Leveraging Insights from Unique Artifacts for Creating Sustainable Products

H. Zannoun[1(✉)], J. Okorafor[1], T. Asensio[1], G. Guedes[1], F. Badurdeen[1], P. Wang[1], I. S. Jawahir[1], G. Campana[2(✉)], M. Mele[2], and B. Cimatti[2]

[1] Institute for Sustainable Manufacturing (ISM) and Department of Mechanical & Aerospace Engineering, University of Kentucky, Lexington, KY, USA
hamzah.zannoun@uky.edu

[2] Department of Industrial Engineering, University of Bologna, Bologna, Italy
giampaolo.campana@unibo.it

Abstract. Sustainable manufacturing pursues the achievement of economic, environmental, and societal benefits by promoting the long-term use of materials, products, and components within a circular economy. The analysis of one-of-a-kind classical products reveal some designs that exhibit a creative combination of parts from a variety of industrial sectors. For example, Italian designers behind some innovative artifacts have managed to integrate components from different sources into attractive and emotional-oriented objects that are revered to this day. The present work aims to combine 6R-based sustainable manufacturing with insights gained from some classical products of Italian design characterized by simplicity and decontextualization of common objects. This manuscript presents the design process for leveraging concepts embodied in some unique artifacts from the Italian design movement to inspire the realization of sustainable products. A commercial household item was redesigned to demonstrate the application of the approach by utilizing end-of-life items collected from municipal solid waste. The potential benefits of the triple bottom line approach associated with leveraging concepts, such as those from Italian design, to develop more sustainable products is also discussed.

Keywords: Sustainable manufacturing · 6Rs · Italian design · Sustainable design

1 Introduction

The foundation of sustainable manufacturing (SM) is the triple bottom line (TBL): economic, environmental, and societal benefits. SM is achieved by means of the 6Rs: reduce, reuse, recycle, recover, redesign, and remanufacture, which enable closed-loop material flow [1]. Reuse and remanufacture are preferred strategies over recycling as it destroys most of the embodied energy (the resources invested into making products), but neither is possible without end-of-life (EoL) recovery strategies [1, 2]. One critical R that is most overlooked is redesign. The design/redesign stage dictates the extent to which closed-loop material flow is possible, and it requires thinking beyond a single

H. Kohl et al. (Eds.): GCSM 2022, LNME, pp. 1065–1073, 2023.
https://doi.org/10.1007/978-3-031-28839-5_118

loop [3]. If a product is not designed to be recovered and recirculated from the outset, then it becomes harder to apply the 6Rs approach as 80% of costs and sustainability impacts are determined during design [4].

Besides, as the world becomes more urbanized, there is more consumption of manufactured products and an increase in waste when those products are disposed. Municipal solid waste (MSW) is defined as items that are discarded from residential and commercial sources, or materials that have lost their value to the holder [5, 6]. More than 292 million tons of MSW was generated in the U.S. alone in 2018, and only 38.2% of it was recycled or composted [7]. Thus, integrated waste management, which is the handling of waste in an economically and environmentally sustainable, socially acceptable manner, becomes paramount [5].

This study leverages insights from the discipline of Italian design (ID). While it is difficult to give a univocal definition of ID, it can be said that Italian designers consider three benefits when creating a product: functional, emotional, and symbiotic [8]. This is supported by Bosoni [9], who states that the Italian designer is "*the antithesis of the engineer or technician concerned only with function or production*". Emotional and symbiotic benefits speak to the consumer on a level deeper than just the core functionality. This aspect of human nature is described by Verganti [10]: "*what matters to the user (in addition to the product's functionality) is the product's emotional and symbolic value—its meaning. If functionality aims at satisfying the operative needs of the consumer, the product's meaning tickles her or his affective and sociocultural needs*." Thus, Italian designers naturally have a different perspective on 'aesthetics' than designers from other schools of thought, especially those lacking a designer background, such as a corporate executive who thinks that design is purely styling [10].

The classical IDs that inspired this work (shown in Fig. 1) were designed by Achille and Pier Giacomo Castiglioni, brothers who pioneered the ID scene in the '50s and '60s. These designs represent a relevant development of ID, combining functionality, aesthetics, and simplicity. The Castiglioni brothers masterfully joined functionality and beauty in these three objects characterized by the principles of the Dadaist "ready-made" concept that decontextualizes common objects. They proposed the Mezzadro (Fig. 1a) and Sella (Fig. 1c) stools, which creatively combined components from different industrial sectors, realizing unique and iconic products. For instance, the Mezzadro utilizes a tractor seat, and the Sella utilizes a bicycle seat. All components were new, but instead of being employed in the product they were designated for, they were repurposed into a different product entirely. In 1962 they followed up this concept by proposing the Toio floor lamp (Fig. 1b), which encompasses a car headlamp (automotive industry), a fishing rod (sporting industry), and a transformer (electrical industry). All these products went on to become icons of ID and are still being produced to this day. Looking at these items from the lens of SM, they demonstrate opportunities to apply many of the 6Rs: common items (e.g., stool, lamp), were *redesigned* to incorporate components from various industrial sectors as materials, which enhances their long-term use and reduces efforts during manufacturing [11]. While the ID classics shown in Fig. 1 were not designed with the intent to promote SM, they do offer insights to deploy the 6Rs approach, and possibly extend their definition and meanings. For example, if the components were to be sourced from MSW (i.e., EoL items) instead, but keeping the decontextualization concept and origin from different industrials sectors, this could enable closed-loop material flow over multiple life cycles.

Fig. 1. Images of (**a**) Mezzadro stool [12]; (**b**) Toio floor lamp [13]; (**c**) Sella stool [14].

2 Methodology for Leveraging Insights from Existing Designs

2.1 Proposed Design Process

The aim of the present work is to bridge some ideas and concepts from ID artifacts with those from SM to synthesize new sustainable products. To illustrate the proposed design process for creating such products, the sustainable engineering design framework by Gagnon et al. [15] was adapted to align ID ideas/concepts with SM. The four stages of the product design process are described below (Fig. 2).

1. ***Planning & Problem Definition*****:** To incorporate different perspectives, the chosen design team should be multidisciplinary, including individuals from diverse backgrounds. The design principles (6Rs, closed-loop flow, aesthetics, etc.) and TBL sustainability goals should be established early on and investigated through literature review to broaden the design team's understanding. The planning process must consider all stakeholders' interests and possible inputs.
2. ***Conceptual Design*****:** The product/material requirements can cover the use of EoL items sourced from MSW. While some virgin materials (e.g., screws, paint, adhesives, etc.) may be required to fabricate the new products adopting the proposed approach, it is envisioned that most of the component usage for the products would consist of EoL items. Thus, the starting point is finding potential usable EoL items and compiling them into a list. The chosen items must be compatible for assembly into a final product such as those shown in Fig. 1. To meet the sustainability criteria, items should be selected based on their impact on the waste stream and accommodation for closed-loop flow.

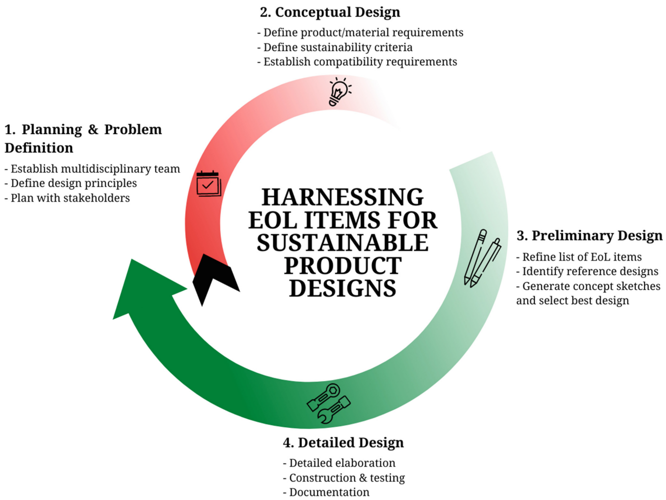

Fig. 2. Framework for leveraging insights from classical IDs to create sustainable products.

3. ***Preliminary Design*:** The previous list of EoL items must then be filtered to include only items suitable for a new life cycle by excluding single-use, disposable components that may be contaminated and cannot be treated/cleaned. Then, examples that offer opportunities to incorporate 6R-based sustainable design practices (such as the designs shown in Fig. 1) must be identified to serve as reference. The refined list of EoL items and the reference examples can then be used to inspire novel products. The integration of insights from ID classics is especially prevalent in this stage, as the design of products based on components taken from different industrial sectors implies high artistic creativity. The best design is determined by considering sustainability impact, functionality, ease of prototype construction, aesthetics, and stakeholder input.
4. ***Detailed Design*:** Once a design that satisfies the required criteria is selected, minor design modifications might be necessary to ensure feasibility and functionality. After the design is finalized, the next step is to procure materials for assembling a prototype. Then it must be tested and strained to guarantee quality and safety. Finally, the project should be documented for presentation to stakeholders.

2.2 Application of the Proposed Design Process

The above process was applied to redesign a common household item by building a proof-of-concept prototype from EoL items across different sectors. The three ID classics shown in Fig. 1 inspired this work for their 'out-of-the-box' thinking. Using this idea of combining miscellaneous EoL items into a new product, the aim was to see if usable materials and components could be incorporated to form new, sustainable products that are practical, affordable, and attractive. As MSW generation has been rapidly increasing, the vision here is that reusing EoL items for new products can contribute to landfill reductions. Additionally, it is not necessary to build new manufacturing tools to produce the components, because those components are currently available, and the manufacturing process is already established. This section discusses how each stage of the design process in Sect. 2.1 was performed to develop a sustainable prototype.

For Planning & Problem Definition, a multidisciplinary team of four members was formed. A literature review on the history of ID companies and products, as well as sustainable design practices, was conducted to establish an understanding of both disciplines. The team also studied different aspects of sustainability across the TBL.

For Conceptual Design, special attention was given to selecting items that had a major impact on the waste stream. To this aim an extensive web search was conducted to find the most common and impactful examples of MSW, and a list of 22 items was compiled. Some of the most notable (and eventually selected) identified items are:

- Polystyrene (PS) coat hangers and polyvinyl chloride (PVC) pipes: Coat hangers and piping are some of the most common uses for PS & PVC, respectively; 15 billion hangers are produced by the garment industry annually [16]. The CO_2 emissions generated from this is equivalent to the usage of 4 billion plastic bags or the emissions from 1.5 million cars [16, 17]. Millions of tons of PS & PVC products contaminate oceans at EoL in the form of microplastics every year, ensnaring marine species, leading to morbidity and mortality [16, 18]. Less than 1% of PS & PVC was recycled in 2018 [7]. What little is recycled is granulated into chips, which destroys the embodied energy. Another EoL recovery method is incineration, which is not viable for plastics because of the emission of toxic compounds [19].
- 2×4 wooden studs: Nearly all residential structures in the U.S. use traditional 2x4 wood-framing [20]. Recycling wood requires it to be ground and used for mulch or boiler fuel (again, destroying the embodied energy), so it is preferable to reuse in its whole form [20]. Diverting wood recovered from structures at EoL from landfills can significantly improve the energy and carbon balances of buildings, as landfilling creates large greenhouse gas emissions because of methane release [20, 21]. Wood recovery and reuse can also decrease deforestation because there is less need for timber harvest [21]. It is estimated that about 43–90% of solid wood waste is suitable for recovery and reuse [20, 21]. However, again signifying the importance of the design process, the recovery rate is highly dependent on whether structures are designed to facilitate the recovery of materials at EoL [22]. Only 17.1% of MSW from wood was recycled in 2018 [7].

For Preliminary Design, the list from the previous stage was filtered to remove items that were deemed unfit for a new life cycle, after which only 15 items remained. Next, the products in Fig. 1 were chosen as the reference designs for brainstorming. Using the filtered list of EoL items and the selected ID classics in tandem as inspiration, two concept sketches were produced by each member of the multidisciplinary team. The concepts were mainly furniture items, trying to imitate the examples in Fig. 1. Using feedback from stakeholders, the best design was found to be a coat rack constructed from PS coat hangers, a PVC pipe, and 2×4 wooden studs—coat hangers come from the garment industry and the latter two are found in multiple industries like construction.

For Detailed Design, the coat rack concept sketch was modified for a more robust configuration—e.g., in the concept sketch, the coat rack originally only used the swivel hooks from coat hangers as the hooks, but that was changed to utilize the entire hanger. The final coat rack assembly is shown in Fig. 3. It was tested and found able to support a 9 lb. load on each hook, comparable to the capacity of a similarly sized conventional coat rack of 11 lbs. Thus, the prototype is capable compared to its conventional counterpart.

Fig. 3. Assembly of coat rack prototype.

3 Sustainability Impact

The sustainability performance of the coat rack could not be evaluated due to the lack of available data (quantity, condition, sizing, etc. for the items used in the product). MSW is difficult to quantify because most solid waste data is not collected regularly [23]. The limited MSW data that does exist is unreliable because it may be outdated, inaccurate, or inaccessible [24]. An assessment of the reductions achieved because of already available, reliable, and optimized manufacturing tools will also be necessary.

The authors envision a system where companies can use the residuals from EoL products to create new products, such as the coat rack prototype presented in this paper. Commercializing products such as the coat rack exemplified in this work can have many potential benefits for the TBL:

- ***Economic*****:** Promoting the long-term use of materials/components and the use of shared manufacturing tools will contribute to decreased resource and production costs. Since companies would be symbiotically dependent, costs would be shared amongst multiple companies [25]. There would also be decreased costs during pre-manufacturing: since MSW is being used as raw material, this lowers the need to extract resources from the environment. The novelty of the products can also increase their attractiveness, raising the economic value to customers.

- ***Environmental*****:** The waste that would normally be considered worthless and sent to landfills is now being absorbed and incorporated into other products [25]. Therefore, the greenhouse gas emissions generated from natural resource extraction and waste disposal is mitigated. Wildlife also benefits from less waste entering ecosystems such as forests and oceans. The reduced material usage for tools and longer life for products/materials also decreases waste generation.
- ***Societal*****:** There are emotional and symbiotic benefits for the consumer associated with products resembling ID classics. Society benefits from goods that are made for lasting and for long-term use. Furthermore, if the concept of using EoL components as a resource is normalized, then there would be a foundation for policy makers to implement regulation that furthers environmental-protection and eases economic restrictions on businesses, which allows for new jobs to be created [25]. Society also benefits from more affordable products because goods made from MSW would be cheaper to make than goods made from virgin material.

4 Conclusions

The conventional approaches of landfilling, incineration, or even recycling of waste are not sustainable because of their harmful effects on the environment and low retention of embodied energy. Thus, the idea of synthesizing new, sustainable products from EoL items using inspiration from ID classics was presented in this paper. A foundational framework was proposed to design novel and sustainable products leveraging ideas such as those from ID and SM. The proposed framework was applied by redesigning a coat rack to illustrate the potential products that can be manufactured. Furthermore, depending on what kinds of EoL items are incorporated into the product, there are numerous potential benefits for the TBL.

Due to time and resource constraints, a full sustainability performance assessment could not be conducted. Another topic that was not explicitly addressed is the logistics for the return, transportation, and treatment of MSW items at EoL. Incentives for the return of EoL materials will be required, and it is imperative to ensure that the materials recovered are safe for reuse and not too costly for refurbishment. The commercial viability of products such as the coat rack prototype depends on more in-depth analyses relating to the aforementioned factors. Future work could attempt to analyze these issues and assess the business case for designing novel products that generate value from waste, which would enable closed-loop SM and promote a circular economy.

References

1. Badurdeen, F., Aydin, R., Brown, A.: A multiple lifecycle-based approach to sustainable product configuration design. J. Clean. Prod. **200**, 756–769 (2018)

2. Jawahir, I.S., Dillon Jr., O.W., Rouch, K.E., Joshi, K.J., Venkatachalam, A., Jaafar, I.H.: Total life-cycle considerations in product design for sustainability: A framework for comprehensive evaluation. In: Proceedings of the 10th International Research/Expert Conference, "Trends in the Development of Machinery and Associated Technology" TMT 2006, vol. 1, p. 10. Citeseer, Barcelona, Spain (2006)
3. Jawahir, I.S., Bradley, R.: Technological elements of circular economy and the principles of 6R-based closed-loop material flow in sustainable manufacturing. Procedia CIRP **40**, 103–108 (2016)
4. Jayal, A.D., Badurdeen, F., Dillon, O.W., Jr., Jawahir, I.S.: Sustainable manufacturing: Modeling and optimization challenges at the product, process and system levels. CIRP J. Manuf. Sci. Technol. **2**(3), 144–152 (2010)
5. Kreith, F., Tchobanoglous, G.: Handbook of Solid Waste Management. 2nd edn. McGraw Hill (2002)
6. McDougall, F.R., White, P.R., Franke, M., Hindle, P.: Integrated Solid Waste Management: A Life Cycle Inventory. 2nd edn. Wiley-Blackwell (2001)
7. Advancing Sustainable Materials Management: 2018 Tables and Figures. Environmental Protection Agency. https://www.epa.gov (2018)
8. Porcini, M.: What is Italian Design? (Mauro Porcini). Cottini, L., Italian Innovators, YouTube (2019)
9. Bosoni, G.: Italian Design. The Museum of Modern Art (2008)
10. Verganti, R.: Design as brokering of languages: Innovation strategies in Italian firms. Design Manage. J. **14**(3), 34–42 (2003)
11. Campana, G., Cimatti, B.: Integration of Italian design concepts for 6R-based sustainable product design. Unpublished Working Paper, University of Bologna, Italy (2022)
12. Zanotta, S.p.A.: Castiglioni Mezzadro Stool. Hive Modern. https://hivemodern.com (2022)
13. Decor, B.: Toio Floor Lamp. Burke Decor, https://www.burkedecor.com (2022)
14. Zanotta, S.p.A.: Sella. Zanotta, S.p.A., https://www.zanotta.it
15. Gagnon, B., Leduc, R., Savard, L.: From a conventional to a sustainable engineering design process: different shades of sustainability. J. Eng. Des. **23**(1), 49–74 (2012)
16. Braiform Case Study. Green Entrepreneurship Europe, https://www.geelearning.eu (2018)
17. García, L.F.S.: Impacts on recyclability and sustainability in hanger production by replacing polystyrene with the biocomposite DuraSense® Pure S40 Impact D. MS Thesis, Halmstad University (2020)
18. Derraik, J.G.B.: The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. **44**(9), 842–852 (2002)
19. Sadat-Shojai, M., Bakhshandeh, G.-R.: Recycling of PVC wastes. Polym. Degrad. Stab. **96**(4), 404–415 (2011)
20. Falk, R.H., McKeever, D.B.: Recovering wood for reuse and recycling: A United States perspective. In: European COST E31 Conference: Management of Recovered Wood Recycling Bioenergy and other Options, pp. 29–40. University Studio Press, Thessaloniki, Greece (2004)
21. Dodoo, A., Gustavsson, L., Sathre, R.: Recycling of lumber. In: Worrell, E., Reuter, M.A. (eds.) Handbook of Recycling, pp. 151–163. Elsevier B.V. (2014)
22. Kibert, C.J.: Deconstruction: the start of a sustainable materials strategy for the built environment. Ind. Environ. **26**(2), 84–88 (2003)
23. Vergara, S.E., Tchobanoglous, G.: Municipal solid waste and the environment: a global perspective. Annu. Rev. Environ. Resour. **37**, 277–309 (2012)
24. Wilson, D.C., Araba, A.O., Chinwah, K., Cheeseman, C.R.: Building recycling rates through the informal sector. Waste Manage. **29**(2), 629–635 (2009)
25. Lowe, E.A., Evans, L.K.: Industrial ecology and industrial ecosystems. J. Clean. Prod. **3**(1–2), 47–53 (1995)