousers. Islam et al. (2013) have evaluated how technology and lean manufacturing methods were applied in the apparel sector to discover that these methods had advantages over competitors in the areas of efficiency, accuracy, material improvement, and minimizing waste. According to Cay (2018), the use of environmentally friendly industrial practices is important in order to achieve sustainable production. In order to meet production requirements, organizations must use ecologically sustainable manufacturing practices, incorporating effective utilization of energy, water, and raw materials (Glavic et al., 2007). Many garment factories worldwide have created and effectively adopted green manufacturing techniques to address the aforementioned issues in apparel manufacturing.

Printing and embroidery. Complex operations, such as industrial printing and embroidery, waste resources, necessitate breakthroughs in raw material and production technology. Vanderploeg et al. (2017) have investigated that even though screen printing is frequently utilized, other green methods like digital printing technology or sublimation printing possess multiple benefits over screen printing, which include intensified design, decreased lead time and expenses, minimal waste, green procedures and chemical recycling, decreased consumption of water and transport. Digital textile printing, which uses laser or inkjet printing equipment, has the potential to create low-cost personalized patterns, whereas CAD technology is becoming popular due to its sustainable printing procedure and ability to produce less waste than conventional printing techniques (Nayak et al., 2015).

Washing. The procedure of cleaning clothing uses both sustainable electricity and a laser water washing apparatus (Luan, 2022). According to the study, treating denim fabrics using ozone particles reduces the processing time for clothing and uses less water and chemicals than traditional finishing techniques. Ozone-based finishing also generates a negligible quantity of effluent due to the low chemical and water usage, making it less harmful to the environment and the effluent treatment plant (ETP) than conventional denim washing (Sarker, 2021). A few environmentally friendly dry-cleaning techniques for clothing include whiskering, hand-sanding, grinding, and

destruct effects. Contrarily, several wet processes (such as enzyme washing, ultra white washing, bleach washing, acid washing, acid-stone washing, enzyme-stone washing, and stone washing) use a very little quantity of harmful colors and chemicals (Hasan et al., 2021). When using green chemicals, enzyme, bleach, and acid wash chemical concentrations provide environmental impact measurement (EIM) results that are less than 80% of those obtained when using conventional chemicals. We discover alternate methods, such as the ozone process, which shortens the time required for enzyme washing and de-sizing. It produces a result akin to a bleach wash. Ozone is used in place of bleach wash when immediate enzyme action is required (Islam, 2021).

Finishing and packaging. The process poses a significant environmental burden throughout the whole production process due to the usage of toxic chemicals and the development of waste (Khan and Islam, 2015; Joyner Armstrong and Park, 2017). Green practices in the packaging industry have become increasingly dependent on factors like reducing waste, sustainable goods and production of technological equipment, green labelling, energy efficiency, and green chemicals, due to growing global trade and e-commerce (Meherishi et al., 2019). The ecological footprints have been calculated by Janaina et al. (2020) using the labelled fiber proportions and pertinent sustainability remarks. The authors also suggested a labelling system that would include the ecological footprint as a tool for environmental management, to sway consumer choices and so inspire manufacturers to create more environmentally friendly products.

Other. Carbon emissions are produced by the fashion industry's extensive material and garment transportation. According to Shen (2014), HandM acknowledged that its transport operations were responsible for 51% of the company's carbon footprint. Reduced product quantities via ocean and air shipments were the consequence of the company's utilization of full-load capacity, automated logistics operations, and more direct shipments to minimize intermediate storage. Using life cycle assessment (LCA), Muthukumarana et al. (2018) established a framework to measure the green implications of energy usage in the Sri Lankan textile and apparel industry. Even though the research excluded all of the downstream and upstream manufacturing processes, biomass and solar photovoltaics were recommended as other forms of energy. Alternative low-carbon raw materials, renewable grid energy blends, and significant consumption re-

ductions can all be used to bring about radical changes (Muna singh et al., 2016). Gunathilaka and Gunewardena (2014) have investigated how the CO_2 emissions from Sri Lanka's garment manufacturing sector affected global warming. According to Patnaik and Tshifularo (2021), end-of-life clothing and waste generated during garment manufacturing are two reasons why the apparel sector contributes to climate change. Reusing and recycling materials can be utilized to create new materials, lowering the pollution generated by clothing. To reduce wastewater output and improve the usage of renewable energy, several researchers have concentrated on rethinking contamination and waste management systems.

Conclusions

Due to the wide range of topics covered in each section, the study of sustainable manufacturing practices is a complicated field of study. The research illustrates how sustainable practices are applied in several departments that make up the garment manufacturing units, including the design department, inspection, spreading and cutting, assembly, printing embroidery, washing, finishing, and packing. For business professionals to effectively mix functional, organizational, recurrent, and preventive green practices without dividing money invested unevenly, mapping green practices based on operational aspects is helpful. By highlighting innovative routes that are comparatively untapped, the mapping might aid academics in their investigation of ecologically friendly practices in fashion businesses. To improve sustainable competency and accomplish desired outcomes, one must consider the complete spectrum of skills, not just one or two. The implementation of environmentally sustainable practices in the garment manufacturing sector has inherent challenges and requires the active participation of manufacturers, purchasing departments, and many stakeholders at multiple levels. Throughout the phases of operations and the life cycle, these activities must be proactive and well-planned. The study findings highlight the green manufacturing practices that the readymade garment (RMG) sector may embrace across departments, providing informative data on the industry's environmental impact. Additionally, pertinent research data need to be updated often, and future studies might further strengthen the apparel manufacturing knowledge roadmap as investigated concepts and uses within the realm of clothing manufacturing expand and advance.

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