Designers' potential in sustainable fashion: a systematic literature review

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ABSTRACT – REZUMAT

Designers' potential in sustainable fashion: a systematic literature review

Given the unsustainable issues of environmental pollution, resource waste, and industrial cycle blockage, the garment industry, has sought an innovation for sustainable development led by the linear economy. The circular economy (CE) advocates closing and correcting material and energy circuits, minimising resource entry and waste, and improving emissions and energy consumption. Most practices under the existing CE model address the outcome rather than comprehending the source. As one of the most critical players in the apparel industry, designers understand the source of product development. In this paper, existing sustainable design practices (SDPs) in the transition of the apparel industry to CE were summarised through a systematic literature review. The extent of designers' involvement in CE was explored through a correlation study and data analysis between SDPs and the processes of product development (PDP) and production process (PP). Furthermore, the designers' potential to contribute sustainably to the CE transformation within the apparel industry was discussed via qualitative analysis. The findings demonstrated infrequent involvement in PP by designers, whose voices were limited in the apparel industry, and that the possibility of more designer involvement in SDP. Therefore, this research only focused on the sustainability potential of designer-led PDPs. Lastly, the potential and limitations of applying PDP three-dimensional visualisation as a designer-led SDP were presented.

Keywords: *designer, circular economy, sustainability, sustainable design practice, product development process*

Potențialul designerilor în moda sustenabilă: un studiu sistematic al literaturii

Având în vedere problemele nesustenabile ale poluării mediului, ale deșeurilor de resurse și ale blocajului ciclului industrial, industria de îmbrăcăminte a căutat o inovație pentru dezvoltarea sustenabilă condusă de economia liniară. Economia circulară (CE) pledează pentru închiderea și corectarea circuitelor de materiale și energie, minimizarea intrării de resurse și a deșeurilor și îmbunătățirea emisiilor și a consumului de energie. Majoritatea practicilor din cadrul modelului CE existent abordează rezultatul, mai degrabă decât să înțeleagă sursa. Fiind unul dintre cei mai importanţi jucători din industria de îmbrăcăminte, designerii înțeleg sursa dezvoltării produsului. În această lucrare, practicile de design sustenabil (SDP) existente în tranziția industriei de îmbrăcăminte la CE au fost rezumate printr-un studiu sistematic al literaturii. Amploarea implicării designerilor în CE a fost explorată printr-un studiu de corelare și analiză a datelor între SDP-uri și procesele de dezvoltare a produsului (PDP) și procesul de producție (PP). În plus, potențialul designerilor de a contribui în mod sustenabil la transformarea CE în cadrul industriei de îmbrăcăminte a fost discutat prin analiză calitativă. Studiile au demonstrat implicarea rară în PP a designerilor, ale căror voci erau limitate în industria de îmbrăcăminte și posibilitatea unei mai mari implicări a designerilor în SDP. Prin urmare, acest studiu s-a concentrat doar pe potențialul de sustenabilitate al PDP-urilor conduse de designeri. În cele din urmă, au fost prezentate potențialul și limitările aplicării vizualizării tridimensionale PDP, ca SDP-uri conduse de designeri.

Cuvinte-cheie*: designer, economie circulară, sustenabilitate, practică de design sustenabil, proces de dezvoltare a produsului*

INTRODUCTION

The fashion industry is one of the leading international economy sectors, where global transactions amounted to $45 billion in 2016 [1]. As the fashion industry employs more than 300 million people worldwide, it is a significant economic force and a critical driver of global gross domestic product (GDP) [2]. Nevertheless, the fashion industry is the second largest polluter globally with a carbon footprint that exceeds that of all maritime transport and international flights combined [3]. Worldwide, the fashion industry generates approximately 40 million tons of textile waste annually most is sent to landfills or incinerated [4]. Dozens of trends that change products between seasons yearly drive the fashion industry [5], specifically fast fashion. With economic globalisation, the textile and apparel industry can compare the value of raw materials and labour globally and identify the most convenient and profitable channel to grow [6]. Naturally, there are hidden costs behind the high turnover and profitability, such as the unsatisfactory quality of low-priced products. Additionally, the fast-changing fashion styles conceal thousands of overstocked products. Fast fashion popularity also leads to unhealthy use habits [7] and short product lifespan [8].

The World Commission on Environment and Development (WCED) introduced the sustainable development concept in 1987. Sustainable development refers to "the ability to meet the needs of the

present without compromising the needs of future generations" [9]. The goal of sustainability is open, unrestricted, and acting on the environment, economy, and society as a whole [10]. 'Closed-loop recycling' refers to an early sustainability initiative to recycle resources and avoid waste and pollution. Closed-loop recycling is positive but its environmental benefits cannot offset the ecological damage caused by the fashion industry. In an ideal recycling system, recycled textile materials should generate added value rather than increase the energy burden and create secondary waste.

Sustainability has become a critical driver of the future of the fashion industry [2]. In the sustainable fashion brand Stella McCartney, every brand department and aspect is required to focus on sustainability thinking. Sustainability thinking enables brands to achieve the environmental milestones of 2030 (halving carbon emissions) and 2050 (zero emissions) [4]. Thus, sustainability is no longer an option but a path that must be developed, leading fashion brands to consider ethical and social responsibility in their value systems.

The apparel industry has been dominated by the linear economy where linear resources and products flow in one direction to waste [11]. Contrastingly, a circular economy (CE) is a closed material flow loop in a financial system [12] that aims to dissociate economic growth from resource consumption while maintaining the highest value for product components and resource use [13, 14]. The CE seeks to reduce waste generation while increasing resource utilisation, which indicates it is a sustainable development model [15]. The shift in the apparel industry's economic model towards a CE is not a trend but a requirement of market, economic, social, and ecological factors. The CE model prioritises sustainability [16] and advocates maximising the product cycle as a key strategy to extend product sustainability [17]. In the ideal CE, production and energy resources form a closed loop, which enables "using waste as production" [18]. The involvement of all stakeholders in sustainable innovation can lead to a valid CE.

The CE reverses waste use as an essential and sustainable resource [19] where waste generated at various production stages is technologically redistributed and reused [20]. Examples of waste redistribution and reuse include zero-waste practices, second-hand shops, upcycling, chemical recycling [3], collaborative fashion, slow fashion [21], trash fashion [22], and open-resource fashion [23]. For example, zero waste aims to reduce fashion industry resource waste, where raw material waste and pollution are reduced by developing and experimenting with more efficient production processes [14]. Slow fashion refers to slowing product development and production and engaging in small-volume, slow clothing production using local infrastructure, resources, and traditional craftsmanship [24]. Supply chain streamlining is predominantly established locally [18], which encourages local businesses to commit to sustainability through a collaborative sharing approach and collaborating to build local CE models that support green ecology, drive resource- and knowledge-sharing, and promote sustainable diffusion [14]. Reuse (recycling) re-energises production waste, excess products, and waste of various origins (production process residues and technical residues from physical and chemical recycling) through chemical and physical recycling. Long-life design [25] and second-hand fashion both aim to extend product life and increase durability [26]. As an open and shared design philosophy, the open-source design emphasises knowledge-, skill-, and resource-sharing, which renders the industry chain transparent [21] and encourages consumer participation and self-design. Subsequently, the open-source design creates an emotional bond between the product and the consumer and introduces emotional value to the product, thus extending its lifespan.

The CE pioneers developed many sustainable design practices (SDPs), most of which were strategically proposed from the top down by business owners or companies. Eco-entrepreneurs who advocate sustainability from a designer's perspective proposed some practices [27]. Each aforementioned SDP exhibits distinctive characteristics that reflect sustainable approaches to transform the CE from different perspectives. These SDPs consider CE and sustainability based on material use, refined production, post-consumer recycling, and the emotional value of the product.

The study has two recursively related objectives: to (i) study designers' involvement in existing SDPs during the apparel industry transition to a CE and (ii) explore specific directions for designers to create sustainable contributions between the product development process (PDP) and production process (PP). Sustainable garment industry development cannot achieve a valid CE by relying solely on a material revolution and addressing waste. Previous scholars have demonstrated the theoretical possibility of a single-perspective SDP. Nonetheless, some SDPs involve many additional resources and energy exchange in practical application. Designers have little influence on aspects beyond the PDP and PP, such as supply chain and marketing activities [28]. Furthermore, PDP and PP sustainability in the fashion industry should be considered; therefore, deconstructing them from a designer's perspective is vital.

The CE transformation and sustainable development of the fashion industry is a wide-ranging circular system that requires the participation of the whole chain, mutual assistance and collaboration, and completion. The linear development mindset should be abolished to challenge the traditional industrial structure. The traditional linear PDPs and PPs should be separated and the innovation of each link should be discussed individually. In this research, designers' organisational functions and obligations were thoroughly examined. The dissection of various PDP and PP segments aided the examination of traditional industrial process limitations and the discovery of designers' sustainability potential and each link.

RESEARCH DESIGN

The first research layer involved a systematic literature review (SLR). The SLR aids in the identification of the academic literature appropriate to a particular research area and the critical evaluation of the topic. The SLR was used to summarise the SDPs that have emerged in the CE-led apparel industry, deconstruct PDPs and PPs, and discuss the relationship between designers and the PDP and PP aspects. In the first layer, the phenomena presented by the data were discussed using qualitative analysis; subsequently, the second layer was built on the findings. Designers' potential to contribute sustainably to SDPs from the PDP and PP perspectives and specific strategies for designers to engage with SDPs were explored.

Before the articles were read and filtered out, research questions were established for the two research directions (SDP and PDP plus PP). The questions were based on the research objectives to aid the discovery of the objectives in a logical and targeted manner and to improve the literature reading efficiency. The SDP questions are as follows:

1. Who are the proposers of the existing SDPs?
2. What are the specific forms and limitations of these SDPs?
3. Can these SDPs be categorised among themselves at a strategic level?

The PDP and PP questions are as follows:

1. How many processes are included in traditional PDP and PP?
2. Does the PDP in the industry differ based on the business direction?

1. Which individual steps in the PDP and PP are relevant to designers?

Figure 1 depicts the flow chart of the SLR. The first layer targeted three critical areas: SDP, PDP, and PP. An initial literature search was conducted using the keywords (figure 1), which retrieved 91 SDP-related articles and 329 articles related to PDP and PP. Inclusion and exclusion criteria were established to limit the study scope and increase precision and efficiency, which included the aspects of language, publication year, article type, and the relevance of the article level, title, and abstract. The study focused only on English-language literature with the publication date limited to within the last 10 years. The article type mainly entailed review papers while journals and article level were limited to Science Citation Index (SCI) journals and PhD theses, respectively. The articles that were weakly relevant to the study were screened out based on the titles and abstract contents. Finally, 32 SDP articles and 26 PDP and PP articles were included in the analysis.

Snowball research was conducted during the literature reading by expanding the references of articles with greater relevance. Eleven articles in addition to the initial 32 were selected in the SDP direction and six articles in addition to the initial 26 were selected in the PDP and PP direction. The final part of the SLR involved analysing and filtering helpful information from the 75 publications screened. Subsequently, the articles were thoroughly read and analysed to address the research questions. The typical SDP forms were summarised, the essential PDP and PP components were listed, and the results were analysed.

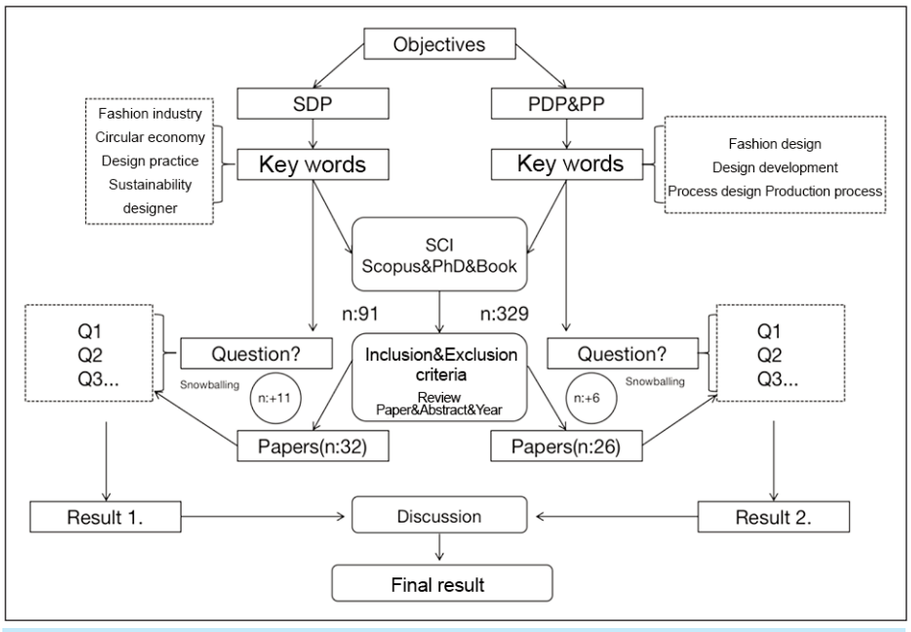

Fig. 1. The SLR flow chart

RESULTS AND DISCUSSION

Elaboration and discussion of SLR results

In this section, the SLR findings are presented, the specific SDP types are summarised, and the strategies and limitations of the proposed SDPs are discussed. The PDP and PP are listed in this section and designers' relevance at each step is discussed. The 17 types of SDPs currently applied in the fashion industry under the CE were summarised based on the literature research (see figure 2). The 17 SDPs are related to four fashion industry segments: product development, production, supply chain, and marketing services (figure 2).

Longevity design [25] and open-source design are ostensibly product development initiatives by a company or business owner and not designers, who are only one of the necessary participants in both initiatives. 'Longevity design' is an overarching term for other sustainable practices [29], which include high-quality design, design for permanence, functional design [18], and modular design [30]. The SDPs in

Serial Number	Sustainable Design Practices
SDP1	Zero Waste
SDP2	Slow Fashion
SDP3	Sustainable Materials
SDP4	Recycle
SDP5	Streamlining Supply Chains
SDP6	Second-hand Fashion
SDP7	Trade-in
SDP8	Rental Services
SDP9	Restoration
SDP10	Longevity Design
SDP11	Quality Design
SDP12	Timeless Design
SDP13	Functional Design
SDP14	Modular Design
SDP15	Open Source Design
SDP16	Collaborative Design
SDP17	Halfway Product Design

Fig. 2. List of typical SDPs in recent years

longevity design aim to extend product life and increase emotional permanence between the product and the consumer [26]. Traditional design concepts that challenge changing fashion aesthetics influence longevity strategies [31]. High-quality design is a designer-proposed sustainable design tool based on garment durability and aesthetic longevity [25]. Designers believe that high-quality design products could lead to consumers viewing their purchase as an investment and even result in a legacy for the product [18]. The difference between timeless and high-quality design is that timeless-design products should be free of season and trend constraints [25]. Therefore, instead of following seasons and trends, the PDP develops a timeless series contemporaneously and places more initiative into supply chain and production optimisation. Nevertheless, timeless design ignores an apparel product function: bringing emotional value to the consumer. Designs that eschew trends and seasons are limited and fail to meet consumers' fashion expectations and demands [32]. Functional design refers to products designed with more inclusive construction. For example, sizes can be added, removed, or adapted to a broader range of seasons. Modular design is a means of extending product life via disassembly into individual groups that can be freely combined to render the product more pleasing to use. While modular design may be feasible for accessories, such as shoes, bags, and jewellery, modular clothing structure is complex.

Open-source design encourages consumer participation in design. For example, Threadless, an online artist community and e-commerce site based in Chicago, USA, is sustainable by providing a supply chain for artists and consumers. The practice encourages each artist to build their community on the platform, publish their work, and facilitate sales. The emphasis of open-source design on participation is aligned with bespoke businesses as it does not apply to traditional industrial product development structures. Collaborative design and halfway product design attempt to create an emotional bond between the product and consumer via consumer involvement, which introduces emotional value to the product and thus extends its lifespan. While consumers can create an emotional bond by engaging with the design, the longevity of this emotional bond and whether it is only a short-term passion challenges the applicability of this SDP.

Zero waste and slow fashion are two SDPs that focus on production processes. Bruna [14] suggested that "zero waste involves innovation in key resources, key activities, and cost structures". Zero waste attempts to maximise the use of every inch of fabric in fashion production via efficient layout and cutting techniques, which leads to near-zero production waste [17] but inevitably extends the cutting bed process and consequently risks reducing productivity. The concrete forms of zero practices are to reduce and improve packaging materials [33] and recycle textile waste. Slow fashion initiatives advocate slowing product development and production to focus on local supply chains and production. The limitation of slow fashion is that companies and brands cannot economically compete with economies of scale where their sales and profits decline with slowing turnover rates [34]. Furthermore, the traditional processes and small production runs for slow fashion products may lead to higher production costs [35]. Despite being cognizant of the importance of sustainability, consumers also expect more economical, fashionable, and high-quality products. Therefore, the slow fashion initiative requires more incentives.

Sustainable materials, reuse, and supply chain streamlining are SDPs that are relevant to the supply chain. In the aforementioned SDPs, the use of biodegradable fabrics, accessories, and packaging use was identified as a promising practice to effectively reduce the apparel carbon footprint. For example, vegan initiatives eliminate animal-based raw materials, furs, and leather given that processing and finishing animal-based raw materials use much energy and generate much pollution [14]. Regardless, even the production and consumption processes for 100% biodegradable materials do not necessarily produce fewer carbon emissions than non-environmentally friendly materials [18].

'Reuse' encompasses recycling and reuse. Recycling strategies include energy recovery and resource recovery and the forms of recycling include mechanical and chemical recycling [3]. For example, textile waste can substitute fossil fuels as a heat and electricity source [26]. Recycled textile waste is shredded to form cloth strips for carpet production. Synthetic materials are chemically treated to refine fibres again [36] and textile finishing waste water is recycled and

purified for other uses. Although emerging technologies can sort recycled fibres by type [37] and reprocess them into fibres [38], blended textiles are difficult to refine in practice due to a lack of technology and only natural fibres (cotton, linen, silk, and wool) are relatively easy to refine [18]. Reprocessing and refining also involve using chemical additives, water, and energy [37]. Furthermore, the consideration of economic factors should examine whether the technical and economic costs required for textile separation and recycling follow a CE and are not additional waste. The motivation and incentive of supply chain companies to recycle and reuse also affect the applicability of the practice. Streamlining supply chains can reduce some unsustainable impacts of off-site supply chains. For example, transport and logistics pollute the environment and waste resources. Collaborative supply chains require a common economic philosophy and values among partners and satisfy the profit motive. Therefore, identifying compatible partners is a potential challenge.

Recycling and restoration are SDPs applied to market services. Second-hand, replacement, and rental services are all part of product recycling. Effective selection and sales through second-hand shops and online platforms aim to achieve sustainability by extending product life [39]. For example, consumers have the opportunity to trade used products through a consumer-to-consumer (C2C) model on platforms, such as Xianyu in China and Vinted in Lithuania. Rental services are designed to extend product life, which provides customers with short-term access to products. These aforementioned SDPs are also subject to limitations, such as water- and labour-intensive screening, cleaning, and sorting during recycling. Furthermore, what is the fate of rejected products that are screened out? Whether they remain in landfills or are incinerated is also unknown. Moreover, consumers consider the hygiene of second-hand products a significant obstacle. Restoration extends the life of a garment through preservation and repair. Regular maintenance and restoration ensure that the product quality and appearance remain satisfactory. Additionally, highly skilled repair craft and techniques can fully restore the beauty of a product. Repair is more complicated than maintenance, and standard refinishing techniques cannot satisfy consumers' fixation on aesthetics.

Elaboration and discussion of PDP and PP results

Apparel company PDPs can vary significantly based on the business type and are mainly divided into branded and bespoke PDP (PDPb and PDPc, respectively). Figure 4 depicts the specific PDPb and PDPc processes. Traditionally, seasons and trends guide the apparel industry to enhance product line development [5], which begins with collecting trends and summarising previous season market feedback. Product development begins only after design planning and designing have been completed. The subsequent steps involve fabric selection for collection, item, and pattern design, pattern presentation, and iterative pattern adjustment until the final pre-production pattern is finalised [40]. The PDP for customised products begins with customer communication where the product is designed by combining the client's intentions with the designer's professional knowledge. The design, paper pattern, and process are finalised via communication and adjustment with the client and repeated fittings until the custom-made product is completed [41].

Figure 3 lists all the steps in branded and bespoke product development separately. In this figure, the designer-related aspects of PDPb and PDPc are marked in blue. In PDPb, the designer leads the design concept, fabric selection, and style design and is involved in the subsequent patterning, process design, style and construction examination, and idea exchange. In PDPc, the designer is mainly responsible for communicating with the client, supporting the client professionally, collaborating on the product design, and participating in the subsequent stages of patterning, craftsmanship, fitting, and idea exchange. Figure 4 demonstrates that the designer can lead 38% and 33% of the sessions in PDPb and PDPc, respectively. The PDP does not involve a set number of sample adjustments but typically includes two reviews: the first for the style and pattern and the second for the overall effect of the sample in the correct fabric. If the style, structure, and process details require modification during the second review, a third sample will be made and reviewed until the desired

Serial Number	Product Development Process (Brand)	Serial Number	Product Development Process (Customization)
PDPb1	*Collecting Fashion Trend and Market Feedback*	*PDPc1*	*Communication of customer needs*
PDPb2	*Fashion Trend analysis*	*PDPc2*	*Information gathering*
PDPb3	*Planning Design*	*PDPc3*	*First draft design*
PDPb4	*Fabric Selection*	*PDPc4*	*Selection of fabrics and accessories*
PDPb5	*Collection Design*	*PDPc5*	*First proposal discussion (without physical objects)*
PDPb6	*Item design*	**PDPc6**	body measurements
PDPb7	Pattern Design	**PDPc7**	paper pattern design
PDPb8	Sewing Technology Design	**PDPc8**	sewing process design
PDPb9	Preliminary sample production	**PDPc9**	first prototype production
PDPb10	Examination of style and construction	*PDPc10*	*Second design discussion (physical fitting)*
PDPb11	pattern modification	**PDPc11**	Revision of the design
PDPb12	Reproduction	**PDPc12**	Paper pattern revision and craftsmanship
PDPb13	Examination of pattern, construction, fabrics and sewing techniques	**PDPc13**	Reproduction
PDPb14	Modification of 2nd samples	**PDPc14**	Review of pattern, construction, fabrics and workmanship
PDPb15	2nd sample production	**PDPc15**	Modification of the second sample
PDPb16	Confirmation of pre-production samples	**PDPc16**	Production of 2nd samples
		PDPc17	Modification of 2nd samples
		PDPc18	Production of final samples

Fig. 3. The PDPb and PDPc processes

Serial Number	Production Process
PP1	Pre-production Sample Confirmation
PP2	Determining Production Quantities
PP3	Purchase of Fabrics and Fccessories
PP4	Pattern Grading
PP5	Cutting Process
PP6	Sewing
PP7	Finishing Process
PP8	Quality Control
PP9	Packaging
PP10	Stocking

Fig. 4. List of all the steps of the product process

effect is achieved. During bespoke product development, the number of prototype adjustments may increase due to changes in customer opinions.

Figure 4 depicts the PP flow. Following confirmation of the pre-production sample, the production department determines the production quantity with the merchandising department and senior management. The purchasing department purchases the fabric and accessories according to the production quantity and transports them to the factory. Simultaneously, the pattern maker performs bulk goods production, followed by cutting, sewing, finishing, quality control, and packaging. Thus, the entire PP process requires minimal designer involvement.

Designer involvement in the CE

Each PDP and PP session is matched to the SDP. To measure the designer's involvement in the current SDP, indirect measurements were made via the PDP and PP to enumerate the involvement of the PDP links associated with the designer in the SDP. The designer's involvement was calculated using the following formula:

$$Designer\ involvement = X/(X + Y + Z) \times 100\% \quad (1)$$

where X, Y, and Z refer to the number of green, blue, and white markers.

Figure 5 shows the link between the SDPs and the two types of PDP and PP, with different coloured markings showing the relevance of the fashion designer to the SDPs. In Figure 5, the green markers indicate the PDP and PP steps that could theoretically be matched to the SDP. Blue markers indicate the designer-related steps in the PDP that could match the SDP. White markers indicate that the SDP is irrelevant to any PDP and PP step.

Based on the formula, the designer's involvement in the SDP was ideally 41% in both PDPb and PDPc (figure 6). Ideally, a proportional representation of the fashion designer's participation in the presentation of the SDPs is expected. Theoretically, the involvement level was approximately 50% but differed from the actual situation as PDPs and SDPs were matched using the ideal state (all possible aspects of a designer's involvement in a PDP were counted as valid data). The SLR revealed that designers' sole involvement in the fashion industry was in selecting biodegradable and environmentally friendly fabrics, high-quality designs, and bespoke collaborative designs. In practice, designers' involvement with SDPs in PDPb and PDPc was only 11.76%. Figure 7 shows the actual level of involvement of fashion designers in SDPs after the survey.

Figures 6 and 7 depict the ideal and actual designers' involvement in the SDP, respectively. The comparison between Figures 6 and 7 demonstrates that designers' actual participation in SDP is shallow

Serial Number	Sustainable Design Practices	Steps associated with SDP in PDPb	Sign	Steps associated with SDP in PDPc	PDPcn.	PSteps associated with SDP in PP	Sign
SDP1	Zero Waste	PDPb9、PDPb12、PDPb15	●	PDPc9、PDPc13、PDPc16	●	PP5	●
SDP2	Slow Fashion	PDPb8	●		○		○
SDP3	Sustainable Materials	PDPb4	●	PDPc4	●	PP3、PP9	●
SDP4	Recycle	PDPb12、PDPb15	●	PDPc13、PDPc16	●		○
SDP5	Streamlining Supply Chains		○		○		○
SDP6	Second-hand Fashion		○		○		○
SDP7	Trade-in		○		○		○
SDP8	Rental Services		○		○		○
SDP9	Restoration	PDPb12、PDPb15	●	PDPc13、PDPc16	●		○
SDP10	Longevity Design	PDPb3	●	PDPc3、PDPc10	●		○
SDP11	Quality Design	PDPb6、PDPb8	●	PDPc3、PDPc10	●		○
SDP12	Timeless Design		○	PDPc3、PDPc10	●		○
SDP13	Functional Design	PDPb6、PDPb7	●	PDPc3、PDPc7、PDPc10	●		○
SDP14	Modular Design	PDPb6、PDPb8	●		○		○
SDP15	Open Source Design	PDPb3	●	PDPc1	●		○
SDP16	Collaborative Design	PDPb3	●	PDPc1	●		○
SDP17	Halfway Product Design		○		○		○

● the steps of the PDP and PP that could theoretically be matched to the SDP.
● the steps related to the designer in the PDP that could match the SDP.
○ the SDP is irrelevant to any of the steps in the PDP and PP.

Fig. 5. The designer's involvement in the PP and PDP

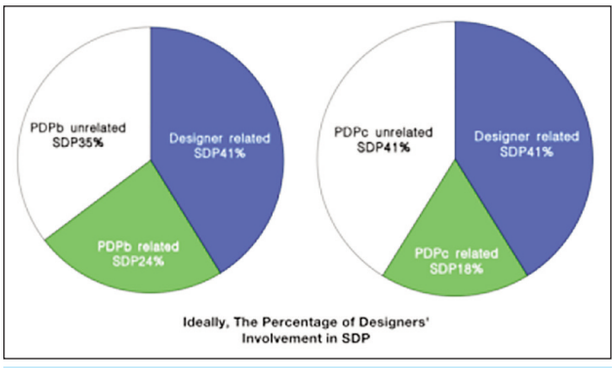

Fig. 6. Ideal designers' involvement in SDP

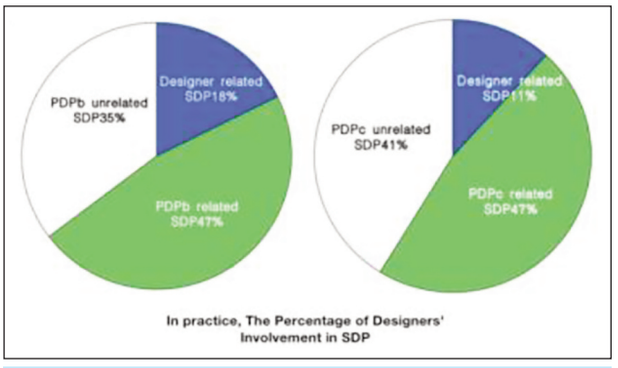

Fig. 7. Actual designers' involvement in SDP

when analysed at both internal and external levels. The internal factor is that designers have a limited voice in the traditional apparel industry. Designers only work based on the set direction issued by top management and are typically only responsible for the tasks within their responsibilities. Designers are rarely involved in strategy-level company or brand work. Thus, designers lack sufficient motivation to engage in subjective CE.

The external factor refers to the organisational and entrepreneurial neglect of the role of designers and traditional PDP and PP. Entrepreneurs typically deem the transformation of the CE and sustainable growth as strategic company deployment and should evaluate their systems regarding CE transformation in more detail. Furthermore, the lack of knowledge on sustainability leads to strategic transformation initiatives being limited to obsessive recycling actions and addressing the wasteful results. The SLR revealed that strategy proponents believe that the apparel industry's sustainable development breakthroughs are limited to addressing pollution, recycling waste, enhancing product durability, increasing the added value of products, and fostering emotional customer value. The limitations of the aspects above were discussed in the previous section.

PDP three-dimensional (3D) visualisation

Resolving local pain points cannot improve the fashion company's transition to a CE and involvement in sustainable development. Companies should make both internal and external changes. Internal reform refers to the achievement of sustainability in all business aspects while external reform requires building an externally sustainable industrial ecology by linking with partners, such as supply chains, manufacturers, and customer service providers. As an internal key to the apparel business, PDP is inherently unsustainable. As illustrated in figure 3, the repeated prototype adjustment link in both PDPb and PDPc is an unsustainability pain point and a sustainability breakthrough point. Eliminating prototype conditioning in PDP is an advantageous approach to transition to sustainability in PDP where product iteration efficiency is improved and resource waste associated with repeated prototype production is resolved. Thus, sustainable design is not an afterthought but focuses on the entire design process.

Designers can upgrade their PDPs with technology by using computerised 3D virtual technology to replace the sample commissioning aspect of traditional PDPs to render the PDP a 3D visual, which digitally produces the design presentation. Ideally, computers perform style design, pattern-making, sample-making, and structural commissioning. The PDP 3D visualisation enables rapid iteration of the design solution, reducing the lead time to obtain the desired design and swiftly identifying the design early in the process. More importantly, 3D visualisation replaces traditional proofing and addresses the unsustainable issues caused by repeated prototyping. Therefore, the PDP 3D visualisation initiative is an effective means for designers to contribute to sustainable development. The PDP 3D visualisation challenges the traditional PDP process by combining a workflow that would otherwise require several departments to collaborate in one session.

Appropriate 3D rendering software, such as Clo3D, Gerber Technology, and Human Solutions [40], requires the software user to possess a comprehensive range of skills. Using 3D software requires knowledge and skills in design, construction, technology, and software operation, which challenges designers and other PDP participants. Furthermore, PDP 3D visualisation presents the following organisational challenges: how the key players (experienced paper pattern-makers and skilled craftspeople) in traditional PDP should be involved in PDP 3D visualisation when the PDP structure requires major reorganisation. The perceptions and imagining of 3D virtual products differ from physical reality. Therefore, the extent to which the visualised product would fulfil organisational and consumer expectations is subject to unknown challenges.

CONCLUSION

The apparel company's transition to the CE requires a concerted effort from internal and external business cycles. In this study, 75 articles on SDPs, PDPs, and PPs in the apparel industry were analysed. First, existing SDPs in the apparel industry were identified

and the motivations of existing sustainable initiatives at the strategic level were analysed. Second, the internal links between the current PDP and PP in the apparel industry were deconstructed. Mapping the internal links to existing SDPs enabled the indirect measurement of designers' involvement in the CE. Third, a sustainability breakthrough in designer-led PDP was proposed by replacing physical garment sample production with PDP 3D visualisation, eliminating the waste associated with repeated sample commissioning. Finally, the barriers and limitations of PDP 3D visualisation were presented. Sustainable reform of the PDP segment challenges traditional processes, where it presents challenges to the direct collaborative approach of segment participants. This suggests that the designer-led application of PDP sustainability faces many obstacles.

The limitations of this research were as follows: apparel industry PDPs were not limited to PDPb and PDPc due to the different audiences and markets served by the companies, such as original equipment manufacturer (OEM) business PDPs and webcast product PDPs. Thus, it is possible to expand research on apparel industry PDPs. Furthermore, the main research aim is to focus on designers' sustainable potential, as the PP and designers were weakly correlated. Therefore, studying SDPs in PPs requires further development. As the PDP 3D visualisation application faces several barriers, more in-depth research on how it can be integrated into practical organisational applications is needed, such as how designers can be trained with comprehensive skills and how the aesthetic differences between 3D renderings and natural objects can be reduced.

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