ATTI

XIII Convegno della Rete Italiana LCA
VIII Convegno dell'Associazione Rete Italiana LCA

Il Life Cycle Thinking a supporto delle strategie di mitigazione e adattamento ai cambiamenti climatici

Università degli Studi Roma Tre, Dipartimento di Economia Aziendale
13-14 giugno 2019

A cura di Gabriella Arcese, Maurizio Cellura, Sara Cortesi, Laura Cutaia, Maria Claudia Lucchetti, Erika Mancuso, Marina Mistretta, Chiara Montauti, Simona Scalbi

ROMA TRE UNIVERSITÀ DEGLI STUDI Dipartimento di Economia Aziendale

ENEA
Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

Rete Italiana LCA

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Atti del XIII Convegno della Rete Italiana LCA -VIII Convegno dell'Associazione Rete Italiana LCA
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PROGRAMMA

12 Giugno 2019

11.00 – 13.00 Riunioni Gruppi di Lavoro dell'Associazione Rete Italiana LCA

15.00 Pre-registrazioni

15.45 – 18.45 Side event: "Life Cycle Assessment: una metodologia a sostegno dell'Obiettivo 7 dell'Agenda globale 2030"

18.45 Welcome Party

13 Giugno 2019

8.30 – 9.30 Registrazione dei partecipanti

9.30 – 10.00 Apertura dei lavori e saluti introduttivi

Luca Pietromarchi – Magnifico Rettore Università Roma Tre

Marco Tutino – Direttore Dipartimento di Economia Aziendale Università Roma Tre

Maurizio Cellura – Presidente Associazione Rete Italiana LCA

Maria Claudia Lucchetti – Università Roma Tre

10.00 – 11.00 Sessione I: Il Life Cycle Thinking a supporto delle strategie di mitigazione e adattamento ai cambiamenti climatici

Chair: Bruno Notarnicola – Associazione Rete Italiana LCA
Maria Claudia Lucchetti – Università Roma Tre

Clima ed Energia nel nuovo Piano Nazionale della Ricerca 2021-2027: Stato dell'arte e prospettive (Maria Cristina Pedicchio – Istituto Nazionale di Oceanografia e Geofisica Sperimentale)

Metodo PEF: Ultimi sviluppi (Luca Zampori – European Commission, Joint Research Center)

Il ruolo della Life Cycle Assessment nella decarbonizzazione del settore edile (Maurizio Cellura - Presidente Associazione Rete Italiana LCA, Università di Palermo)

11.00 – 11.30 Pausa caffè

11.30 – 13.00 Sessione II: "Metodi e strumenti LCT-based nelle politiche ambientali"

Chair: Roberta Salomone – Associazione Rete Italiana LCA
Carlo Alberto Pratesi – Università Roma Tre

The effectiveness of LCA-based emissions policies against carbon leakage: theory and application (Nicolò Gulinucci – FEEM)

La tossicità dei metalli pesanti nei metodi LCIA: gli effetti delle incertezze sui fattori di caratterizzazione (Maria Laura Parisi – Università di Siena)

Towards the harmonization of the environmental footprint methodology of construction products: insights from the experiences on EPDs (Francesca Reale – Ecoinnovazione srl)

Social Life Cycle Assessment: past, present and future initiatives (Gabriella Arcese – Università Niccolò Cusano)

Funzionalità e applicabilità del modello LANCA a scala regionale: un caso studio in Emilia-Romagna (Serena Righi, Daniele Terranova – Università di Bologna)

13.00 – 14.00 Pausa pranzo

14.00 – 15.00 Sessione Poster

15.00 – 16.30 Sessione III "Metodi e strumenti LCT: esperienze e casi studio"

Chair: Serena Righi – Associazione Rete Italiana LCA
Gabriella Arcese – Università Roma Tre, Università Niccolò Cusano

Process modelling-supported LCA: flue gas cleaning of a waste-to-energy plant (Alessandro Dal Pozzo – Alma Mater Studiorum, Università di Bologna)

Sviluppo di una PEFCR applicata ai servizi (Paola Sposato – ENEA)

Sustainable recovery of phenolic compounds from olive mill wastewater: an LCA evaluation (Mattia Rapa – Sapienza Università di Roma)

Valutazione LCA di pavimentazioni stradali contenenti plastiche da riciclo come materia prima seconda (Francesca Rosa – Università di Milano)

Enhancing the environmental performance in the hollow glass production. A case study (Annarita Paiano – Università degli Studi di Bari Aldo Moro)

Comparison of Carbon Footprint of the Italian LCA Network Conferences 2017-18: lesson learnt to mitigate and compensate emissions for the future (Giovanni Mondello – Università di Messina)

16.30 – 17.30 Premiazione del concorso "Giovani Ricercatori LCA"

Chair: Andrea Raggi – Associazione Rete Italiana LCA

La Life Cycle Assessment applicata alla valutazione della sostenibilità ambientale del riuso delle batterie da trazione (Maria Anna Cusenza – Università di Palermo)

Development and testing of a new life cycle assessment method for the monetary evaluation of water scarcity impacts (Matteo Simonetto – Università di Padova)

Application of a decision framework to explore stakeholders' opinions for comparative LCA and LCC studies (Sara Toniolo – Università di Padova)

17.30 – 19.00 Assemblea dei Soci dell'Associazione Rete Italiana LCA

20.30 Cena sociale

Ristorante "Al Pompiere" in Via di S. Maria de' Calderari, 38, Roma

14 Giugno 2019

8.30 – 9.45 Registrazione dei partecipanti

9.45 – 10.45 Sessione IV “Energia”

Chair: Marina Mistretta – Associazione Rete Italiana LCA
Francesco Asdrubali – Università Roma Tre

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Environmental effectiveness of the Solar Home Systems based on LCA (Federico Rossi – Università degli studi di Siena)

Carbon footprint di impianti modello per la produzione di energia dal mare (Morena Bruno – Università degli Studi di Siena)

Analisi del ciclo di vita e monetizzazione dei costi esterni: un’applicazione al confronto tra auto (Pierpaolo Girardi – RSE S.p.A.)

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11.15 – 12.15 Sessione V “Edilizia”

Chair: Monica Lavagna – Associazione Rete Italiana LCA
Alessandra Zamagni – Ecoinnovazione srl

Ottimizzazione Multi-Obiettivo delle Prestazioni Energetiche e Ambientali di un Edificio Residenziale (Sonia Longo – Università di Palermo)

Life Cycle Analysis applications for Nearly Zero Energy Buildings (Francesco Asdrubali – Università Roma Tre)

Literature review on remanufacturing strategies and LCA forward the building sector (Tecla Caroli – Politecnico di Milano)

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12.15 – 13.45 Sessione VI “LCT ed Economia Circolare”

Chair: Antonio Scipioni – Associazione Rete Italiana LCA
Roberto Merli - Università Roma Tre

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End-of-life management of photovoltaic modules from a circular economy perspective (Elisa Veronese – Eurac Research, Politecnico di Milano)

Towards the accounting of resource dissipation (Fulvio Ardente – EC JRC)

Life Cycle Assessment for measuring Circular Economy at company level: is it suitable? (Eric Roos Lindgreen – Università di Messina)

LCA delle casse del sistema “usa e recupera”: un esempio di closed loop in economia circolare (Paola Masotti – Università di Trento)

Introducing the Plastic Leak Project: a pre-competitive initiative to harmonize plastic indicators in Life Cycle Assessment (Andrea Corona – Quantis Italia)

13.45 – 14.45 Pausa pranzo

14.45 – 15.30 Sessione Poster

15.30 – 16.45 Sessione VII "Esperienze e casi studio nel settore agro-alimentare"

Chair: Laura Cutaia – Associazione Rete Italiana LCA
Olimpia Martucci – Università Roma Tre

Carne coltivata in laboratorio e climate change: un'analisi critica (Pasqua Labbate – Politecnico di Bari)

Il metodo PEFMED a supporto dell'eco-innovazione nel settore agroalimentare mediterraneo: il caso del Taleggio DOP (Simona Scalbi – ENEA)

Gestione dei residui di potatura del vigneto: Impatto ambientale di diversi scenari gestionali (Jacopo Bacenetti – Università degli Studi di Milano)

Eco-design per il miglioramento dell'impronta ambientale: il Passaporto Ambientale per i prodotti agroalimentari della Montagna Vicentina (Alessandro Manzardo – Università di Padova)

Valorizzazione dei sottoprodotti di una filiera agroalimentare: co-frangitura di olive e bucce e semi di pomodoro per la produzione di olio con licopene (Simona Scalbi – ENEA)

16.45 – 17.15 Pausa caffè

17.15 – 18.45 Tavola Rotonda "Criteri di Finanza sostenibile: stato dell'arte e prospettive"

Chair: Maurizio Cellura – Associazione Rete Italiana LCA

Partecipano:

Paolo Masoni – Ecoinnovazione srl

Luca Di Marco – Cassa Depositi e Prestiti

Bruno Notarnicola – Associazione Rete Italiana LCA

Giuseppina Galluzzo – Consip

PREFAZIONE

La Life Cycle Assessment (LCA) è una disciplina che rappresenta un esempio concreto di convergenza di differenti discipline e la naturale evoluzione del concetto di interdisciplinarietà verso il concetto di sincretismo di discipline eterogenee in una disciplina unica, seppur variegata e multiforme. Il percorso è molto simile a quanto accaduto alla scienza della sostenibilità, con profonde analogie e punti di convergenza, laddove si osservi che la LCA è considerata la metodologia principe in termini di metrica della sostenibilità.

Tuttavia, la LCA non può essere considerata una disciplina ormai matura, o un *tool* a corredo di scelte ambientali già prese con poche spinte innovative di ricerca, o ancora un metodo finalizzato a stabilire delle eco–gerarchie fragili, individuate attraverso dei software "scatola nera", privi dei requisiti di trasparenza e ripercorribilità necessari, elementi fondanti di qualunque sistema di supporto alla decisione. Al contrario, la LCA deve costituire una disciplina aperta a impulsi di ricerca innovativi, che necessita di sviluppi orizzontali e verticali, di approfondimenti soprattutto nell'approccio *consequential*, nell'introduzione di elementi dinamici, nella predisposizione di database contestualizzati, che consentano ai progettisti di introdurre sostanzialmente il "Life Cycle Thinking (LCT)" nei percorsi progettuali, integrando l'eco-design alla progettazione. Occorre, pertanto, rifuggire da logiche riduttive e semplificative a favore di approcci organici fondati su database robusti, in grado di fornire dati di "background" affidabili e riproducibili, da integrare a dati di *foreground* rilevati sul campo e oggetto di processi di revisione scientificamente fondati.

Fin dalla nascita come Rete, l'Associazione Rete Italiana LCA si è posta come punto di riferimento in Italia per i principali operatori in materia di Life Cycle Assessment (LCA), al fine di promuovere il LCT nella definizione di strategie per lo sviluppo sostenibile.

Le sue attività scientifiche, contraddistinte da entusiasmo e dinamicità, hanno dato un grande impulso in questi anni alla diffusione della metodologia e hanno condotto l'Associazione Rete Italiana LCA a costituire un autorevole riferimento nel dibattito nazionale sulla metodologia LCA e sugli strumenti di metrica della sostenibilità. A testimonianza del contributo culturale e scientifico che l'Associazione Rete Italiana LCA offre costantemente nel panorama nazionale e non solo, ogni anno il Convegno nazionale costituisce il principale momento di confronto e scambio di esperienze scientifiche, metodologiche e applicative, tra le realtà operanti in ambito LCA in Italia.

Quest'anno il XIII Convegno della Rete Italiana LCA (VIII Convegno dell'Associazione Rete Italiana LCA), si è svolto a Roma nei giorni 13 e 14 giugno 2019, con il patrocinio del Ministero dell'Ambiente e della Tutela del Territorio e del Mare (MATTM) e dell'Associazione Condizionamento dell'Aria Riscaldamento e Refrigerazione (AICARR).

Tema del convegno è stato il "Life Cycle Thinking", a supporto delle strategie di mitigazione e adattamento ai cambiamenti climatici. La sfida al cambiamento climatico e i suoi effetti sulla società e sull'ambiente si sviluppa in due direzioni: la mitigazione, volta a ridurre progressivamente le emissioni di gas climalteranti responsabili del riscaldamento globale, e l'adattamento, che mira a diminuire la vulnerabilità dei sistemi ambientali, sociali ed economici e aumentare la loro capacità di resilienza climatica. In tale contesto, la Life Cycle Assessment (LCA) è considerata la metodologia principe in termini di metrica della sostenibilità, in quanto efficace nella definizione di obiettivi di sostenibilità e strategie innovative nella sfida ai cambiamenti climatici e nel supporto ai processi decisionali delle policy pubbliche e aziendali. Il Convegno si è, pertanto, focalizzato sulle suddette tematiche, con particolare riferimento alla valutazione e al miglioramento delle prestazioni ambientali di prodotti, servizi, processi e sistemi, in ottica di consapevolezza, innovazione, ricerca e sviluppo, e alla definizione di strategie per il raggiungimento degli obiettivi di sviluppo sostenibile nelle sue varie dimensioni ambientali, economiche e sociali. Gli studi presentati al Convegno e pubblicati in questo volume, oltre a fare il punto sulle politiche internazionali e nazionali basate sul LCT, sui connessi sviluppi nelle strategie di mitigazione e adattamento ai cambiamenti climatici, nonché sull'evoluzione metodologica dell'approccio al ciclo di vita, testimoniano – come poc'anzi affermato- che la LCA è un reale sincretismo di differenti discipline.

In dettaglio, i **65** contributi scientifici, presentati durante le sessioni tematiche orali e le sessioni poster, a seguito di un processo di *double peer review* gestito dal Comitato Scientifico, sono stati suddivisi nelle seguenti sezioni:

- Metodi e strumenti LCT – based nelle politiche ambientali.
- Impiego del LCT nelle strategie di mitigazione e adattamento ai cambiamenti climatici.
- Valutazione delle conseguenze socio-economiche legate ai cambiamenti climatici
- Sviluppi metodologici di LCA, LCC e S-LCA e integrazione con altri strumenti per studi di sostenibilità
- Impiego del LCT per il raggiungimento dei Sustainable Development Goals
- LCT ed Economia Circolare: esperienze, casi studio di eco-design e approcci metodologici.
- PEF e OEF: esperienze applicative e possibili utilizzi nelle politiche ambientali
- Poster.

Nell'ultima sezione sono riportati i contributi presentati dai primi tre classificati della decima edizione del Premio Giovani Ricercatori LCA, rivolto ai giovani ricercatori, che operano nel campo dell'analisi del ciclo di vita al fine di promuovere la ricerca e divulgare le loro attività.

Il Presidente
Maurizio Cellura

ENERGIA

Literature review on Remanufacturing strategies and LCA forward the building sector

Tecla Caroli, Monica Lavagna, Andrea Campioli

Politecnico di Milano, Department of Architecture, Built environment and Construction engineering
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Abstract

The aim of the research is a literature review referred to the combination of Remanufacturing strategy and the Life Cycle Assessment in the building sector. Remanufacturing is a strategy that in the latest decades is applied in design and engineering sectors. The analysis of topics is based on the investigation of sources on Bibliography and European Research Projects platforms. The paper describes the state of art of the Remanufacturing as EOL recovery strategy and the necessity to promote the application on the building sector considering the entire Life Cycle of the building.

1. Introduction

1.1. Background

The world is more crowded, more polluted, more urban, more ecologically stressed, and warmer than ever before in recorded history. Over the last decades, the growth of the society generate a linear economy development (*take-make-use-dispose*), that leaves a trail of economic, environmental and societal challenges and problems in its wake. The Circular Economy, as new economic framework (Pomponi et al., 2016) can be combined with the 6R-based elements of sustainable manufacturing in order to relieve these challenges by establishing a closed-loop material flow, considering the product life cycle.

Sustainable value in manufacturing requires yet another transformation from a 3R concept and Life Cycle Costing to a 6R strategy: a transformation of vision where economics, environmental and societal aspects are considered simultaneously. By extending the original 3Rs of Reduce, Reuse, and Recycle to a 6R concept, with the addition of widespread Recovery of materials, Remanufacturing of products, and Redesigning legacy technology, it makes possible a type of sustainable development in which LCA and Circular Economy. These topics are ingrained in the idea that End-Of-Life (EOL) materials should be viewed as “raw materials” to the next generation of a product life cycle (Fig. 1). This closed-loop approach not only targets the growing problem with depleting resources, but also reimagines what was once considered waste into an economic asset for the future (Jaafar et al., 2007).

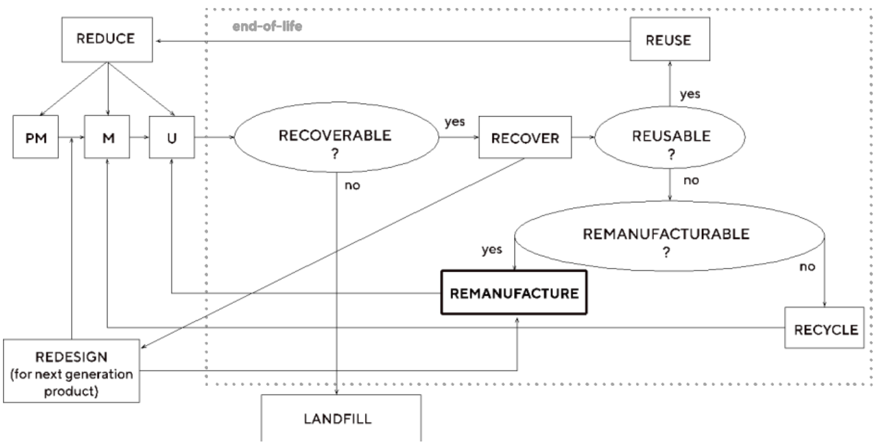

Figure 1: End-Of-Life: Life Cycle Process (Zhang et al., 2013)

Due to environmental regulation and economic viability, industries are showing the growing interest in the product recovery (Fegade et al. 2015) applying the following EOL strategies: recycling, remanufacturing, reuse, repair and refurbishment components. If reuse and repair are not possible, remanufacturing is the preferable option because it preserves the raw materials and the energy value added in the initial production of the product, this allows the manufacturer to increase the productivity as well as the profitability in the business.

1.2. **Remanufacturing**

Remanufacturing is an End-Of-Life strategy that reduces the use of raw materials and energy necessary to manufacture new products. The Remanufacturing process can be defined as a product recovery strategy focused on product restoration and reconditioning of its parts, in order to rebuild it according to its original design. In particular, a product is suitable for the remanufacturing or not is depends on the decisions taken in the early phase of the design process. The whole life cycle of the product is analyzed and optimized to reach the scope.

Currently, the Remanufacturing strategies are applied on few industrial sectors (automotive, electronic, interior design), the challenge of the research is to apply it also in building sector. Buildings are responsible for up to 40% of the materials produced and consumed globally (by volume), approximately 40% of the world's waste generation (by volume) (Becqué et al., 2016) and they account for 20–35% of the contribution to most environmental-impact categories such as global warming and smog formation (European Commission, 2006). Thus, the construction sector represents a major set of opportunities for achieving local and global environmental objectives, such as the UN Sustainable Development Goals (United Nations, 2015) to reduce waste and environmental impacts, with the application of Circular Economy approach.
In practice, the effort to apply remanufacturing strategy is related to the furniture (chairs, desks, shelves, etc.) of the buildings (Krystofik et al., 2018). According to the Brand's "Pace Layers Framework" scheme (Fig. 2), the current applications refer to the *stuff*; the future research plans to fill this gap, extending remanufacturing to the other building parts: *skin, service, space plan*.

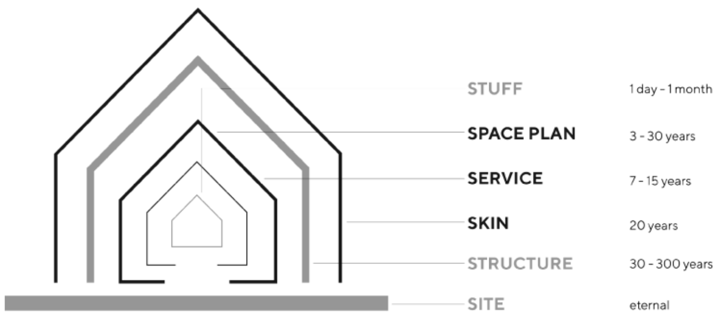

Figure 2: Pace Layers Framework (Brand, 1994)

Before this challenge, it is necessary to access whether and to what extent, a remanufactured product is better for the environment, with a Life Cycle Assessment (LCA).

This paper reports on a literature review conducted to analyze how the LCA is shaped for remanufactured products and to identify guideline for the application also in the building sector. The next paragraphs analyze the materials and method used to develop the state of art of the research and the most relevant contents of the documents collected. The goal is to define some guideline for the future research.

2. **Materials and Methods**

The literature review follows the steps provided by Fink (2013): selection of the research question, selection of the used databases, application of the screening criteria and conducting the review.
The initial research question is: there is a current intersection between LCA and remanufacturing theme in the building sector?
The review is carried out on four bibliography databases, that provide similar results: Web of Science, Scopus, Google scholar and Semantic Scholar. As search strings, the keywords used derive from the definitions given in the introduction, whose different notations are combined: "Remanufacturing" (OR "Re-manufacturing") AND "Life Cycle Assessment" (OR "LCA" OR "Life-cycle-assessment") AND "built environment" (OR "building sector" OR "construction sector" OR "construction engineering"). At the beginning, the filters applied are: open access documents, articles and proceedings papers as type of documents and English language.
The only one result obtained is the research article of Krystofik et al. (2018), that talks about a comparative Life Cycle Assessment between remanufacturing, adaptive remanufacturing and new furniture of an office.

So, the research is redefined using only Remanufacturing and LCA (and their notations) keywords and applying not only the previous filters but also one referred to the categories: building environment, environmental engineering. The results are quite different compared to previous, so also other documents are selected and classified in different themes to do a critical review:
- LCA evaluation of Remanufacturing strategies in automotive sector;
- LCA evaluation of Remanufacturing strategies in electronic sector;
- LCA and Remanufacturing strategies for the decision making;
- LCA and Remanufacturing strategies for the management of product-service design.

Table 1: Classification of papers

Author	Keywords	Theme
Ardente et al.	"remanufacturing" AND "LCA"	LCA and Remanufacturing in electronic sector
Bey et al.	"remanufacturing AND "LCA"	product-service design
Bradley et al.	"remanufacturing AND "LCA"	product-service design
Eichner et al.	"remanufacturing AND "LCA"	product-service design
Fang et al.	"remanufacturing AND "LCA"	product-service design
Fegade et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making
Filho et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making
Krystofik et al.	"remanufacturing" AND "LCA" AND "built environment"	LCA and Remanufacturing in the building sector
Peng et al.	"remanufacturing" AND "LCA"	LCA and Remanufacturing in automotive sector
Ramani et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making
Wakkary et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making
Winkler et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making
Xu et al.	"remanufacturing" AND "Life Cycle Assessment"	LCA and decision-making

A search is also conducted on European Project Platform (CORDIS) defined with the intersection of keywords: Life Cycle Assessment, Remanufacturing and built environment (as it is done for the bibliography research). The filters applied concern the type of collection (projects, projects publications, programme and news) and the domain of application (industry technologies and change and environment).

3. **Analysis and Results**

3.1. **Literature analysis**

The documents collected are published in the period 2001-2018.
The largest share of publications (research papers) appeared in the *Journal of Cleaner Production and Resources, Conservation & Recycling*. Other important journals regarding the field of interest are *Waste Management, Journal of Mechanical Design* and *Journal of Environmental Economics and Management.*

Instead, the proceedings papers refer to the following conferences: *13th Global Conference on Sustainable Manufacturing, 13th CIRP International Conference on Life Cycle Engineering, 1st CIRP Industrial Product-Service Systems (IPS2) Conference, IEEE International Conference on Robotics&Automation* and *4th International conference on Materials Processing and Characterization*.

Regarding to the authors of the collection, they work on different affiliations in Europe, Asia and America. In Europe the most cited affiliations are located in Germany (TU Dresden University and University of Siegen) and in Denmark (Danish Building Research Institute, Aalborg University). In Italy, the affiliation that deal with remanufacturing theme is the Joint Research Centre in Ispra (LCA of remanufacturing strategy on electronic products). In America and in Asia the most cited affiliation are respectively Rochester Institute of Technology and The Hong Kong Polytechnic University.

3.2 European projects analysis

In this case the results are similar to the literature research. With the same combination of the previous keywords, there aren't research projects referred to the remanufacturing of construction products, or the LCA evaluation of the remanufacturing strategy.
This research highlights that now the remanufacturing strategy is applied only in the engineering sector (automotive, electronic) and the application in the design sector of Life Cycle Assessment is marginal.

The results of both analyses are consistent but not satisfactory. Despite of it, they are important to identify the themes and methods necessary for the application of remanufacturing strategy and to highlight its strengths and weaknesses.

3.3. Contents

3.3.1 End-Of-Life management

Managing End-Of-Life products has become a field of rapidly growing interest for product manufacturers (Ramani et al., 2010). As environmental regulations urge stronger stewardship for product retirement, disposal can no longer be the primary retirement strategy for End-Of-Life products. Manufacturers need to find more proactive ways to reduce waste and save resources. EOL management should be considered at the design stage in order to facilitate efficient and effective take-back and recovery. There is also the necessity to create new regulations and to improve others that allow the promotion and the facilitation of the application of new End-Of-Life strategies.

3.3.2 Design for Remanufacturing

The concept of design for remanufacturing comes in the focus due to the technical barrier during the process of the remanufacturing (End-Of-Life) and these factors are related back to the design process of the product.

The decisions have to be made based not only on structure, material and manufacturing choices, but also on transportation, distribution and End-Of-Life logistics and management (Krystofik et al., 2018). LCA has been established as the most widely used methodology to evaluate the environmental sustainability of a product, applied also to support the design decision-making (Wakkary et al., 2009) and to lead innovative recovery model for which we have not envisioned building products yet: remanufactured building products.

3.3.3 Life Cycle Assessment

The following report focuses only on the three documents that include a complete Life Cycle Assessment of three case studies:

- Ardente et al., 2018: paper A;
- Krystofik et al., 2018: paper B;
- Peng et al., 2019: paper C.

The analysis carries out the assumptions fixed during the evaluation, following the LCA methodology, defined by ISO 14044 (2006) and ISO 14040 (2008). The investigation focuses on the definition of the goal and scope, the definition of functional unit, the environmental impact indicators considered and some relevant results (Table 2).

The paper A talks about the application of remanufacturing strategies on the electronic sector. The aim of the study is to compare the environmental impacts between a new server or a remanufactured one. The functional unit of the study was the use of one average server (27.8 kg in mass) for 4 years of its lifetime. The system boundaries are set based on the assumption that a remanufactured product is functionally equivalent to (substitutes) a new product (also in terms of average life). The study assumes that the life of a product could be extended (e.g. through repair) for a limited time, delaying the purchase of a new product by several years.

The potential environmental impacts assumed are: Abiotic depletion potential; Acidification midpoint; Climate change midpoint (excluding biogenic carbon); Ecotoxicity: freshwater; Eutrophication: freshwater; Eutrophication: marine; Eutrophication: terrestrial; Human toxicity, cancer effects; Human toxicity, non-cancer effects; Ionising radiation; Ozone depletion; Particulate matter/respiratory inorganics; Photochemical ozone formation; Primary energy demand (from fossil and renewable sources); Resource depletion (water).

In the paper B, the remanufacturing strategies are applied to recover office furniture and the LCA is used to estimate the impacts of multiple remanufacturing cycles and how these are affected by “adaptive remanufacturing”, a neologism to describe the use of an End-Of-Life product core to create a similar, non-identical product. The goal is to compare the environmental impacts of virgin products, adaptive remanufactured products (Reman.1) and remanufactured products (Reman. 2).

The scope is the study of office workspace system that includes three components: work surfaces, storage units, wall panels. The boundary parameters regarding materials, manufacturing and transportation processes (A1-A3 stages). The functional unit considered in this study is one workspace system supporting one user for a service life of ten-years. To develop the assessment is used Simapro 8.0.4, a LCA modelling software in conjunction with the Ecoinvent 3 lifecycle database, to create the model based on “real-world data”. Environmental impacts were evaluated using the ReCiPe 1.11 midpoint+ method and the Cumulative Energy Demand (CED) 1.09 impact assessment library.

Instead, the study proposed in the paper C, focuses on restoring technologies (automotive sector) and wants to develop an effective and comprehensive multi-criteria decision-making approach for the application to the remanufacturing process considering the environmental, the economic cost and technical property.
The goal is to quantify the environmental impacts of the four restoration processes. Restoration is one of the main stages in remanufacturing and the costs of this procedure
According to the boundaries selected, the study considers all the materials of the product, the energy and their own upstream generation, as well as transportation and landfill processes, are considered. The functional unit is defined as "a restoring process with certain deposition layer (720 mm^3)".
Moreover the analysis consider only five environmental impacts: Chinese resource depletion potential (CADP), global warming potential (GWP), respiratory inorganics (RI), acidification potential (AP), and water eutrophication potential (WEP). This study include also a LCC.

Considering also the sensitivity analysis and the definition of Life Cycle Inventory, in all three studies, it is possible to highlight some weaknesses. In particular Winkler (et al. 2007) underline that the sensitivity analysis use a static and linear approach to model the emissions of a waste management system, which is far from the reality. Moreover, many assumptions are an oversimplification of the real conditions. Although comparisons of LCI results show that a complex model does not guarantee better results and that a simple model must not deliver unrealistic conclusions, the models need to reflect the complexity of a real case.

Table 2: Literature review details and analysis

paper with LCA	journals	sectors	goal of the study	FU description	results reported
Ardente et al., 2018 (A)	Journal of Cleaner Production	electronic	to compare the environmental impacts between a new server or a remanufactured one	the use of one average server (27.8 kg in mass) for 4 years of its lifetime	remanufactured product reduces the environmental impacts but consume up to 7% more of energy
Krystofik et al., 2018 (B)	Resources, Conservation & Recycling	building	to compare the environmental impacts of virgin products, adaptive remanufactured products and remanufactured products	one workspace system supporting one user for a service life of ten-years	both the two remanufacturing cycles consume 18% as much energy as new product and the environmental benefits of adaptive remanufacturing are low
Peng et al., 2019 (C)	Journal of Cleaner Production	automotive	to quantify the environmental impacts of the four restoration processes	a restoring process with certain deposition layer (720 mm^3)	economic advantages using remanufactured technologies

It is evident how different assumptions led to different results, because all three studies are modelled according to the characteristics of the case studies and the initial objectives set. Even if the results are similar - a low environmental advantage with the use of remanufacturing products - the analysis of this topic could me improved.

4. **Conclusions**

The focus of the research on the remanufacturing recovery strategy is led by the current not sustainable development and the dissemination of issues related to the circular economy. The paper collects a lot of information about the dissemination of the future research, knowing towards which direction these issues move, in terms of place and notions.
The literature review highlights the lack of the application of remanufacturing in the building sector and that LCAs for remanufacturing still form a niche in the LCA literature.
Despite of the environmental vantages to use remanufactured products are low, the results obtained are also useful to know which are the challenge to move on and problems to solve for the application of remanufacturing strategy in the building sector. It is important also to say that the remanufactured products, used in other sectors have different characteristics, dimensions and quantities, compared to the building sector, so the LCA results could be more advantageous.

However, before a consistent prospective LCA concept promoting remanufacturing in the building industry can be formulated, further research is needed:

- to identify and account materials and component that could be recovered;
- to identify the influence of material compositions has on the environmental performance of different building types;
- to promote how to handle the EOL products and which are the benefits related to the application of Circular Economy concepts;
- to determine how to best implement these factors into environmental performance assessments.

This will provide key stakeholders (designers, clients, users, manager etc.) with a valid and consistent basis for life cycle-based decision-making and policy initiatives to better link recovery strategies concepts to the environmental performance of buildings. It will help to establish clear objectives and to develop the future research.

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