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Enabling Circular Business Models through Design Methods and Tools

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Abstract

Despite the availability of multiple CBMs that merge economic sustainability with environmental considerations, each enterprise faces its own challenges in the transition from a linear to a circular economy. This work proposes an approach for organizations to determine which CBM aligns best with their practices, starting from available design tools, and being supported by the correlation matrix serves as allowing design tools to be integrated among core resources. With the support of the proposed approach, designers can extend their overview over multiple stages of a product's lifecycle. The paper focuses on three design tools and identifies the lifecycle extension strategies they enable. The application provides an example of the implementation of the approach and involves three tools: the first quantitatively evaluates the environmental and economic sustainability of durable products; the second interrogates virtual 3D models and identifies recycling criticalities; the latter supports the research of new supply chain partners to avoid landfilling and incineration. The correlation matrix correlates the functionalities of the tools and ecofriendly models to commercialize goods and offer services, scheduling and prioritizing the introduction of innovative aspects and business models. Future work could introduce quantitative milestones for a more robust evaluation.

Keywords: Design tools; Circular Business Models; Design for circular economy; Business Model innovation

1. Introduction

The concept of circular economy (CE), a global focus on addressing current production and consumption challenges, emphasizes the need for companies to reevaluate supply chains and business models (BM) [1]. CE advocates a regenerative economic system, calling for a paradigm shift from the End-of-Life (EoL) concept to prioritize reducing, reusing, recycling, and recovering materials throughout the supply chain. This shift aims to promote value maintenance and sustainable development, addressing environmental, economic, and social concerns [2].

Sustainable EoL management is achievable through long-lasting design and optimized strategies for maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Such sustainability efforts must consider the complexity of socio-economic systems, including economic, ecological, social, and political factors, and adhere to the hierarchical organization of nature[3]. Improving EoL management is crucial for waste reduction, minimizing environmental impact, and achieving cost savings. Circular Business Models (CBMs) bloomed with the spread of CE and involve recycling, extending, intensifying, and dematerializing products and energy loops to reduce organizations' resource inputs and waste and emissions [4]. Incorporating technologies improves EoL management by enabling predictive maintenance, monitoring product conditions[5], and facilitating more effective recycling or disposal strategies [6].

Digitalization enables goods lifetime extension for both old and new products, contingent on the relationships established by Original Equipment Manufacturers (OEMs) with other value-chain actors. OEMs play a pivotal role as the original producers sometimes double as remanufacturer[7]. Outsourced remanufacturers and independent remanufacturers contribute

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to EoL processes under different arrangements. The literature argues that design thinking does not necessarily include sustainability considerations, and it has not been sufficiently explored for application in BM innovation [8].

Besides the complexity involved in slowing, closing, and narrowing resource loops that require questioning the feasibility of generating a proprietary dominant design for resale and instead relying on eco-systemic solutions, a high potential is attributed to design [9]. There are different design strategies to reduce the environmental burden, eco-design strategies. At the product level of 'sustainability-by-design', extended lifetime is a key principle for achieving sustainability by reducing the environmental footprint [10]; the Life Cycle Assessment (LCA) methodology can be used to assess the initial baseline and further changes from the environmental perspective [11]. The research objectives aim to investigate how design tools enable the adoption of circular economy-based BMs in manufacturing companies, specifically OEMs. This study seeks an answer to the research question (RQ):

- *How can design tools for sustainability enable the implementation of CBMs?*

In answering the research question, the present work analyses three design tools, developed in the context of design for environmental sustainability. These tools are applied to support the design phase in defining solutions with lower environmental impacts, in terms of resource use and final emissions. The method proposed by Cappelletti et al [12] has been revised, so that it is applicable to design for sustainability tools. Therefore, the methods support the selection of the LCES (Life Cycle Extension Strategies) for circular transition by OEMs supported by the design tools. Three design tools are considered, and the method is applied.

The present paper is structured as follows: Section 2 studies the research background related to the combined introduction of design for sustainability tools and CBMS; Section 3 shows the approach followed in identifying how design tools support the implementation of CBMs, Section 4 applies the approach to three design tools; ultimately, Section 5 closes the work.

2. State of the art

CBMs play a pivotal role in extending product life cycles. In the realm of CE, traditional BMs can either facilitate or obstruct product circularity. Numerous sustainable and innovative BMs emerged in recent decades, demanding a careful selection that simultaneously creates economic value while contributing to environmental and social sustainability [13. Assessing circular performance involves various methods, and frameworks like ReSOLVE are commonly employed to assist organizations in implementing circular products and processes [14]. Fontana et al. defined a taxonomy of CE and LCES, offering a comprehensive understanding of the implementation of new strategies and methods [15]. This can stand for a pivotal baseline to investigates alternatives to linear BM. Overcoming obstacles related to EoL management, such as reverse logistics, inspection, disassembly, and subsequent activities (i.e., cleaning, remanufacturing, reassembly, and reintroduction to the market), requires addressing uncertainties in product and volume, design constraints, brand reputation, and intellectual property. Each company approaches CE with its timing and schedule, evaluating which pathway best fits environmental benefits, processes, and revenues. CE strategies can focus on partial products or target elements (i.e., the most valuable, critical from the environmental perspective) and some of the whole value (i.e., those including products taking back). On the other side, design for sustainability methods and tools follow a similar classification. For example, design for disassembly tools can either seek target elements [16], or assess the disassembly sequence of the whole product [17].

In this context, the present work revises and applies a framework to identify CBMs and leverage design tools. Compared to the original approach, the present approach doesn't target any specific industrial sector or product. Driven towards CE and environmentally sustainable strategies, companies started developing tools for supporting the design phase; their scope is to introduce awareness into design teams and lead towards design choices that allow proper management of the product at its EoL. Nevertheless, most firms face many challenges in developing and integrating sustainable BMs and product and service innovation [18].

LCA stands out as a widely used approach for assessing environmental impacts [19]; such results are used to make informed decision regarding environmental sustainability. Yet, when effectively leveraged, the results of an LCA can serve as the initial stage for additional analyses or even serve as the foundation for other tools. For example, several examples are available in the literature, where LCA outputs are employed in assessing the sustainability of durability (with [20] or without modifying functional unit [21], recyclability[22]or other product environmental indices [23]. During the design phase, whether as the initial stage of the lifecycle or during a later re-design, there is a potential to enhance the advocacy and adoption of a multi life cycle approach. This approach can facilitate the extension of product lifecycles, allowing goods to retain their original forms and characteristics or serve as valuable secondary raw materials. Design methods and tools should enable the valorization of waste and scrap. The integration between commercial/existent tools should be spurred to harmonize workflow and encourage the dissemination of lifecycle information. The goal is to increase awareness of environmental sustainability and the choices made in the first design phase; moreover, to support industries and increase their competencies in developing products with a life cycle perspective and optimized in environmental terms. Ultimately, research is needed to couple technical success with the overall company success, with consequences on the business mode of doing business.

According to the abovementioned findings, the literature urges for methodologies and tools to support the design phase and the introduction of alternative economically sustainable LCES. The main strength of the proposed approach is on its focus on design tools: even though the methodology for selection of a suitable CBM strategy does not vary greatly either it is performed at the design phase, or at a later point with, the maim differences lay on the costs, that are lower if the decision-made is took at the design phase [24].

3. Method

The proposed approach extends the applicability of the method proposed by Cappelletti et al. [12] from the digitalization context to the design of sustainability methods and tools. The initial method focuses on digitalization toolkits and is based on digitalization and BM of the machinery sector; the herein proposed approach encompasses design tools. Therefore, is allows for anticipating the product's fate definition to the first phase of the lifecycle, in the perspective of "sustainable-by-design" [25]. The main purpose is to streamline the identification of CBMs boosted by the introduction of such methods and tools in the design phase. This is relevant for companies aiming to adopt more sustainable business practices, facilitating the prolongation of product lifespans and the efficient use of resources in production, utilization, and disposal. The incorporation of CBMs frequently creates opportunities for entry into new markets and additional market segments.

Fig. 1 summarizes the approach followed: on a general basis, the correlation matrix approach is applied. Design tools are exploited in their purposes, functionalities, and outputs so that they can be assigned to the LCES in the correlation matrix. Among the many available in the literature, they were chosen for their positioning relatively to the good production (reactive and proactive) and because they address different aspects of the ecology dimensions of Design for X [26].

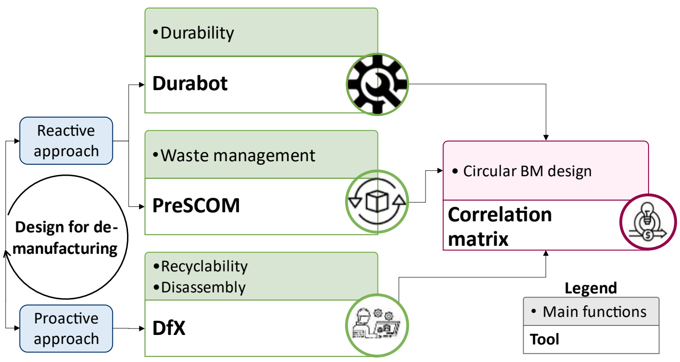

Fig. 1. Approach proposed to exploit the correlation between design tools and CBMs, adapted from Cappelletti et al. [12] (pink box).

The analysis of the main functions goes through the purposes and functionalities of the three tools. All were developed by applying design for de-manufacturing approach. However, some are intended for actions on used products (Reactive approach), others for new products (Proactive approach). The reactive approach refers to actions taken to products and processes that are already commercialized without a systematic approach toward sustainability. Their lifecycle, at different stages, is willing to be improved. In the proactive approach, actions are taken before the good production, so criticalities are detected in advance and tackled.

When working with the correlation matrix, three main steps take place. The first step is the correlation, where LCES and CBMs are classified and described through a correlation matrix. Next, tools are attributed to LCES, and finally, prioritization is assigned to obtain a roadmap towards Circular Economy (CE). The matrix was created as a tool for prospective users of the method. After analyzing the tools, specific tools can be attributed to LCESs in the matrix, relying on the tool. The prioritization phase necessitates an examination of the current state of the company seeking new CBMs. This involves conducting interviews, sketching canvases, and undertaking similar actions to delineate their existing linear business model.

3.1. Correlation

The initial step involved a comprehensive literature review to associate validated approaches with LCESs. The correlation matrix derived includes information on potential strategy and CBMs (Table 1). Criteria for value creation and delivery covered aspects like value and supply chain, human resources, and capabilities employed in building the product or service. The correlation, referencing LCESs and general business models, aimed at capturing widely valid data, with variations arising from the correlation of available BMs. Regarding the Value proposition, it can be either a physical product or a service (P/S). It is crucial to define the customers and the market segment they belong to (S/M), as well as the problem that the value proposition addresses, which is the customer pains (CP). Secondly, the Value creation and delivery consider the value and supply chain (VC), human resources (CC), and the capabilities needed in building the P/S (RC). Ultimately, the Value capture section examines the potential cash flows associated with the current BM, including both expenditures (CD) and incomes (RS). What often sets CBM apart from traditional BM is the revenue model (RM), as it may introduce additional strategies for the P/S provider to receive payment. The correlation matrix structure is depicted in Figure 1.

Table 1 Correlation matrix structure

Strategy	CE-driven LCES	Value proposition	Value creation & delivery	Value capture	CBM introduction
		P/S	VC	RS	
		S/M	CC	CD	
		CP	RC	RM	

3.2. Assignment

The core of the approach is its integration into the decision process. It is essential to evaluate each tool's main functionalities and features, even if not strictly related to LCES. These tools might initially serve various design purposes; however, they can advocate product's life cycle extension.

During this phase, the allocation of each analyzed tool to the correct LCES is based on its features and functionalities. For each design tool:

- Purpose
- Functionalities
- Inputs and output

Must be analyzed. As for digitalization tools, a single tool may serve more than one strategy and is considered a core resource and capability of the CBM. To support the investigation and allocation of tools, workshops, interviews, and questionnaires are valuable resources and ensure a gathering of insight and a comprehensive understanding of the tools and their alignment with LCES.

4. Case study

Besides showing how the concept of the correlation matrix can be extended from digitalization tools to design tools, Fig. 1 also introduces three design approaches that were considered in assessing which CBMs are enabled by design tools. The considered tools were previously developed and first proposed in [27], [28], [29]. The tools are used in the decision-making process that involves a professional espresso coffee machine. According to the CREDIT analysis [7], the design tools address some of the main design lacks claimed in the literature; Fig. 2 shows a summary of the main tackled challenges.

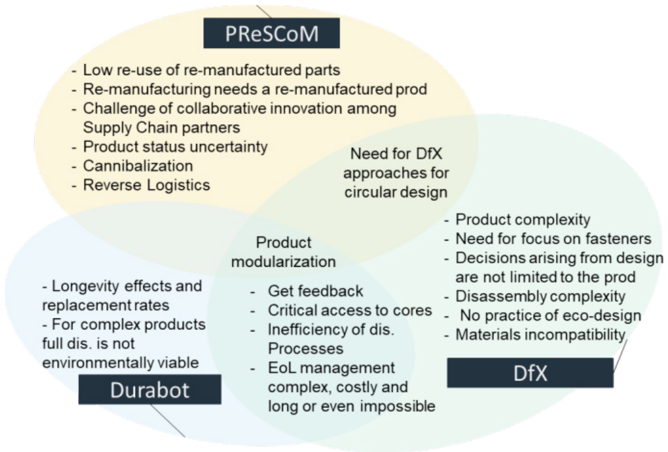

Fig. 2. Main CREDIT analysis' factors [7] tackled by the considered tools.

Durabot has been developed to accomplish the environmental analysis. The tool enables the assessment of environmental consequences of durability, also considering the evolution of energy grid mix and product performances over time. It allows for assessing the environmental consequences of durable products in various circumstances during the design phase; therefore, it paves the way to design for accessibility and disassembly. PReSCOM stands for Processes and Products' Re-design, Involving Scraps from Composite Material; the approach aims at transforming industrial processes' scraps and off-specification pieces in primary materials, through re-design, without the risk of cannibalization. It is mainly intended for industrial processes of composite materials; its objective is to find alternative applications to their invaluable final disposal and support the merging of existing supply chains. DfX is a Design for X Tool to Introduce Sustainability in the Design Process; it supports designers in the optimization of environmental sustainability aspects of their products, through a Knowledge Based Engineering approach.
The Durabot tool is reactive when employed in the maintenance phase, as it outlines the less impacting alternative between product or part substitution. Indeed, whenever used in the design for de-manufacturing context, the preventive durability analysis can identify the components whose substitution is encouraged to lower the environmental impact of the whole product lifecycle. This might happen by upgrading the product and introducing more efficient components, i.e., more efficient motors, compressors or batteries.
As based on managing industrial scraps, without any optimization of those, PReSCOM is considered among the reactive approaches. However, it is proactive whenever applied when designing new products. The focus is on circular strategies, mainly applied to composite materials. The main goal is to transform scraps and off-specification products into primary materials for manufacturing different goods, also thanks to their re-design. Table 2 summarizes the main functionalities, inputs and outputs.

Table 2 Tools' main input and outputs

Tool	Main function	Input	Output
Durabot	• Durability assessment • Environmental impact according to product performances.	• Env. impacts • Use scenario • Aging scenarios • Replacements	• Durability index (specific case) • Durability trends
PReSCOM	• Value chain intersection • Re-design • Sscraps de-manufacturing	• Scraps characterizing factors • Target components characterizing factors	• Symbiosis analysis (env. benefits, supply chain changes, EoL costs)
DfX	• Retrieve information from a product model • Providing sustainable feedback	• 3D CAD • User inputs • Manufacturing features	• Env. impacts • Disassembly sequence • EoL indices

4.1. Assignment

The analysis allowed the tools' assignment to the LCES of the correlation matrix (Table 3). The Durabot tool can positively impact the implementation of all the maintenance strategies, as it provides feedback about the sustainability of component substitution; those encompass the repair/corrective, the time-base and the predictive maintenance. DfX tool can bring positive contributions as well, as can provide feedback on the complexity of disassembly of the parts to be substituted. Specifically for time-based maintenance, where the OEM often suggests the maintenance schedule, the design analysis through the DfX tool can highlight criticalities of disassembly for the components that are often to be substituted (target components). The tool's support can tackle and diminish the target components' criticalities. It supports an advanced scheduling and easing of recycling. Besides the Durabot and DfX tools, the re-manufacture and re-condition strategies are also supported by the PReSCoM approach, which enables their technical feasibility.

Table 3 Correlation matrix, focus on LCESes enabled by the tools and approaches proposed in this work.

Strategy	CE-driven LCES	Value creation & delivery	CBM
Extending	Repair/Corrective Maint.	Durabot	Diversification
	Time-based maintenance	Durabot, DfX	
	Predictive maintenance	Durabot	
Cycling	Re-manufacture	Durabot, DfX, PReSCoM	Acquisition
	Recondition	Durabot, DfX, PReSCoM	
	Refurbish	DfX, Durabot	
	Recycle	Durabot	

4.2. Prioritization

The company that produces the professional espresso coffee machine is a large company, in the center of Italy. Most income comes from the B2B (Business to Business) market. At first, an analysis of the current BM is carried out. Customers are retailers for bars and coffee shops or multinational restaurant chains. Most sales are overseas. Parts production is outsourced, while machines are assembled in the headquarters. Suppliers of customized components (i.e., parts specifically designed and updated for the machines such as the boiler) are among the key partners. Even though professional espresso coffee machines are mostly made of recyclable materials, up to now the OEM doesn't handle the machine at the EoL; many technicians take care of the off-guarantee machines; they are independent; therefore, OEM seldom fix broken machines. Customers are reached through the sector's fairs and direct channels (i.e., salesmen). What happen to the machine once sold, is mostly unknown to the company. The product's useful life can reach 10 years. The company releases its integrated report yearly; this allows to communicate to stakeholders its commitment in social and environmental contexts. The three design tools were developed to introduce environmental sustainability awareness and know-how in the design process [30]. Thanks to the approach herein proposed, the same tools become part of a roadmap to implement CBM, as shown in Fig. 3.

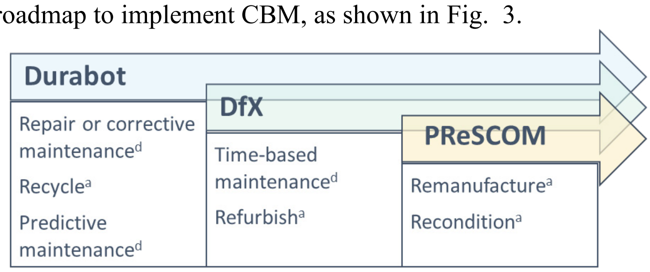

Fig. 3. Roadmap enabled by tools. d= BM diversification, a= BM acquisition

According to Table 3, Durabot can be the first tool enabling CBMs, followed by the exploitation of DfX and PReSCOM tools later on. Knowing the environmental benefits of substituting certain components, might support the diversification of the traditional BM, for example with the introduction of additional packages of maintenance package services. The design feedback from the DfX tool, might be useful to schedule and optimize the product disassembly. If coupled with a longer customer management, the OEM could also take care of machine refurbishment. A great exploitation of the PReSCOM tool could further extend the potentialities of CE and support the extension of the revenues from the traditional value chain, to new, interweaved value chains, that take value out of scraps and industrial waste.

5. Discussion and conclusion

The transition from a linear to a Circular Economy (CE) is a growing focus for enterprises. While many organizations are interested in embracing circular strategies, management and direction departments are aware that often it requires support, especially in the initial stages. Despite the availability of multiple CBMs that merge economic sustainability with environmental considerations, each enterprise faces its challenges. This work proposes an approach for organizations to determine which CBM aligns best with their practices, offering several strengths: i) support for Design Tools; the correlation matrix serves as a foundational base, customizable for individual organizations, allowing design tools to be integrated among core resources; ii) qualitative evaluations for very first decision-making steps; iii) wide applicability; the approach is adaptable across various sectors, with the correlation matrix customizable to meet the specific needs and features of each organization.

The transformation from linear to CE necessitates significant changes in organizational structures, customer relationships, key resource roles, revenue streams, and modes of operation. The gradual shift toward circular equilibrium requires a precautionary strategy to avoid disruptive business modes, emphasizing the importance of progressive change. The present paper indicates a strategy for the professional coffee machine OEM for a gradual change. The roadmap is progressively open to new BMs. Feedback from business cases supports the effectiveness and acceptability of the framework, particularly as a simple tool for gaining a roadmap for new BMs. The qualitative nature of the output is suitable for initial CBM investigations, but quantitative outcomes may help the transition monitoring; future works could introduce quantitative milestones and Key Performance Indicators (KPIs) for a more robust evaluation. Moreover, a focus on technologies and digital solutions is needed. In fact, sometimes CBMs are enabled by digital innovations [31]. Currently any tool doesn't pave the way toward servitization. The introduction of digital tools next to the design tools can extend the journey toward servitization. Finally, the present approach is suitable for companies which already handles design tools. Whenever an enterprise does not make use of any, more robust guidelines to choose suitable design tools should be introduced.

In conclusion, the classification of design tools as reactive and proactive, together with the implementation of the correlation matrix approach to design tools, successfully provided an answer to the RQ and showed the contribution that design tools can bring to the implementation of new CBMs.

Future research should focus on quantifying the proposed roadmaps' boundaries. Establishing KPIs for economic, environmental, and social spheres at each step will guide enterprises through the transition. Additionally, a thorough study of resources involved in each LCES during different life cycle phases should complement the presented approach.

6. References

[1] S. Yang, A. M. R., J. Kaminski, and H. Pepin, "Opportunities for Industry 4.0 to Support Remanufacturing," *Applied Sciences*, vol. 8, no. 7, p. 1177, Jul. 2018, doi: 10.3390/app8071177.

[2] S. Yang, A. M. R., J. Kaminski, and H. Pepin, "Opportunities for Industry 4.0 to Support Remanufacturing," Applied Sciences, vol. 8, no. 7, p. 1177, Jul. 2018, doi: 10.3390/app8071177.

[3] J. Kirchherr, N.-H. N. Yang, F. Schulze-Spüntrup, M. J. Heerink, and K. Hartley, "Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions," Resour Conserv Recycl, vol. 194, p. 107001, Jul. 2023, doi: 10.1016/j.resconrec.2023.107001.

[4] C. A. Ruggerio, "Sustainability and sustainable development: A review of principles and definitions," Science of The Total Environment, vol. 786, p. 147481, Sep. 2021, doi: 10.1016/j.scitotenv.2021.147481.

[5] M. Geissdoerfer, P. Savaget, N. M. P. Bocken, and E. J. Hultink, "The Circular Economy – A new sustainability paradigm?," J Clean Prod, vol. 143, pp. 757–768, Feb. 2017, doi: 10.1016/j.jclepro.2016.12.048.

[6] J. M. Fordal, P. Schjølberg, H. Helgetun, T. Ø. Skjermo, Y. Wang, and C. Wang, "Application of sensor data based predictive maintenance and artificial neural networks to enable Industry 4.0," Adv Manuf, vol. 11, no. 2, pp. 248–263, Jun. 2023, doi: 10.1007/s40436-022-00433-x.

[7] J.-P. Schöggl, M. Rusch, L. Stumpf, and R. J. Baumgartner, "Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector," Sustain Prod Consum, vol. 35, pp. 401–420, Jan. 2023, doi: 10.1016/j.spc.2022.11.012.

[8] F. Cappelletti, M. Rossi, and M. Germani, "How de-manufacturing supports circular economy linking design and EoL - a literature review," J Manuf Syst, vol. 63, pp. 118–133, Apr. 2022, doi: 10.1016/j.jmsy.2022.03.007.

[9] T. Santa-Maria, W. J. V. Vermeulen, and R. J. Baumgartner, "The Circular Sprint: Circular business model innovation through design thinking," J Clean Prod, vol. 362, p. 132323, Aug. 2022, doi: 10.1016/j.jclepro.2022.132323.

[10] M. Arribas-Ibar, P. A. Nylund, and A. Brem, "Circular business models in the luxury fashion industry: Toward an ecosystemic dominant design?," Curr Opin Green Sustain Chem, vol. 37, p. 100673, Oct. 2022, doi: 10.1016/j.cogsc.2022.100673.

[11] F. Mathieux, F. Ardente, and S. Bobba, "Ten years of scientific support for integrating circular economy requirements in the EU ecodesign directive: Overview and lessons learnt," Procedia CIRP, vol. 90, pp. 137–142, 2020, doi: 10.1016/j.procir.2020.02.121.

[12] O. Ellingsen and S. S. Vildåsen, "Developing circular business models: LCA and strategic choice," Procedia CIRP, vol. 109, pp. 437–442, 2022, doi: 10.1016/j.procir.2022.05.275.

[13] F. Cappelletti and S. Menato, "Developing a Circular Business Model for Machinery Life Cycle Extension by Exploiting Tools for Digitalization," Sustainability, vol. 15, no. 21, p. 15500, Oct. 2023, doi: 10.3390/su152115500.

[14] M. Henry, T. Bauwens, M. Hekkert, and J. Kirchherr, "A typology of circular start-ups: An Analysis of 128 circular business models," J Clean Prod, vol. 245, p. 118528, Feb. 2020, doi: 10.1016/j.jclepro.2019.118528.

[15] A. B. Lopes de Sousa Jabbour et al., "Circular economy business models and operations management," J Clean Prod, vol. 235, pp. 1525–1539, Oct. 2019, doi: 10.1016/j.jclepro.2019.06.349.

[16] A. Fontana et al., "Circular Economy Strategies for Equipment Lifetime Extension: A Systematic Review," Sustainability, vol. 13, no. 3, p. 1117, Jan. 2021, doi: 10.3390/su13031117.

[17] S. S. Smith and W.-H. Chen, "Rule-based recursive selective disassembly sequence planning for green design," Advanced Engineering Informatics, vol. 25, no. 1, pp. 77–87, Jan. 2011, doi: 10.1016/j.aei.2010.03.002.

[18] N. Shabanpour and M. Colledani, "Integrated Workstation Design and Buffer Allocation in Disassembly Systems for Remanufacturing," Procedia CIRP, vol. 69, pp. 921–926, 2018, doi: 10.1016/j.procir.2017.11.135.

[19] K. Karuppiah, B. Sankaranarayanan, and S. M. Ali, "A systematic review of sustainable business models: Opportunities, challenges, and future research directions," Decision Analytics Journal, vol. 8, p. 100272, Sep. 2023, doi: 10.1016/j.dajour.2023.100272.

[20] T. Ekvall, "Attributional and Consequential Life Cycle Assessment," in Sustainability Assessment at the 21st century, IntechOpen, 2020. doi: 10.5772/intechopen.89202.

[21] C. Li, J. Li, Q. Ren, Q. Zheng, and Z. Jiang, "Durability of concrete coupled with life cycle assessment: Review and perspective," Cem Concr Compos, vol. 139, p. 105041, May 2023, doi: 10.1016/j.cemconcomp.2023.105041.

[22] F. Cappelletti, F. Manes, M. Rossi, and M. Germani, "Evaluating the environmental sustainability of durable products through life cycle assessment. The case of domestic refrigerators," Sustain Prod Consum, vol. 34, pp. 177–189, Nov. 2022, doi: 10.1016/j.spc.2022.09.008.

[23] S. Huysman et al., "The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders," Resour Conserv Recycl, vol. 101, pp. 53–60, Aug. 2015, doi: 10.1016/j.resconrec.2015.05.014.

[24] E. Fregonara, R. Giordano, D. G. Ferrando, and S. Pattono, "Economic-Environmental Indicators to Support Investment Decisions: A Focus on the Buildings' End-of-Life Stage," Buildings, vol. 7, no. 4, p. 65, Jul. 2017, doi: 10.3390/buildings7030065.

[25] J. V. Taboada, V. Diaz-Casas, and X. Yu, "CBM challenges and opportunities for O&M of the Oil and Gas Field," J Pet Sci Eng, vol. 205, p. 108890, Oct. 2021, doi: 10.1016/j.petrol.2021.108890.

[26] M. Coffay and N. Bocken, "Sustainable by design: An organizational design tool for sustainable business model innovation," J Clean Prod, vol. 427, p. 139294, Nov. 2023, doi: 10.1016/j.jclepro.2023.139294.

[27] A. Chaouni Benabdellah, K. Zekhnini, I. Bouhaddou, and A. Benghabrit, "Analysis and Modeling the Intersection of Design for X Techniques, Business Strategies and Product Life-Cycle Management," 2022, pp. 84–99. doi: 10.1007/978-3-030-94335-6_7.

[28] F. Cappelletti, G. Menchi, M. Rossi, and M. Germani, "Durabot: the tool to introduce durability in the design process," Proceedings of the Design Society, vol. 3, pp. 1515–1524, Jul. 2023, doi: 10.1017/pds.2023.152.

[29] F. Cappelletti, M. Rossi, L. Manuguerra, and M. Germani, "Design for X Tool to Introduce Sustainability in the Design Process," Comput Aided Des Appl, pp. 234–247, Aug. 2022, doi: 10.14733/cadaps.2023.234-247.

[30] F. Cappelletti and M. Germani, "Carbon reduction engineering through value chains intersection, product and process re-design, industrial processes' scraps de-manufacturing," Int J Prod Res, pp. 1–22, Aug. 2023, doi: 10.1080/00207543.2023.2243527.

[31] M. Rossi, F. Cappelletti, and M. Germani, "Design for environmental sustainability: collect and use company information to design green products," Procedia CIRP, vol. 105, pp. 823–828, 2022, doi: 10.1016/j.procir.2022.02.136.

[32] F. Zhang, B. Yang, and L. Zhu, "Digital technology usage, strategic flexibility, and business model innovation in traditional manufacturing firms: The moderating role of the institutional environment," Technol Forecast Soc Change, vol. 194, p. 122726, Sep. 2023, doi: 10.1016/j.techfore.2023.122726.