ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20220410142313

Preliminary communication
Received: 2022-04-10, Accepted: 2022-04-11

Towards a Circular Product (Re)Design Methodology: Proposition of the Unlinear Method to Foster Circularity

Bixente Demarcq*, Dimitri Masson, Jérémy Legardeur, Antoine Millet

Abstract: Works on garment and shoe dismantlement and recycling have highlighted the complexity of this kind product and the difficulty to find a recycling channel for each material they are made of. The way they are designed perturbate the recycling process at products end of life. This paper examines these product complexities and proposes Unlinear methodology to help product design teams to redesign a more circular products which materials can be recovered at the end of their life. This method is based on a standardized product representation tool where each component product is made of is represented with its material and the function it ensures.

Keywords: circularity; design for recycling; material recovery; product dismantling

1 INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) report highlights the urgency of climate change and the need of changes in our societies to keep global warming below 4 °C [1]. This change will be imposed on all industrial practices with a view to reducing CO_2 emissions and preserving natural resources. To this end eco-design is, according to the definition given in the ISO 14062 standard, a design approach aiming to reduce the environmental impacts of products and services throughout the whole lifecycle, while assuring similar or improved services to the end customer [2].

The circular economy promotes to move from linear economy where products go from cradle to grave to cradle-to-cradle [3]. It reposes on principles of eliminating waste and pollution, circulation of products and material, and regeneration of nature [4]. It involves creating cycles, both biological where materials at the end of life of a product are returned to natural regeneration processes, and technical cycles where materials, components or whole product are reused for as long as possible.

Moving from linear economy to a circular economy requires transforming the **destroy-value** processes of the post-use of a product into **retain-value** processes as it is shown in Fig. 1 [5]. This implies reuse/redistribute, refurbish, remanufacture and recycle processes.

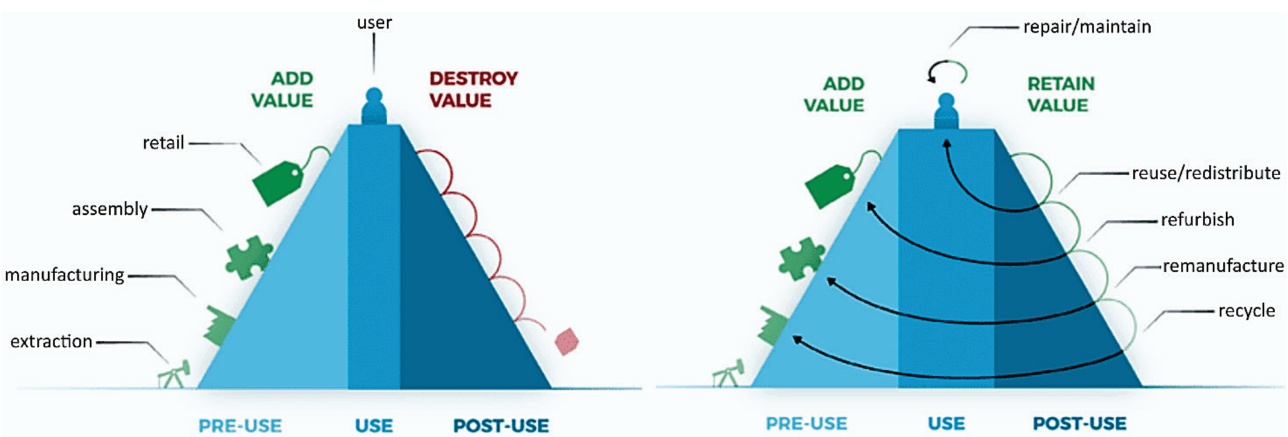

Figure 1 From destroying value in Linear Economy to retaining value in Circular Economy [5]

The current fashion industry is facing a lot of barriers and issues to reach sustainability goals [6]. Some of them are due to the **linear aspect** of the supply-chain with a take-make-dispose model. Policies are being put in place, such as in France, to prevent the destruction of unsold products and to favor circularity by encouraging the development of recycling solutions for shoes and clothing [7]. In France, 55% of the clothes collected are reused [8]. However, in 95% of the cases they are sent for export to the African or Asian continent to be reused or landfilled. Only 1% of textile fibers used to make garment are recycled into new garment [9].

This failure to manage the end of life of clothing or shoe is due to a lack of technology to achieve integral product dismantling, and separation of materials to a degree of purity that is necessary for reuse (think a plastic bottle is made only of PET and a paper label, a shirt is made often made of a mix of fiber, of different colors, assembled with different thread, added with buttons and labels).

If some "hard & traditional products" can be designed with design for X approaches: Design for recycling [10], Design for maintainability [11], Design for disassembly [12] few clothes or shoes are designed with end-of-life in mind. They cannot know a high-quality recycling process due to their complexity: materials they are made off cannot be separated properly, garment or shoe composition includes recycling perturbator, too much different material to recycle each of them on a dedicated channel. It starts form product design stage: there is a need to highlight this design choices that at products end of life prevents a qualitative recycling

This paper proposes a eco-design methodology to **Unlinear** existing products by understanding how they could be redesigned to (1) be dismantled and (2) be made with material that could be recycled, while retaining functional (e.g. Durability) and non-functional properties (e.g. Aesthetic choice). Our approach is based on a functional analysis of the structural decomposition of the existing product by a team of stakeholder in the design and production of the product from various background (e.g., designer, product engineer, and salesperson).

2 IDENTIFICATION OF FACTORS INFLUENCING PRODUCT'S CIRCULARITY

It has been noted that at present, there is few quantity of textile fibers recycled in close loop (only 1%). One of the challenges for the textile industry will therefore be to increase this ratio and to allow clothes at the end of their life to be recovered in quality.

To do this, integrating end-of-life from the (re)design phase is an important means to activate. This means providing for the recovery of materials from the initial design phases as well as the dismantling of the product.

An important product dimantling and recycling brakes is product complexity. In fact the more complex is a product, the more dismantling steps it will be. It is therefore important to be aware of these sources of complexity in order to target them during the redesign phase.

A way to help identify areas of complexity to be changed/removed from a product is to adopt functional reasoning. This allows you to target the essential functions of the product and identify the components or materials that provide them.

2.1 Identification of Product Dismantling Complexities

To be able to scope products design choices that prevent a high quality recycling of it, it is important to identify clearly, its complexity sources.

The project takes its roots in two industrial case studies where the goal was to define a dismantling process for complex products. These two studies were on shoes and complex garments. To do this, a systematic approach inspired by design thinking process with divergence and convergence phases have been used in order to analyse the product and propose a dismantling process. The different steps of the process were:

- **Understand the product:** Dismantling the product to understand the way components are assembled and the material used.
- **Prioritization of recycling challenges:** Categorization of extracted materials and classification the dismantling steps according to the difficulty of carrying them out. Extracted material categories must integrate a recycling channel and must be enough significant in volume to have an economical interest to be recycled. Otherwise, these materials will be landfilled.
- **Generating a generic dismantling process:** Summarize the observations on a standardized way to represent the dismantling process. Each stage of dismantling is illustrated with the technologies available or that can be envisaged to carry it out as well as the materials that can be recovered. The generic dismantling process is represented with high level dismantling steps in black. They correspond to product sub-assemblies. In each high-level steps, important operational dismantling steps are detailed to complete sub assembly full dismantling (see Fig. 2).

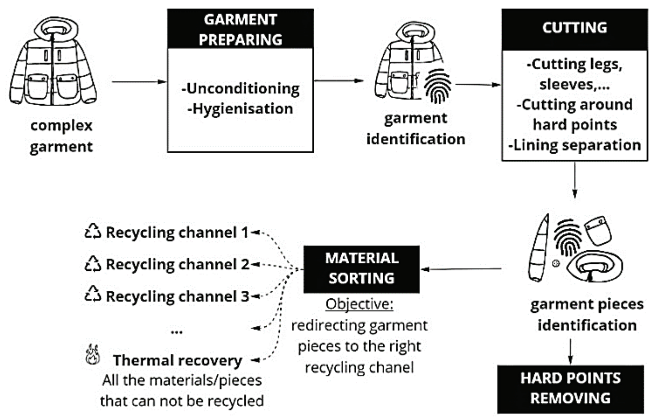

Figure 2 Complex garment simplified dismantling process

This complexity will constitute challenges to product recycling. As the Fig. 3 illustrate it, ten criteria have been proposed to define complex garments. These criteria were identified by gathering insights from product designers from brands and by a literature review [13, 14]:

	COMPLEX GARMENT		
SOURCES OF COMPLEXITY	A) MATERIALS	B) ASSEMBLIES	C) HARD POINTS
CRITERIA	• Number of fabrics (colors and materials) • Number of layers of different materials • A fabric with multiple materials • The ennoblement and treatments	• Reversibility of glued assemblies • Reversibility of stitched assemblies • Accessibility of assembly parts	• Kind of hard points • Number of hard points • Location of hard points

Figure 3 Identified sources of complexity for a garment

This set of criteria constitutes the whole elements to be considered to evaluate the complexity of a garment. It is difficult for a designer to consider all these criterias on a garment at the same moment. We propose to break down the product as a sum of components. A component is an element of the final assembly. Each component is defined by the material is made, its function in the assembly and its own recyclability. The assemblies and the accessibility of components influence the dismantlability of the product. It justifies the necessity to have a tool that allows modelling all these information about the product in a simplified and understandable way.

Unlinear represent the product as the sum of component it is made of. It is necessary help to identify through the component representation the obstacles to the circularity of the product. It could be used in a circular product redesign process to target the components or parts hindering circularity and make changes. Component's functions or material they are made of could be useful to help product designers to take decisions.

2.2 Related Work to Functional Reasoning

It is well accepted that nowadays a product is not only an artefact but an experience providing meanings and values to user all over the product lifecycle.

With the ecological awareness, the depletion of raw resources, the revalorisation of finished products has become an industrial issue and a challenge for designers to provide meaningful products and strong values to users.

These functional and emotional values are the result of designers' choices within the design process. Selected colours, used materials, all these choices are made on one side with a functional point of view like the strength, permeability or flexibility of a material. On the other side these choices are perceived and felt by users and provide them an emotional value [15]. In order to revalue a product, it is interesting to identify the high-value technical and emotional functions of the product that can be reused.

Regarding technical functions, there are different approaches in the field of engineering to break down a product into technical functions. These include Functional Analysis and Quality Function Deployment.

The Functional Analysis is a method of structuring the functions and sub-functions of a product hierarchically down to the technical and technological solutions that provide them [16]. Applying this method and especially several tools related like Structured Analysis and Design Technic (SADT) or Function Analysis System Technic (FAST) provide designers a global representation of the product and its technical function. Despite this method allows to identify all function of a products it does not provide information about the values of these functions. The Quality Function Deployment can help in this way by associating price, esteem, or pleasure value to these functions.

About the emotional value, designers' choices concerning colours, materials and more generally product attributes, strongly determine the user's experience [17]. Each attribute is felt and perceived by users, providing them meanings, affects and emotions and thus a subjective value to the product.

During the redesign phase of a product, it will be important to consider both technical and emotional functions.

3 UNLINEAR, A METHODOLOGY TO SUPPORT CIRCULAR PRODUCT REDESIGN

3.1 Unlinear methodology description

The complexity of footwear and clothing make it difficult for a brand's teams to rethink the design of their product outside of eco-design and life cycle analysis improvement. Transitioning towards more circularity [18] implies to decouple the composition of the product from its assembled physical version. This meant allowing the designer to isolate all the components, to be able to study their interest alone and then to move on to a more global approach and to examine the product and the way it is assembled**.** The aim is to create a clear, simplified, and generic modelling of the product and its components to question the product design. Designers to propose more circular products alternatives will use this modelling.

It is for this purpose that the Unlinear method was created. It is a methodology, which aims to facilitate circular product redesign by giving designers insight about the product. This method consists of 5 steps:

1) **Product dismantling**: To enable designers to understand the product: its components, the way they interact and their assembly.
2) **Completing the Unlinear facilitation cards**: These cards are a redesign facilitation tool. Each card represents one component of the product. It is necessary to fill each card with: the material used, the name of the component it represent and the function of the component. These facilitation cards are detailed below
3) **Product mapping:** It is the moment when the redesign team go back at the product dimension. To do this, cards that have been completed are used and product assembly links are represented. These links are those identified in the first phase.
4) **Product design critical analysis:** Identification of the obstacles to product circularity by using the product mapping. Participants have to ask themselves:

- Is component's function essential? Can it be removed from the assembly?
- Is the component easily extractable?
- Is the component recyclable?
- Is it possible to replace the material of the component?
- Can the function of the component be assumed by another component?

5) **Generate product redesign proposals: B**uild on identified design obstacles in the previous phase to provide solutions. The aim is to make the product more circular and recoverable at the end of its life.

3.2 Unlinear Facilitation Cards

The role of the Unlinear facilitation cards is to allow workshop participants to identify all the product components individually without considering them as part of the product and to represent them with a standardized aspect: hexagons. In a second time, the interaction between components is studied while the product mapping phase.

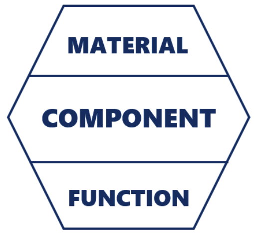

Figure 4 Unlinear facilitation card

As we can see above, these cards are filled in with 3 different information:

- **The material the component is made of:** This information enables workshop participants to know each material in the product and to target non-recyclable components in order to replace them.
- **The name of the component:** This information aims to help the redesign team to precisely identify each component.
- **The function:** This information represents the main function performed by the component. It helps in the redesign phase to prioritize the components for which modifications are required according to the importance of the function they perform and the value it gives to product. This type of functional analysis is also inspired by building and disassembly research. This research proposes to move to a model where each function/component pair is independent [16]. This independence favors the dismantlability of the product and therefore its circularity.

4 CASE STUDIES: WORKSHOPS WITH 2 FASHION INDUSTRY BRANDS

4.1 Workshops Description

To validate the methodology, two experiments took place with shoe and clothing marketers. For confidentiality issues, their name was anonymized and called brand A & brand B. The redesign workshop with brand A took place in March 2021 and the one with brand B in March 2021.

The product chosen by brand A was a high heel shoe. It was a complex shoe made of leather with a heel and a large amount of accessories. The number of components present in this shoe made it impossible to recycle it at the end of its life.

Brand B defined 4 "categories of product" of circular redesign:

- **Aquatic vision**: The team had to work on complex swimming goggles for advanced swimmers.
- **Mobility**: The team had to work on fins, children's buoy and pool shoes.
- **Swimming**: Several men's and women's swimsuits were being redesigned.
- **Wetsuits:** Participants were asked to work on a mid-range wetsuit.

The objective of these brands through these workshops was to use the methodology by taking their products and to identify solutions for improving their circular potential.

Each workshop followed Unlinear methodology:

- Presentation of Unlinear methodology
- Workshop participants were divided in groups, taking care to distribute the participants' profiles: The following profile of employees were mobilized: designer, product design engineers' production manager, seamstress, buyers, CSR department… The objective was also to see the collaboration between technical profiles and to identify their complementarity during the redesign work.
- Workshop proceedings.
- Feedbacks and analysis about the methodology interest.

Table 1 Unlinear workshop's summary

	Brand A	Brand B			
Workshop duration	3 hours	4 hours			
Attendees profile	Designer, product design engineers' production manager, seamstress, buyers, CSR department				
Number of attendees	13	31			
Number of groups	2	4			
Number of attendees per group	6-7	5-11			
Product	High heeled Shoe	Swimming goggles	Fins, Pool shoes, Children's buoy	Swimsuits	Wetsuits

Expectations through these experimentations were to:

- Validate the interest of using Unlinear methodology in a circular redesign process.
- Study how a schematic way to represent a product enables different profiles to collaborate while redesigning it.
- Study the interest and the complementarity of different profiles collaboration.

  Identify research axes to ameliorate methodology's efficiency.

4.2 Workshops' Results & Analysis

The redesign of the products presented allowed identifying 3 benefits about using Unlinear in a circular product redesign process. The use of the methodology allowed to:

- **Illustrate product complexity**

Initially, wetsuits were a product perceived as non-complex by the redesign team. As it is shown below with the Fig. 5, the Unlinear facilitation tool illustrated the complexity of this product with 31 cards used to represent the whole wetsuit. The complexity comes from the hard points, the welding and its main material: the neoprene (which actually is not recyclable in close loop).

The complexity of the high-heeled shoe was also shown. To enable respect the duration of the workshop, il was decided to divide the shoe in two sub-assemblies: the sole and the upper part. Each group was working on one part of the shoe. Finally, to represent this shoe more than 30 cards were used. It demonstrates the complexity of the shoe and the difficulty to recycle each component in the right recycling channel.

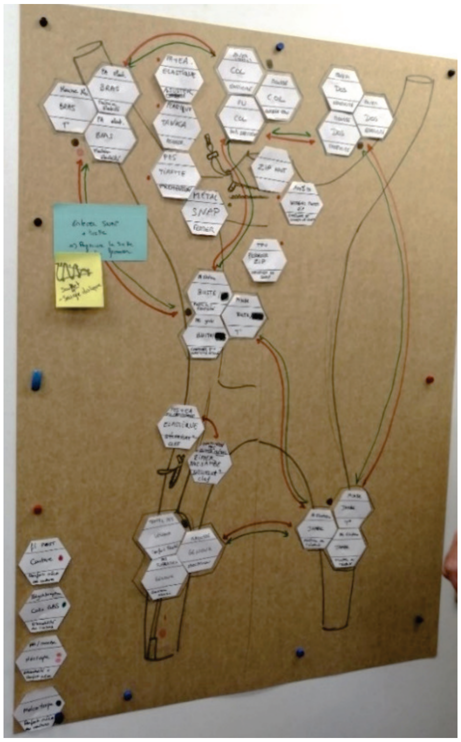

Figure 5 Wetsuit's representation with Unlinear methodology

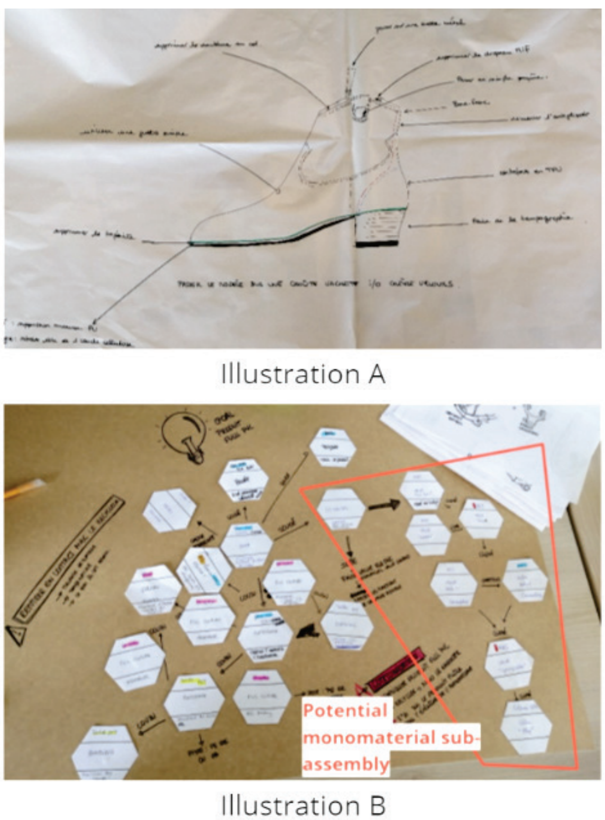

Figure 6 Illustration A: Circular redesigned high heeled shoe. Illustration B: Children's Buyo alternative design proposal

- **Generate more circular product alternatives:**

The methodology enabled for swimming goggles and for brand A high heeled shoes to remove from their product each component without an essential function. It led to design a clean product where each component ensures one essential function in the assembly. The Fig. 6 - Illustration A represent a circular alternative of the high-heeled shoe of brand A designed at the end of workshop.

The methodology allowed to identify product sub-assemblies which can potentially been made in the same material. It will reduce the amount of dismantling steps and generate a more circular alternative. The valve of children's buoy can potentially be made with only one material at is shown in Fig. 6 - Illustration B.

- **Highlight inconsistencies in product design**

The component-by-component study allows the workshop participants to question the presence of the different components. Thus, during the study of certain swimsuit components, reinforcement components were identified as being replaceable. Expert profiles such as seamstresses proposed alternatives to reinforcing materials by means of sewing. The Fig. 7 illustrate it with the identification of components that can be removed.

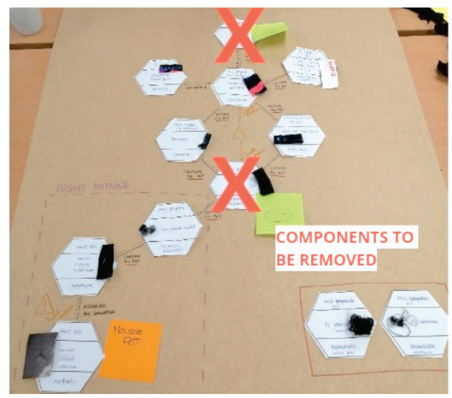

Figure 7 Swimsuit components to be potentially removed

Table 2 Product redesign observations

Benefits of Unlinear	Product	Observations
Illustrate the product complexity	Brand B - wetsuit	The complexity of materials and accessories was shown
	Brand A— - High heeled shoe	The complexity of shoe's sole and its upper part has been demonstrated
Generate circular product alternatives	Brand B - swimming goggles	Design choices: remove each component without an essential function
	Brand A - High heeled shoe	Design choices: remove the welt, remove the inner collar lining and switch to raw edges, remove the French flag or replace the leather pull tab with metal.
	Brand B - pool shoes	To design a monomaterial pool shoe
	Brand B - swimsuit	To replace flockings on swimsuits by embroideries to eliminate disruptors to fibre recycling
	Brand B - children's buoy	The valve sub-assembly of the buoy has been identified as an assembly that could become mono material. This presents a challenge for brand B considering the amount of valves present in their products
Highlight inconsistencies in product design	Brand A - High heeled shoe	The presence of a cambric in the shoe was not necessary, it could be removed
	Brand B - swimsuit	The team identified the presence of unnecessary components or seams.

Tab. 2 is listing the product redesign observations and their categorisation among the 3 identified benefits of using the method.

5 CONCLUSION

We proposed in this paper a methodology to help people to redesign product under circular perspectives. We focused our proposition on the use of a facilitation tool to represent product under a formal and standardized form that help to redesign circular product. We tested this method during two workshops where the objectives were to design circular alternatives to existing products.

As a result, we demonstrated the interest of the methodology in circular product redesign process. We have also been able to identify 3 benefits about using this methodology from our experiments. This methodology enables the collaboration and the complementarity of different profiles during the product redesign phase.

Several next steps have been identified:

- Adopt a way of systematically representing assembling elements according to the complexity of dismantling them. The objective is to allow identifying visually on the product mapping all the assemblies, which could cause problems to product total dismantling.
- Couple this methodology with quantified indicators to validate the redesign phase of the product. These could be indicators such as the environmental impact of each component, their recyclability or their durability.

Notice

The paper will be presented at MOTSP 2022 – 13th International Conference Management of Technology – Step to Sustainable Production, which will take place in Primošten/Dalmatia (Croatia) on June 8–10, 2022. The paper will not be published anywhere else.

6 REFERENCES

[1] IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

[2] ISO. (2002). ISO 14062:2002: Environmental management — Integrating environmental aspects into product design and development, International Organization for Standardization, Geneva

[3] McDonough, W. & Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things.

[4] Ellen Mac Arthur Foundation, (2017). A New Textiles Economy: Redesigning Fashion's Future; Ellen Mac Arthur Foundation: Isle of Wight, UK,

[5] Achterberg, E., Hinfelaar, J., & Bocken, N. M. P. (2016). Master circular business models with the Value Hill. *White paper*.

[6] Desore, A. & Narula, S. (2018). An overview on corporate response towards sustainability issues in textile industry. *Environment, Development and Sustainability, 20*. https://doi.org/10.1007/s10668-017-9949-1

[7] France, Ministère de la transition écologique (2020). Loi relative à la lutte contre le gaspillage et à l'économie circulaire 2020-105. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000041553759 (Accessed: 01.11.2021)

[8] Re_Fashion. (2020). Challenge de l'innovation #10. https://refashion.fr/pro/sites/default/files/fichiers/MAG_INNOVATION_10_REFASHION_A4_WEB_EXE.pdf (Accessed: 02.11.2021)

[9] Newsweek. (2021). Fast Fashion is creating an environmental crisis. https://www.newsweek.com/2016/09/09/old-clothes-fashion-waste-crisis-494824.html> (Accessed: 02.11.2021)

[10] Kriwet, A., Zussman, E., & Seliger, G. (1995). Systematic Integration of Design-for-Recycling into Product Design. *International Journal of Production Economics, 38*, 15-22. https://doi.org/10.1016/0925-5273(95)99062-A

[11] Bralla, J. G. (1996). Design for Excellence. New York: McGraw-Hill.

[12] Rios, F., Chong, W., & Grau, D., (2015). Design for Disassembly and Deconstruction - Challenges and Opportunities. *Procedia Engineering, 118*, pp.1296-1304. https://doi.org/10.1016/j.proeng.2015.08.485

[13] Orée, (2020), livret d'éco conception des vetements professionels: Retours d'expériences du projet FRIVEP, Orée

[14] Re_Fashion, (2014), Etude des perturbateurs et facilitateurs au recyclage des textiles et linges de maison. Re_Fashion. https://refashion.fr/eco-design/sites/default/files/fichiers/%C3%89tude%20des%20perturbateurs%20et%20facilitateurs%20au%20recyclage%20des%20textiles%20et%20linges%20de%20maison.pdf (Accessed: 02.11.2021)

[15] Schütte, S., Krus, P., & Eklund, J. (2008). Integration of Affective Engineering in Product Development Processes. *Quality Management and Organizational Development Conference*, Helsingborg, Sweden, pp. 651-660.

[16] AFNOR. (2014). Management de la valeur - Vocanulaire - Termes et definitions. (NF EN 1325)

[17] Gentner, A., Bouchard, C., Esquivel, D., & Favart, C. (2013). Mapping a Multi-sensory Identity Territory at the Early Design Stage. *International Journal of Affective Engineering, 12*(2), 191-200. https://doi.org/10.5057/ijae.12.191

[18] Heijden, R., Coenen, J., & van Riel, A. (2017). Transitioning from a linear economy towards a circular economy: The case of the apparel industry. https://doi.org/10.31885/2018.00002_3

[19] Durmisevic, E. (2006). Transformable building structures - Design for disassembly as a way to introduce sustainable engineering to building design & construction. *PhD Thesis*, TU Delft.

Authors' contacts:

Bixente Demarcq
(Corresponding author)
Ingénieur d'étude – ESTIA,
90 allée Fauste d'Elhuyar, Technopole Izarbel,
64210 Bidart, France
b.demarcq@estia.fr

Dimitri Masson
Enseignant chercheur – ESTIA,
90 allée Fauste d'Elhuyar, Technopole Izarbel,
64210 Bidart, France

Jérémy Legardeur
Enseignant chercheur – ESTIA,
90 allée Fauste d'Elhuyar, Technopole Izarbel,
64210 Bidart, France

Antoine Millet
Enseignant chercheur – ESTIA,
90 allée Fauste d'Elhuyar, Technopole Izarbel,
64210 Bidart, France