Circular perspectives in Design Education: Packaging disassembly as a tool for enhancing critical thinking

Circular Perspectives in Design Education

Packaging Disassembly as a Tool for Enhancing Critical Thinking

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Abstract
The new Circular Economy models prompt designers to relocate artefacts within socio-technical systems in which the value of the product, its components, and its materials are maintained and not wasted. Design tools such as product disassembly are not only gaining new impetus in the design field but are also becoming important educational resources. In the past, the strategies of Design-for-X and Design for Disassembly have only dealt with technologically complex products, but today, the contextual turn of the challenges that designers must face requires urgent reflection on everyday products. In particular, packaging combines environmental and functional issues with important communication requirements, thus bridging different design disciplines. The paper presents and discusses the case study of a packaging disassembly exercise carried out within the Politecnico di Torino. The results show the effectiveness of disassembly as a design tool to analyse everyday products and foster the critical and forward-looking attitude of young designers.

Keywords
Design education
Circular Product Design
Product disassembly
Packaging
Sustainability

Sustainability Issues in Design Education

In a recent study, Don Norman addressed the issues of design education in the 21st century by making an important premise: there are different design disciplines, from design engineering to design science, but what we refer to is one broad class of Human-Centred Design, and "by this we mean simply designers who design for people and society" (Meyer & Norman, 2020, p. 14). Beyond the divergences around the "human-centred" concept, it is worth noting that designers — as we understand them — are characterised by the intent and, ideally, the ability to design products, services, and systems for humankind. From this perspective, design education has the responsibility to foster the social role of design and to guide future designers in developing greater sensitivity and responsibility towards social and environmental issues (Frascara, 2020). However, in professional practice, and hence in educational processes, a designer is called upon to face several challenges involving different levels of action which are not necessarily easy to reconcile, especially in the field of sustainability (Ceschin & Gaziulusoy, 2019). Design students should address open-ended challenges that must be framed at various levels: from components to products, systems, and communities (Davis, 2018). Friedman (2012) divides design challenges into three macro-groups: performance challenges, related to what a designer must do to tackle individual professional problems; substantive challenges, related to the complexity of the scope, needs, and artefacts that a designer must address; contextual challenges, related to the complexity of the multi-stakeholder and cross-sectoral environments in which a designer must act. These challenges take on different connotations according to specific design disciplines, but whether it is a product, a service, or a system, designers address human needs by acting on the physical world. For this reason, design education has always started from artefacts, tackling the performance challenges posed by industrial products. Even today, design education should start from the product level, but aim to broaden the perspective on artefacts to show students the embedded links to substantive and contextual challenges. In particular, current socio-environmental challenges lie at the last level, and require new analytical and synthetic planning skills from designers to deal with wider frameworks.

A Contextual Turn In Sustainable Products: Towards Circular Product Design

In the 1990s, the focus on the environmental impacts of production processes resulted in new design approaches based on the product life cycle, which took on different disciplinary interpretations. Some pioneering companies experienced the benefit of 'concurrent engineering', i.e. a life-cycle design method to increase design efficiency, optimise costs, reduce development time, and improve product performance. This approach introduced several tools that fall under the umbrella of Design-for-X (DfX), where 'X' refers to different properties related to one or more aspects of the process: manufacturing, quality, reliability, assembly, but also new environment-oriented methods related to the disassembly and recycling of industrial products (Kuo

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et al., 2001). Over the same period, industrial design introduced concepts such as Ecodesign and green product design that, like DfX, aimed to bolster business competitiveness in response to the growing demand for environmental performance, though still with a limited approach to product sustainability (Cruel et al., 2009). DfX and Ecodesign had many points of contact. Among them, Design for Disassembly (DfD) proved to be a key tool for environmental sustainability, as it "focuses on how to design easily disassembled products; meaning that the parts and materials can be easily and economically separated. The possibility of easy separation of the parts facilitates the maintenance, repairs, updating and re-manufacturing of the products" (Vezzoli & Manzini, 2018, p.181). Designing for end-of-life has contributed to triggering an evolution of Ecodesign to include both the social and profit elements of production, becoming what is now defined as sustainable product design.

Given this evolution, DfD displayed the weakness of a narrow approach that focuses on end-of-life only. However, the concept of disassembly remains a key asset for sustainable product design, especially in the current debate around product longevity that has been re-introduced by new circular economy models (Cooper et al., 2015). In particular, Circular Product Design includes a set of strategies supporting designers and manufacturers to improve the long-term sustainability performance of their products (Mestre & Cooper, 2017). The main principle is "designing waste": placing the product in a circular economy in which the value of the product, its components, and materials are maintained and not wasted, aiming at superseding the *take-make-waste* linear economic model. This shift towards Circular Product Design is contextual: the process is not a single event to be made more sustainable but is designed in synergy with its technological, social, and economic system. In this perspective, the recycling of products and materials is overtaken by new strategies for "closed loop value recapture" (Crul et al., 2019), based on maintenance, reuse, and refurbishing. Rather than a unified approach, Circular Product Design is an emerging plurality of design strategies related to the product dimension. This new perspective leads to two emerging outcomes: the first is a widening of the design approach from the product to the system it is set in. The second is a new focus on components and product disassembly, which becomes a priority in circular business models.

Product Disassembly as a Tool for Design Education

As seen above, Circular Product Design adopts a DfD logic by designing products that provide the possibility of maintenance, recycling, and reuse of the item or its components. This design process requires specific environmental sustainability skills and technical knowledge. Hence, designing a maintainable, reusable and recyclable product requires an understanding of the dynamics of assembly/disassembly and their environmental impacts. Although the design literature on product disassembly is poor, the grey literature shows numerous experiences related to product deconstruction in design education Fig. 1. This educational exercise has been adopted by inde-

pendent bodies, such as the *Product Deconstruction Challenges* promoted by the DesignEd CIO (Oxnevad, 2015), the blog series by the *Great Recovery Programme* (2016), and by independent professionals. Moreover, platforms such as iFixit (2020) have brought the disassembly approach and the visual language of product deconstruction into the public domain, also benefiting design practitioners.

Regarding higher education institutions, TU Delft has implemented the *HotSpot Mapping for product disassembly* methodology (Flipsen et al., 2020), which is employed in research projects but also university courses and MOOCs concerning Circular Product Design. The common goal is to understand and visualise how products are designed, made, used, and disposed of through physical disassembly. In some cases, disassembly adopts a figurative approach to show complexity, while in others, the analytical approach aims to assess and understand the relationships between components from a functional and environmental perspective.
Often these methods are applied to complex artefacts, such as

Fig. 1
Examples of product disassembly.

digital devices or household appliances, as these products have a high economic and environmental cost and a relatively long life-cycle. Indeed, disassembly is mainly seen as a reparability assessment method for maintenance. Although this choice is appropriate, it may limit disassembly techniques to certain types of products and design disciplines. For example, everyday products and communication aspects are not considered.

In this paper, we argue that product disassembly is a relevant tool for design education that can also be applied to low-complexity products, addressing functional and environmental issues, but also communication features. The paper presents the case study of packaging disassembly within the Environmental Product Requirements course (Bachelor's degree programme in Design and Communication at the Politecnico di Torino), and it discusses the results achieved in terms of sustainability awareness and product design skills.

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Case Study: Simplified Packaging Disassembly Method at the Politecnico di Torino

The scale and complexity of current distribution systems demand medium-high technical performance from packaging, which has been the subject of pressing debates on environmental sustainability in recent years. While most packaging still has a short life cycle based on the distribution and short-term use of the products it contains, the packaging sector is increasingly witnessing patterns of reuse and regeneration. At the same time, packaging is more than ever a communication medium between producer and user, facilitating interaction and conscious purchasing. The dual functional and communicative value makes packaging an exciting object of study for both product-oriented and communication-oriented designers.

In the first half of the Bachelor's Degree Programme in Design and Communication at the Politecnico di Torino, students tackle fundamental subjects of the design profession before choosing a specialisation in product design or communication design. The Environmental Product Requirements course is part of the 'Design and Sustainability' module and addresses the historical and methodological issues of sustainable design. Alongside the theory, the course includes a practical exercise to enable students to apply the knowledge gained. Since 2019, the lecturers have introduced a practical exercise based on a simplified packaging disassembly method. Indeed, packaging is a "bridge" between different design disciplines, as well as a valuable topic to understand the environmental implications of design. The adopted methodology has been developed over the years in the field of Component Design (Bistagnino et al., 2008; Fiore, 2018) but – much like the above-mentioned *HotSpot Mapping* technique by TU Delft – it mainly aims at evaluating complex products in terms of accessibility and maintenance. Therefore, a simplified method has been designed to facilitate the learning and application of the disassembly technique, suit the peculiarities of packaging, and include relevant analysis criteria such as the communication factors. The analysis pattern addresses sustainability issues that, as stated above, are relevant in circular economy models: material optimisation, reuse strategies, end-of-life management, communication of materials and components, and information transparency.

The exercise was tested in three consecutive courses involving 491 students, who were then surveyed to evaluate the educational outcomes.

The exercise is carried out in teams. Each team is assigned a trainer who facilitates the entire methodological process and, above all, encourages critical thinking through group discussion.

The exercise consists of four phases:

1 *Analysis of existing case studies in a given category*: students identify and classify good packaging practices on the market that are relevant from an environmental, functional, and communicative point of view.

2 *Contact with the company or studio*: together with the tutor, each group identifies two good practices and then contacts the manufacturer or designer to receive a physical packaging sample.

3 *Simplified packaging disassembly analysis*: guided by the tutor, each group carries out a qualitative and quantitative analysis of the packaging, starting from its disassembly. The analysis focuses on environmental sustainability, functionality, and communication. Literature and methods developed within the Observatory of Eco-Pack have been a reference for the analysis (Barbero & Tamborrini, 2012).

4 *Packaging comparison*: students analyse good practices and standard packaging on the market in the same product category. By correlating them in a comparative table, they draw up a report on the category, including a critical analysis of what they have analysed.

Figure 2 shows a good practice and its disassembly. The visualisation adopts the exploded view to show the different packaging elements, indicating the components and materials. The analytical approach allows evaluation of the relationships between different parts of the packaging, identifying critical points and advantages.

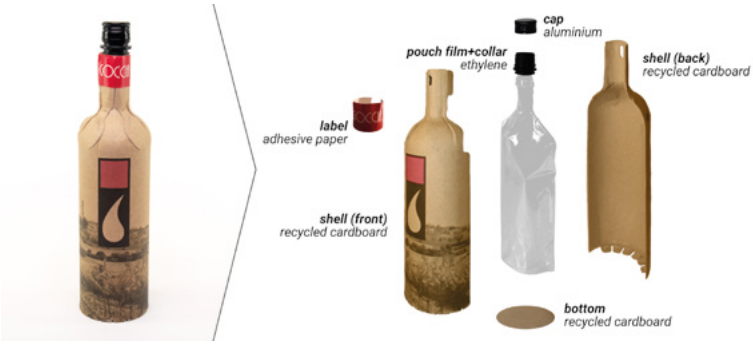

Fig. 2
Example of a packaging disassembly visualisation by Pera S., Salazzari F., Signetti A., Solavaggione M., Tilocca D., Valperga L., 2021.

Analytical product disassembly methods often use component datasheets to map and quantify the disassembly effort and the functional, environmental and economic issues of different components. These tools deepen the knowledge gained through disassembly and visualisation but limit the analysis to quantitative aspects. In order to overcome this limitation, qualitative indicators were introduced into the analysis. Table I shows the 11 indicators that students have to assess and report: the evaluation scale guides the analysis but is intentionally generic, as it requires students to develop a personal understanding of the packaging, especially from a functional and environmental point of view. Students discuss the evaluation with their tutor, sharing reflections on the different issues analysed.

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Tab. I
Qualitative indicators for packaging assessment.

Indicator	Description	Evaluation scale
FUNCTION		
Space optimisation in storage and transport	Packaging has a regular shape that optimises storage and transport.	From 1 (irregular shape + not stackable)To 5 (regular shape + stackable + excellent pack/product ratio)
Product protection and preservation	Packaging effectively meets the actual product needs for protection and preservation.	From 1 (product is damaged or has altered physical/organoleptic properties)To 5 (product is well stored/protected in relation to its actual requirements)
Ease of use	Packaging enhances product usage by different targeted users.	From 1 (difficult to open + does not facilitate the product use/dispensing) To 5 (easy to open + facilitates product use/dispensing for all users)
SUSTAINABILITY		
Overpackaging	Packaging includes overpacks for functional or aesthetic purposes.	From 1 (one or more overpacks + over-protection) To 5 (no overpack + a limited number of components)
Composition and separability of materials	Packaging comprises different components, which can be identified, separated, and recycled.	From 1 (many components whose materials are difficult to identify and separate) To 5 (one-material packaging or made by few components from the same recycling stream)
Weight-to-volume ratio	The size and weight of the packaging are proportional to the product it contains.	From 1 (package/product volume ratio <50% + heavy compared to product) To 5 (package/product volume ratio >90% + light compared to product)
COMMUNICATION		
Appeal	How packaging appeals to users in-store	From 1 (not at all) to 5 (very much)
Identity	How packaging communicates the brand and the product category	From 1 (not at all) to 5 (very much)
Identity	How packaging communicates the brand and the product category	From 1 (not at all) to 5 (very much)
Message	How packaging conveys the message the company aims to communicate	From 1 (not at all) to 5 (very much)
Information	How packaging provides information (origin, end-of-life, etc.) about the product and itself	From 1 (not at all) to 5 (very much)
Affordance	How communication facilitates the interaction and use of packaging	From 1 (not at all) to 5 (very much)

Figure 3 illustrates the two final tables in which students summarise their disassembly analysis by visually reporting the results of the functional, environmental and communicative evaluations. On this basis, students draft a final report that shows their critical reading of the analysed packaging and the investigated product sector.

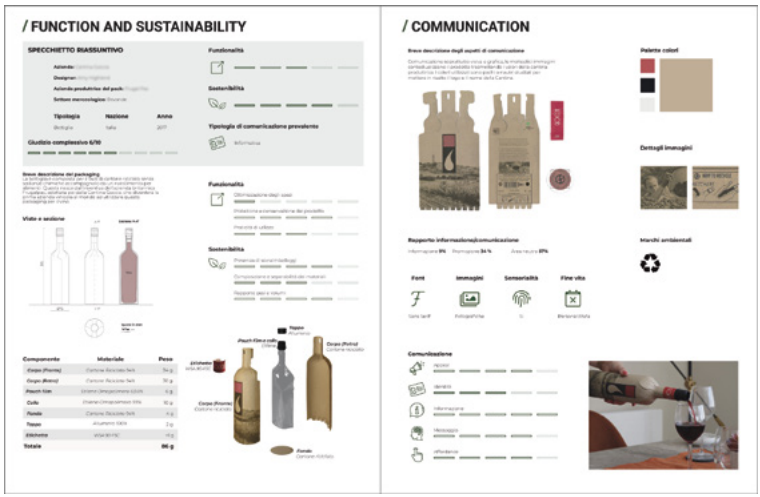

Fig. 3
Example of a simplified packaging disassembly analysis by Pera S., Salazzari F., Signetti A., Solavaggione M., Tilocca D., Valperga L., 2021.

Educational Outcomes of Packaging Disassembly

Beyond the methodological considerations, the case study enables us to evaluate the effectiveness of product disassembly as a tool to create knowledge and awareness of sustainable design issues among students. Literature shows how product disassembly has usually been applied to the analysis of complex products. In the case study, the method was adapted to analyse everyday low-complexity products by extending the scope to usability, communication, and packaging-related issues.

After each of the three courses, students were asked to take part in a survey, to understand and measure how the exercise improves different skills and which students perceived the exercise to be more useful within the bachelor's programme. The latter is relevant, as the bachelor's degree has recently changed curriculum (Tamborrini & Remondino, 2019), and the Environmental Product Requirements course has been included in a new Design and Sustainability module in the first year.

The survey has been divided into four sections: general data, sustainability, skills, general evaluations. Each section was assessed through a series of questions about the training and exercise carried out, of which at least one was open-ended to allow students to report qualitatively on their experience. In addition, some questions were asked about the participants' education (year of the bachelor programme and chosen design specialisation).

The pool for this survey included 491 students, while the final sample comprised ninety-three respondents (response rate: 19%), representing a statistically relevant sample for the study. To

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analyse the results, we decided to divide the sample according to the year of attendance of the students, as in the second and third courses there were both first-year and third-year (students who postponed the course by one year) bachelor's participants. Therefore, we have analysed the three groups shown in Figure 4, which are equally divided between communication and product design students.

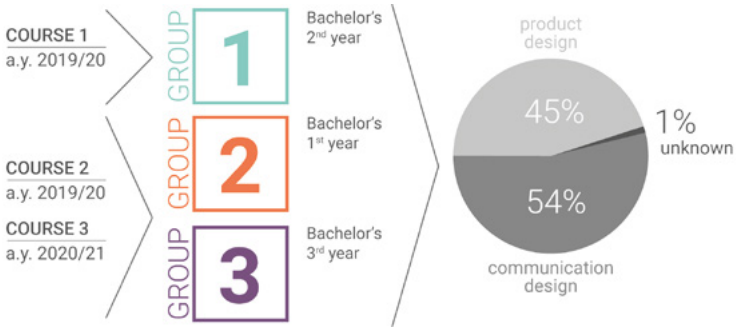

Fig. 4
Classification of the sample and breakdown by design discipline.

Figure 5 summarises the students' satisfaction, showing that 84% of the students are satisfied with the exercise (rating > 6 on a 10-point scale). Nevertheless, some aspects for improvement emerged, and the open-ended questions in the survey highlight how those were mainly related to the online implementation of the exercise due to COVID-19 restrictions (e.g. difficulties in remote teamwork, problems in joint management of digital files). Indeed, the first group of students to have carried out the exercise during the pandemic showed the lowest degree of satisfaction. However, the iteration of the exercise in the following year shows better results as some critical issues reported by the students have been solved, even though the exercise was still performed online. Finally, the survey shows that the topic of packaging disassembly is actually of interest to both design disciplines, showing comparable results in terms of satisfaction for product and communication designers.

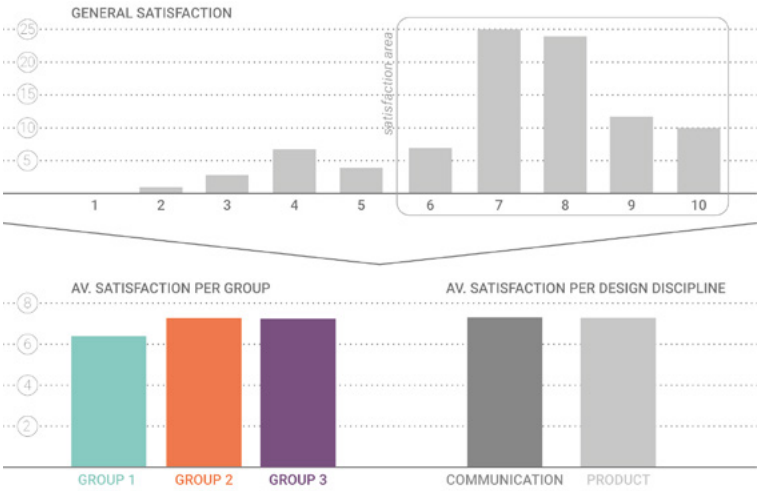

Fig. 5
Student satisfaction with the packaging disassembly exercise.

Another aim of the disassembly method exercise was to raise awareness and interest in environmental issues related to design. At the same time, the choice of packaging entailed acquiring skills related to design and, especially, packaging design. Figure 6 highlights that students felt the exercise significantly contributed to increasing their interest in the three topics. The breakdown by year shows that in group 3 (third year of the bachelor's degree), the impacts are lower: we can assume that the exercise and, more in general, the course are now appropriately placed in the first year of the bachelor's degree, targeting the students for whom it is most relevant. Finally, the proposed activities have the same impact on the product and communication design paths.

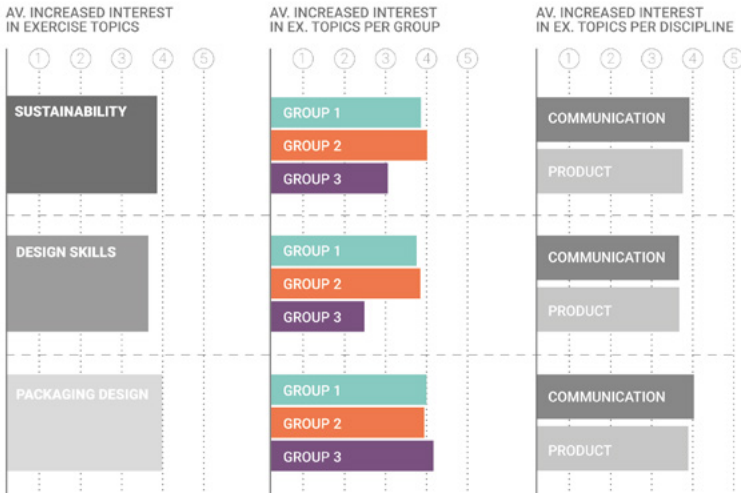

Fig. 6
Increased student interest in the exercise topics.

From a qualitative perspective, the students' work reached a medium-high level, not only in terms of ratings but above all in the critical understanding of the product, which especially emerged from the final reports. The students proved their ability to analyse packaging gaps, understand the required design compromises, and interpret the sustainability aspects in light of the product category requirements.

Within the survey, some open questions were asked about the strengths and weaknesses of the exercise. In general, appreciation emerges for "a methodological approach that can be applied in most cases" and allows "applying theoretical notions to a more practical matter". Furthermore, students confirm how they achieved a "growing awareness of environmental sustainability and what we previously took for granted", especially regarding the relationship between sustainability and communication. On the other hand, as mentioned before, negative aspects mainly concern the practical issues of remote work.

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Conclusions

The transition to the Circular Economy advocated by the European Commission is being implemented in the field of industrial design through Circular Product Design, which reinterprets the tools of DfD in the light of a broader vision that places products within systems designed to be sustainable and to avoid waste. As a result, methods based on product disassembly are experiencing new vitality in a context of increasing attention to maintenance, reuse and recycling.

Although not usually considered in DfD, we chose packaging as our object of study because it integrates function and sustainability with communication. This combination of packaging and disassembly proved to be effective in several respects. Firstly, the disassembly methodology, although simplified, was perceived by the students as helpful in acquiring knowledge not only in the field of sustainability but also in terms of design skills, with a possible application in other non-packaging projects. Methodological experimentation with a less complex product facilitated proper understanding of the tool, despite the difficulties of carrying out the exercise online. Secondly, packaging made it possible to extend the disassembly method to communication, prompting students to address critical and often unknown aspects of the role of communication for sustainability. From being the waste par excellence to being qualified as a medium between users, products and producers: the educational value of packaging lies precisely in boosting critical thinking in students. It leads them to understand the impact of their choices, to carry out a comparison between products, going beyond clichés and thereby deepening the design value.

The case study also provides important feedback for the Environmental Product Requirements course: survey results have shown that addressing environmental sustainability early in the design curriculum is effective and enables students to deal with the social and environmental impacts of the profession at an early stage. From such a perspective, a simple yet multifaceted product like packaging can become the prime challenge for students in new design curricula, pushing them to engage with design, communication and sustainability. Indeed, acquiring theoretical knowledge and learning practical tools is essential from the outset, not only because students face real projects and problems, but above all, because they begin to develop an aptitude for critically approaching contexts and events.

In the words of Richard Buchanan: “Education is more than training in skills and techniques. It is an intellectual preparation for life-long learning that cultivates the capabilities of the mind to encounter new situations and respond with ingenuity, imagination, and creativity” (Frascara, 2020, p. 109). In a world moving towards the complexity of Circular Economy and striving for sustainable development, sustainability education is a primary challenge for contemporary design. Beyond the impacts of models such as Circular Product Design, it is essential to use these tools as an opportunity to educate future designers to approach their profession with enlightenment, reflecting on *what* and *why* they design before *how* they design it.

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