Design Sustainability in Knitwear Industry

Analysis of different studies of Design Sustainability & its scope in the Knitwear Industry.

[1]Urja Kumbhare, [2]Sanika Joshi
[1][2] Department of Knitwear Design
[1][2] National Institute of Fashion Technology, Mumbai, India

Abstract: The pressing need to bring about sustainable change to reduce textile waste right from the apparel conceptualization and design stage has given rise to this study on design sustainability. The study has thus been undertaken to investigate the various design sustainability models prevalent in various industries and their scope for application within the knitwear industry. The question of design sustainability is tackled through a comprehensive literature review on a wide range of subject matter such as sustainable manufacturing practices, design for a circular economy, practices and indices for measuring the well-known triple-bottom-line (Elkington, J.,1997) impact namely (i) economic prosperity, (ii) social justice, and (iii) environmental quality.

Keywords- sustainable design, design for sustainability, circular design, design for remanufacture, manufacturing sustainability, life cycle assessment, knitwear design

I. Introduction

1. Rise in Sustainability

Over the last couple of decades, as the impact of global warming has worsened, the discussion of climate change has grown well beyond the scientific and technocratic circles within which it was long confined. The upcoming climate crisis has driven minds from all walks of life to re-evaluate their contribution towards this crisis and strive for change towards sustainable ways of production and living.

Sustainability has become a global trend. Companies are gaining stronger incentives to work towards product sustainability owing to the paradigm shift in consumer preferences that are now largely influenced by the sustainability and social, environmental impact of the product. This has given rise to a dire need to redesign not only products but also the systems and conditions under which the products are being made. The exponential rise of the fast fashion industry has contributed to a paramount increase in textile waste. A large sector within this industry is knitwear. This pressing need to bring out sustainable change to reduce textile waste starting from the apparel conceptualization and design stage has given rise to this study on design sustainability.

The question of design sustainability is tackled through a comprehensive literature review on a wide range of subject matter such as sustainable manufacturing practices, design for a circular economy, practices and indices for measuring the well-known triple-bottom-line (Elkington, J.,1997) impact namely (i) economic prosperity, (ii) social justice, and (iii) environmental quality.

2. Indian Knitwear Industry overview

The first hosiery unit in India was established in West Bengal in 1893 by Anand Prasad Mukherjee. The industry got deep-rooted in Ludhiana when knitwear craftsmen settled there and the industry flourished during the period due to the heavy recruitment from Punjab. Later the knitwear industry spread to other parts of India. In India, the knitwear industry is organized as well as decentralized. A vast portion of the woollen readymade garment industry is concentrated in the northern states, especially Punjab.

Presently Tirupur, in Tamil Nadu, is hailed as the headquarters of the knitting industry - claiming 51% of the knit apparels exported from India. The Indian knitwear industry is one of the most contemporary global producers of knitwear products. Knitted garments are quite popular with the present generation and consumers of today. With the advancement of knitting technology, the use of knitted fabrics is increasing rapidly worldwide. The knitwear sector and its markets are constantly evolving worldwide. Knitted garments are no longer limited to lingerie, sportswear or just winter wear. There has been a revolution in knitwear. The range of styles, raw materials that can be made or purchased is constantly expanding so have the manufacturing techniques.

The Indian knitting industry is characterized by small scale units that lack essential facilities for dyeing, processing and finishing. The knitting industry in India is focused on Tirupur, Ludhiana and Ahmedabad. Tirupur is responsible for 60 percent of India's total knitwear exports. Knitted garments account for almost 32 percent of all exported garments from India. The knitwear exporters from all over India from Delhi, Mumbai, Bangalore, Chennai and Tirupur have already been busy with making new designs and collections to match the recent trends and to meet the global buyers' requirements.

As per a study conducted by a consultancy firm, Wisedge, knitwear constitutes 50 percent of the domestic apparel market in India and 45 percent of the apparel exports from India. Globally, knitwear has grown at a compound annual growth rate of seven percent from 2005-11 and is expected to grow at a faster pace soon. In India, the growth of knitwear has increased by 9-10 percent.

Popular knitwear product categories that dominate the market are: kids wear, infants wear, casual wear, sportswear, activewear, lingerie with loungewear being a steadily emerging new category post-pandemic.

II. Problem Statement

"With increasing consumer environmental awareness and expectation of the company to accept environmental responsibility, there is a need to expand understanding of how the knitwear industry can incorporate sustainable design and development into their production."

The issues highlighted in the problem statement require in-depth research at the micro-level. Hence an in-depth study has been undertaken to address the problems highlighted in the problem statement with the following objectives.

III. Research Objectives

The research study was conducted with following specific objectives:

Objective 1:

To study design sustainability models prevalent across various industries.

Objective 2:

To study design sustainability models prevalent in the knitwear apparel industry.

IV. Review of Literature

To conduct the literature review, the following academic databases were used: EBSCO Information Services Host, Design Society and ProQuest.

Keywords included: sustainable design, design for sustainability, circular design, design for remanufacture, manufacturing sustainability, life cycle assessment.

1. Circular Design

A circular economy is defined as an economic system of closed loops in which raw materials, components and products lose their value as little as possible, renewable energy sources are used and systems thinking is at the core. Design acts as a catalyst to shift from the traditional model of take-make-dispose to pave the way towards a more restorative, regenerative and circular economy. Hence the products need to be designed for closed loops, as well as be adapted to generate revenues (Moreno, Mariale et al., 2016). Terms such as "eco-design", "green design"," design for the environment" and "sustainable design" have emerged, looking for alternative ways to deliver less damage to the environment and sometimes to wider society in general. (Roy R, 2006), as confirmed by Moreno, M., Rios, C. et al in 2016. However, this research has been applied without consideration of the impact on the whole system of production. Hence, the development of a circular design model and incorporation of a circular business model into the industry becomes necessary.

A circular economy can be shaped well through product design. The Ellen MacArthur Foundation states: "At its core, a circular economy aims to 'design out waste. Waste does not exist—products are designed and optimised for a cycle of disassembly and reuse". A circular business model essentially describes how an organization can create and capture value in a circular economy; This is what distinguishes it from traditional, linear models. Hence, circular business models focus on high value and high-quality material cycles. (Korhonen, J.; Honkasalo, A et al., 2018).

"A new textiles economy: Redesigning fashion's future," report was created by the Ellen MacArthur Foundation's Circular Fibres Initiative, published in 2017. The report details a circular textiles economy based on four ambitions namely "phasing out substances of concern and microfiber release, transforming the way clothes are designed, sold and used to minimize disposal, radically improving recycling by transforming apparel clothing, design, collection and reprocessing, and making effective use of resources while moving to renewable inputs" (Scarano, G., 2017). In bringing these ambitions to life, a collaboration between designers, manufacturers, retailers and consumers is essential.

Presently, in the knitwear industry, there are avenues for zero-waste design such as fully-fashioned garment production and seamless knitting that eliminates textile waste during production. To incorporate principles of circular design such as designing out waste, the overall lifecycle of the product needs to be taken into consideration. Knitwear could be redesigned to facilitate disassembly and reuse. Another example of a circular business model around the lifecycle of knitwear is a combination of an access-based payment model, such as a product lease, with a value recovery strategy, such as refurbishment.

2. Product sustainability & Eco-design

Due to the increasing concern on environmental impact and lifecycle considerations, product sustainability has gradually become an important focus in the product development process. Ceschin and Gaziulusoy (2016) describe how the role of design for sustainability has been expanding over the past decades, from the development of single products to complex systems, reflecting a shift from relatively isolated design solutions (i.e., improving a product's energy efficiency) to systemic design innovations (i.e., developing a sustainable product-service system).

As detailed by Lin, C., Chiu, M., & Okudan, G. (2009) in their work, the main challenge when designing with an environmental perspective, is to identify the needs that are relevant to consumers' quality of life. The products designed must meet these needs while ensuring that the product doesn't destroy the ability of future generations to meet their needs. In general, one of the first sustainability considerations is material selection. Then, during the selection of manufacturing processes and functional performance, the concepts with energy efficiency, minimum discharge, emission and waste should be preferred. It is noted that modular design, design for assembly (DfA) and design for disassembly (DfDA) not only increase the efficiency of economic benefits but also have synergies with sustainability. Ceschin, F. (2014) suggests focusing on customer habits, organizational structures and regulative frameworks as main development pathways for manufacturing companies to adopt sustainable Product-Service Systems (PSS).

Among the methodologies available to evaluate the sustainability level of products, Life Cycle Assessment (LCA) provides a holistic approach that considers the potential environmental impacts from all stages of manufacture, product use and end-of-life (Finnveden et al., 2009). In the product and process design stage, the criteria of sustainability encompass three aspects: economic, social, and environmental considerations (Azapagic, A., Millington, A., 2006). Economic criteria include capital cost, operating cost, and profits. Environmental criteria count for materials and energy, emission and solid waste, and environmental impacts. Social criteria consider health and safety. Other indices to consider while designing for sustainability include Design for Assembly (DFA) Index, Functionality Index, Cost Index, Compatibility Index and Sustainability Index. Vadoudi, K. and Troussier, N., (2015), in their research, suggest taking the geographic territory and information into consideration when evaluating product life cycles. Using raw materials and manufacturing capacities for production within a geographic territory not only drastically reduces the cost of the product but also lowers its carbon footprint leading to eco-design. This is a great model to follow for product design sustainability.

According to Wang, L., & Shen, B. (2017), Eco-design can refer to Design for Sustainability (DfS), Design for Environment (DfE), and Design for Recycle (DfR) in fashion. DfE defines product development through environmentally-conscious consideration. DfR aims to extend products' lifetime by optimizing products for repair, refurbishment and the recovery of materials (Kohler, A. R., 2013). In eco-design, the product life cycle and end-of-life treatment in product line development are carefully considered. Wang, L., & Shen, B. (2017) have observed sportswear giant Patagonia's 1% for the planet initiative and thorough usage of eco-labels such as Fair-trade certification in their garments to influence the consumers towards buying sustainably. Naturally, the designers at Patagonia strictly follow sustainability compliances of the eco-labels in product development. Wang, L., & Shen, B. (2017) explain how eco-design can be incorporated into the product design cycle through eco-material selection, eco-design for functionality as well as aesthetics in product line development.

3. Adaptable Apparel

Apparel is a necessity as well as a luxury for many and has been creating a unique situation for producers and consumers. In recent years, the concept of fast fashion or "prêt-à-porter" has emerged allowing designers to clothe the public while promoting continuous sales through rapidly evolving trends. To offer more styles at lower prices, lower-quality materials are utilized. Although the material and garment have lower quality and price, they still use the same number of resources. In addition to the industry sector of the apparel market, consumers play a leading role in excess consumption of garments. People shop to fill an emotional need, buy items that are in trend, to fit in, fulfil basic needs and lastly to impress others. The recent introduction of low-price fast fashion has fuelled rapid consumption of apparel. As a result, it has become common practice to buy clothes one may never wear, dispose of clothing that is still usable, and simply buy excess garments to satisfy psychological needs.
To prolong the service of a product and to address the manufacturing problems of improved product functionality, quality, customization, environmental friendliness, cost efficiency, and short delivery time, As proposed by Gu et al. (2004) proposed an approach called "adaptable design." Industries ranging from architecture to automobile have utilized this concept to extend the life of a product and save resources. Adaptable design requires affirmation and cooperation from both the industry and consumer sectors. The adaptable design also makes it possible to change without purchasing new products. Due to this nature, adaptable apparel design could be a possible solution for the excess apparel consumption problem. The purpose of this research was to apply adaptable design in apparel as a sustainable design solution for excess consumption problems and assess consumers' acceptance of adaptable apparel.

There are two types of adaptability: design adaptability, and product adaptability. Design adaptability refers to the adaptability in the design of a product so that the design can be adapted to produce another product, Gu et al., 2004. Applying product adaptability creates a product that can be changed by the user in a usually reversible and simple procedure to achieve different functions or usages.

Adaptable apparel would increase apparel utilization, eliminate the need to purchase unnecessary additional amounts of clothing and reduce excess consumption. Also, adaptable apparel could help encounter the excessive use of material resources and excessive creation of waste - not only can adaptable garment extend the product's lifespan in the eyes of the consumer, but it can also decrease the use of these material resources and creation of waste.

4. Sustainable manufacturing practices

As detailed by Kishawy, H. A., et al., (2018) in their work, a considerable number of environmental concerns have arisen because of the consumption and pollution of natural resources and this is a highly eminent fact. Hence the implementation of a sustainable system is a requirement in modern manufacturing to take note of these concerns and to come up with practical solutions. To achieve better requirements by utilizing available resources we must focus on the economic, environmental and social directions. To create and implement sustainability each sustainable aspect that has certain objectives should be attained.

Sustainable manufacturing focuses on the new 6R approach; Re-duce, Re-design, Re-use, Re-cover, Re-manufacture, and Re-cycle (Jawahir, I., 2008). At the level of processing, reduction in energy consumption, toxic waste and hazards is accomplished by using an enhanced technological process associated with an effective process planning method while using a supply chain system that reviews all the life-cycle stages which provides an operative sustainable system.

Sustainable manufacturing processes include:

- Energy consumption reduction
- Waste elimination/reduction
- Product durability improvement
- Health hazards and toxic dispersion and elimination
- Higher quality of manufacturing
- Recycling, reuse and remanufacturing enhancement
- Developing of renewable energy resources

Several objectives should be kept in mind to achieve the target for process, product and system scales when it comes to sustainable manufacturing. These objectives are designed keeping in mind the 3R's; repair, reuse, and recycle.
Designed for the effectiveness of cost.
Designed for waste and hazards minimization.
Designed for constant improvements.
Designed for disassembly of the product.
Designed for efficiency of energy.
Designed for remanufacturing.
Designed for optimal usage of materials.

The base of design for sustainable manufacturing, based on the product and operation levels are designed for prime environmental impact, for the utmost utilization of the resources and economy, for the functionality, for manufacturability, for the recyclability and the impact on the general public

4.1 Practice and Implementation of Sustainable Manufacturing

1. Usage of non-hazardous and nontoxic and recyclable materials during the manufacturing process.
2. Prior planning of production processes to ensure reduction in the consumption of carbon footprint, raw materials and water.
3. Using renewable energy that does not have any negative effects on nature.
4. Design development of a product which can be re-usable, re manufacturable or recyclable.

The application of sustainable manufacturing concepts offers many advantages; for example, it can reduce energy consumption, decrease/eliminate wastage, increase product durability, better health and safe environment, and enhancement of the system and processes overall performance (Kishawy, H. A., et al., 2018). Understanding the needs, implementation techniques, methods of assessment is very important to achieve a sustainable environment. Hence, this work considers the sustainable manufacturing application in terms of conceptualization, implementation, and assessment methods. The core points are to reduce energy consumption, decrease/eradicate wastage, enhance the durability of the product, achieve optimum health and safety conditions, and amplify the overall performance. Thus, detailed guidelines to define the notion and practice sustainable manufacturing techniques is necessary. Furthermore, it is required to keep developing the current sustainable technologies to achieve a sustainable manufacturing environment.

4.2 Exploration of 3D printing to create zero-waste sustainable fashion notions

3D printing is synonymous with sustainability (Gebler et al. 2014). The use of 3D printing in manufacturing can assist in waste reduction. Because the entire object is complete once the printing is complete, nothing needs to be cut away. When applied to the apparel industry, using only 3D printing machinery rather than having a multitude of machines, could drastically cut costs and change how the industry manufactures clothing (Sun and Lu. 2015). 3D printing's waste is only 40% versus the waste produced by subtractive technologies and much of 3D printing waste is recyclable (Berman 2012)3D printing has already proven to be an economical and cost-effective way for prototyping and manufacturing. The design and prototyping possibilities with 3D printing are limitless. As it uses CAD, a prototype can be quickly rendered and printed by the designer or the manufacturer (Weller et al. 2015) allowing them to decide, before mass production, whether or not the end product meets their expectations. Additionally, designers and manufacturers can even print on the spot for consumers further eliminating waste. From a sustainability perspective, 3D printing has the possibility of extending the life of a garment by assisting in making it multi-functional.

4.3 Process:

The filament, which is wound on a spool, is passed through and heated in an extrusion head, with the temperature depending on the filament type. Next, the molten material is deposited onto the build platform. Layer upon layer is added as the platform slowly moves down, solidifying after extrusion and bonding as the process continues to form a product.

3D printers heat and extrude plastic filaments (raw material). MakerBot uses materials such as polylactic acid (PLA) (corn-based), Acrylonitrile Butadiene Styrene (ABS), and flexible filament. PLA is preferred because it is biodegradable, has a lower melting point, and has higher dimensional stability as compared to ABS; however, PLA is water-soluble and not best for long-term wear (Pei et al. 2015; Samuels and Flowers 2015). Pei et al. (2015) reported significant findings through experimenting with warping, bond, print and fax with their choice of experimental filaments, PLA, ABS and Nylon 465, in both woven and knit fabrics made from natural or synthetic fabrics. Fair Trade plastic has both environmental and social components of sustainability. Joshua Pearce, a material scientist, has created an ethical filament standard for 3D printing filament, following which the ethical filament was formed. The ethical filament standard and mark is a work in progress. It will serve as a globally recognized fair-trade brand. Once ready, it will certify the ethical credentials of both sourcing and production of a filament. It will partner with waste-picking communities and local entrepreneurs to create a seamless process to create 3D printer filament from recycled waste materials. Proposed grading involves going through the following stages: plastic collection, cleaning, shredding and faking, pigment and extrusion, quality checking, packing and dispatching.

5. Cradle to Cradle Sustainable Apparel Design Model

The most popular modern industrial model is linear, i.e., from the resource to product, to waste: cradle to grave. As explained by Coons, R. (2010), Cradle to Cradle design is the elimination of waste through process design. In C2C, everything is reused, thereby eliminating waste. This is achieved either by returning industrial by-products to the soil as nontoxic and 100% biodegradable biological nutrients, or by infinitely recycling the by-products industrially as a technical nutrient. The primary concept is that there is no waste and every material becomes fuel or feedstock for another process/product. (Anon, Business & the Environment, 2006)

This concept of C2C design was first applied to apparel design by LaBat and Sokoloskwi, (1999) as mentioned by Hae, J. G., Cao, H. et al in 2009. Hae, J et al (2009) details that in the case of Apparels, the sample making process is crucial to determine whether products can be viable in the market as C2C products. In the material selection phase, the designer must ascertain the processes involved in the manufacturing of the products and whether the industrial by-products of these materials can be used as technical nutrients in further processing. The journey of the garment post-use must also be considered. In most scenarios, apparel manufacturing industries do not manufacture their materials, dyes and other components. Hence, to achieve a true Cradle to Cradle model, a collaboration between apparel designers and manufacturing companies is inevitable.

In the case of the Knitwear industry, it is easily possible to observe various processes beginning from spinning of yarn to knitting of the final garment. As implemented by Hae, J. et all in 2009, in a kids' knitwear manufacturing unit, using natural and organic fibres for yarn spinning make the garment a biodegradable nutrient. Next, collaboration with dyeing industries ensured that the synthetically produced dyes procured generated technical nutrients and were truly C2C in nature. This processed yarn was then fully fashioned into children's knitwear, making the apparel C2C in nature. In the case of knitting, design for Disassembly (DfDA) is readily possible owing to the easy unravelling of knitwear.

Cradle to Cradle, hence, provides an alternative approach to Sustainability to use materials that are either biodegradable or can be repurposed as a technical nutrient. It gives a new meaning to Zero-waste design.

V. Conclusion

Sustainability in design is not only limited to the use of sustainable materials but also involves all aspects of the products lifecycle right from sampling to production. To achieve true sustainability in the apparel and knitwear industry, the core principles of sustainability need to be applied across all levels by design. Thus, design sustainability can help transcend apparel brands beyond products and aesthetics to increase consumer appeal and bring in economic prosperity even during trying times.

The scope of application of design sustainability models in the knitwear industry is tremendous as demonstrated by Hae, J. et all in 2009, in a kids' knitwear manufacturing unit. Alongside the Cradle-to-Cradle model of design, adaptability is another avenue that provides multifarious benefits both to the consumer as well as to the seller. Product adaptability is the next big trend that design houses across the world are looking to apply as the leading trend forecasting agency in the world, WGSN predicts. Adaptability greatly increases the lifespan of the product, making it much more sustainable in the long run as consumers consume lesser.

Owing to the principles of knitting, knitwear provides ample opportunities for circular design as knitted garments, especially whole garments produced by computerized knitting machines can be unravelled to provide yarn that can be re-spun or repurposed to create new garments, thus completing the cycle of circular design. Designers looking to include sustainability in their design need to set an objective in mind before commencing so that factors like cost-effectiveness, waste minimization and

optimal use of resources can be fulfilled. Advancement in technology and CAD – computer-aided design is pivotal in contributing to reducing the number of resources that the consumed in the process of design. CAD has now further evolved to make virtual sampling of products possible. Typically sampling process of garments makes the least sustainable use of resources and this wastage can now be easily bypassed using 3D software such as CLO3D or Lectra Modaris.

However, before the application of any design sustainability models in the knitwear industry, the industry members must assess the practicality of these solutions in their practice. No company can apply all of these sustainability solutions at once, as it can lead to more wastage of resources. No single solution fits all practices. To truly be sustainable, all members of the company need to be trained before the application of a practical solution to avoid bottlenecks in the functioning of the industry.

In conclusion, design sustainability has the potential to bring about a lasting change in the knitwear industry and its effects on climate change.

VI. Acknowledgment

The authors of this paper thank Prof. Sushil Raturi, for his invaluable guidance in the writing of this paper. We also thank the Department of Knitwear Design at National Institute of Fashion Technology for providing us with the opportunity and resources to write this paper, as well as, our family and friends, without whose support, the publication of this paper would not have been possible.

VII. References

[1] Moreno, M., Rios, C. D. l., Rowe, Z., & Charnley, F. (2016). A conceptual framework for circular design. Sustainability, 8(9), 937. doi:http://dx.doi.org/10.3390/su8090937(registeringDOI)

[2] Sumter, D., Bakker, C., & Balkenende, R. (2018). The role of product design in creating circular business models: A case study on the lease and refurbishment of baby strollers. Sustainability, 10(7), 2415. doi:http://dx.doi.org/10.3390/su10072415

[3] Korhonen, J.; Honkasalo, A.; Seppälä, J. Circular Economy: The Concept and Its Limitations. Ecol. Econ. 2018, 143, 37–46

[4] Ceschin, F.; Gaziulusoy, I. Evolution of Design for Sustainability: From Product Design to Design for System Innovations and Transitions. Des. Stud. 2016, 47, 118–163.

[5] Lin, C., Chiu, M., & Okudan, G. (2009). Design for sustainability during conceptual design stage. IIE Annual Conference. Proceedings, 1506-1511. Retrieved from https://search.proquest.com/docview/192458387?accountid=38977

[6] Vadoudi, K., Troussier, N., (2015), A sustainable product model, DS 80-10 Proceedings of the 20th International Conference on Engineering Design (ICED 15) Vol 10: Design Information and Knowledge Management Milan, Italy, 27-30.07.15

[7] Ceschin, F. Product-service system innovation: A promising approach to sustainability. In Sustainable Product-Service Systems; Springer: Berlin, Germany, 2014; pp. 17–40.

[8] Bertoni, M. (2017). Introducing sustainability in value models to support design decision making: A systematic review. Basel: MDPI AG. doi:http://dx.doi.org/10.20944/preprints201705.0003.v3

[9] Gam, H. J. (2007). Development and implementation of a sustainable apparel design and production model. (Order No. 3259611, Oklahoma State University). ProQuest Dissertations and Theses, 176. Retrieved from https://search.proquest.com/docview/304776194?accountid=38977

[10] Wang, L., & Shen, B. (2017). A product line analysis for eco-designed fashion products: Evidence from an outdoor sportswear brand. Sustainability, 9(7), 1136. doi:http://dx.doi.org/10.3390/su9071136

[11] Wang, L., & Shen, B. (2017). A product line analysis for eco-designed fashion products: Evidence from an outdoor sportswear brand. Sustainability, 9(7), 1136. doi:http://dx.doi.org/10.3390/su9071136

[12] Kishawy, H. A., Hegab, H., & Saad, E. (2018). Design for sustainable manufacturing: Approach, implementation, and assessment. Sustainability, 10(10), 3604. doi: http://dx.doi.org/10.3390/su10103604

[13] Westkämper, E. Life cycle management and assessment: Approaches and visions towards sustainable manufacturing (keynote paper). CIRP Ann. Manuf. Technol. 2000, 49, 501–526

[14] Jayal, A.D.; Badurdeen, F.; Dillon, O.W., Jr.; Jawahir, I.S. Sustainable manufacturing: Modelling and optimization challenges at the product, process and system levels. CIRP J. Manuf. Sci. Technol. 2010, 2, 144–152

[15] Jawahir, I. Beyond the 3R's: 6R concepts for next generation manufacturing: Recent trends and case studies. In Proceedings of the Symposium on Sustainability and Product Development, Chicago, IL, USA, 7–8 August 2008

[16] Hae, J. G., Cao, H., Farr, C., & Heine, L. (2009). C2CAD: A sustainable apparel design and production model. International Journal of Clothing Science and Technology, 21(4), 166-179. doi:http://dx.doi.org/10.1108/09556220910959954

[17] Kaplan, S.; Winby, S. Organizational Models for Innovation. Available online: http://www.vps.ns.ac.rs/Materijal/mat936.pdf (accessed on 23 September 2019).

[18] Geissdoerfer, M.; Vladimirova, D.; Evans, S. Sustainable business model innovation: A review. J. Clean. Prod. 2018, 198, 401-416.

[19] Ritala, P.; Huotari, P.; Bocken, N.; Albareda, L.; Puumalainen, K. Sustainable business model adoption among S&P 500 firms: A longitudinal content analysis study. J. Clean. Prod. 2018, 170, 216-226.

[20] https://shodhganga.inflibnet.ac.in/bitstream/10603/33834/6/chap5.pdf

[21] Cradle to cradle - designing beyond the three Rs. (2006). Business and the Environment, 17(2), 1-3. Retrieved from https://search.proquest.com/docview/220301980?accountid=38977

[22] Coons, R. (2010). Non-profit launched to advance cradle-to-cradle design. Chemical Week, 172(12), 8. Retrieved from https://search.proquest.com/docview/365427990?accountid=38977

[23] Hae, J. G., Cao, H., Farr, C., & Heine, L. (2009). C2CAD: A sustainable apparel design and production model. International Journal of Clothing Science and Technology, 21(4), 166-179. doi:http://dx.doi.org/10.1108/09556220910959954

[24] Wang, L., & Shen, B. (2017). A product line analysis for eco-designed fashion products: Evidence from an outdoor sportswear brand. Sustainability, 9(7), 1136. doi: http://dx.doi.org/10.3390/su9071136

[25] Köhler, A.R. Challenges for eco-design of emerging technologies: The case of electronic textiles. Mater. Des. 2013, 51, 41–60.

[26] Cimatti, B.; Campana, G.; Carluccio, L. Eco design and sustainable manufacturing in fashion: A case study in the luxury personal accessories industry. Procedia Manuf. 2017, 8, 393–400.

[27] Scarano, G. (2017). A new circularity roadmap charts a more sustainable path forward for apparel. Sourcing Journal (Online), Retrieved from https://search.proquest.com/docview/2272297192?accountid=38977

[28] Cao, H., Chang, R., Kallal, J., Manalo, G., McCord, J., Shaw, J., & Starner, H. (2014). Adaptable apparel: A sustainable design solution for excess apparel consumption problems. Journal of Fashion Marketing and Management, 18(1), 52-69. doi:http://dx.doi.org/10.1108/JFMM-08-2012-0046