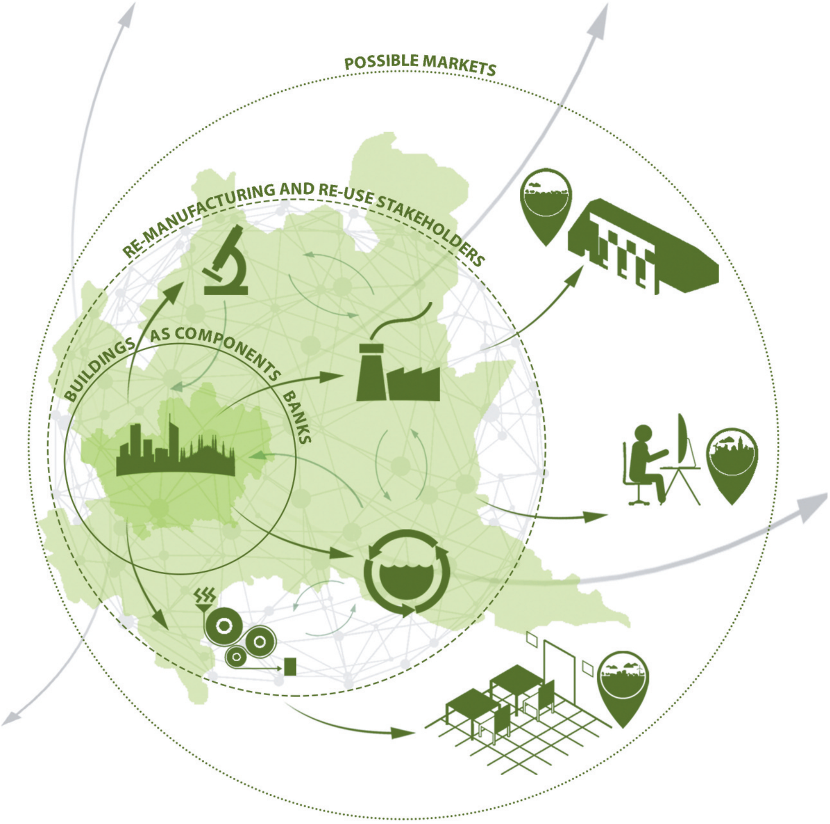
Re-manufacturing networks for tertiary architectures

Innovative organizational models towards circularity

edited by Cinzia Maria Luisa Talamo



Ricerche di tecnologia dell'architettura
FrancoAngeli

RICERCHE DI TECNOLOGIA DELL'ARCHITETTURA

diretta da Giovanni Zannoni (Università di Ferrara)

La collana *Ricerche di tecnologia dell'architettura* tratta prevalentemente i temi della progettazione tecnologica dell'architettura e del design con particolare attenzione alla costruibilità del progetto. In particolare gli strumenti, i metodi e le tecniche per il progetto di architettura alle scale esecutive e quindi le modalità di realizzazione, trasformazione, manutenzione, gestione e recupero dell'ambiente costruito.
I contenuti scientifici comprendono la storia e la cultura tecnologica della progettazione e della costruzione; lo studio delle tecnologie edilizie e dei sistemi costruttivi; lo studio dei materiali naturali e artificiali; la progettazione e la sperimentazione di materiali, elementi, componenti e sistemi costruttivi.
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In questi ambiti la collana pubblica progetti che abbiano finalità di divulgazione scientifica e pratica manualistica e quindi ricchi di spunti operativi per la professione di architetto.

La collana nasce sotto la direzione di Raffaella Crespi e Guido Nardi nel 1974.
I numerosi volumi pubblicati in questi anni delineano un efficace panorama dello stato e dell'evoluzione della ricerca nel settore della Tecnologia dell'architettura con alcuni testi che sono diventati delle basi fondative della disciplina.
A partire dal 2012 la valutazione delle proposte è stata affidata a un Comitato scientifico, diretto da Giovanni Zannoni, con lo scopo di individuare e selezionare i contributi più interessanti nell'ambito della Tecnologia dell'architettura e proseguire l'importante opera di divulgazione iniziata quarant'anni prima.

The book presents the results of the project "*Re-NetTA (Re-manufacturing Networks for Tertiary Architectures). New organizational models and tools for re-manufacturing and re-using short life components coming from tertiary buildings renewal*", developed at Politecnico di Milano (2018-2021) and supported by Fondazione Cariplo, grant n° 2018-0991 (Call "Circular Economy for a sustainable future 2018").

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by *Cinzia Talamo, Marika Arena, Andrea Campioli, Carlo Vezzoli*

2.1 Strategies for extending product lifecycle: Reuse and Re-manufacturing

In recent years the growing diffusion of the fundamental concepts and practices of circular economy has progressively consolidated the awareness that the extension of the lifespan of the products is the winning strategy for pursuing the macro-objectives of reduction of waste, optimisation of material use, and decrease of environmental impacts (COM(2014) 398; COM(2015) 614; COM(2020) 98; Ellen McArthur Foundation, 2013, 2014, 2015, 2016; EEA Report No 2/2016; EEA Report No 6/2017).

The extension of the lifespan immediately brings to prevention and reuse, i.e. the measures and actions that are the top levels of the hierarchy, established by the European Directive on waste[1], and at the same time the key goals for the circular economy. Many recent EU initiatives and regulations, dealing with the wider goals of the climate neutrality and the green transition, witness the increasing interest for the strategies and the practices of reuse. To mention a few:

– Directive (EU) 2018/851, as part of a package of measures on the circular economy, amending Directive 2008/98/EC, sets minimum operating requirements for extended producer-responsibility schemes, also including responsibilities to contribute to waste prevention and

1. The directive 2008/98/EC – besides defining principles such as the 'polluter-pays', the 'extended producer responsibility', the distinction between waste and by-products, the conditions for hazardous waste, recycling and recovery targets, etc. – establishes the well-known waste hierarchy: prevention; reuse; recycling; recovery for other purposes, such as energy; and disposal.

to the reusability and recyclability of products. The Directive boosts measures to support sustainable production and consumption models and encourage the design, manufacturing and use of products that are resource efficient, durable, reparable, reusable and capable of being upgraded;

- The Green Deal[2], in launching the new growth Commission strategies to implement the United Nation Agenda 2030 sustainable development goals and the other EU priorities[3], outlines policies and measures for various fields. Between these, the Green Deal opens to a Circular Economy Action Plan oriented to a 'sustainable products' policy aiming to boost the circular design of all products based on a common methodology and shared principles. The priority is to reduce consumption and reuse materials before recycling them. The Green Deal document underlines the importance of new business models, extended producer responsibility and new measures to encourage businesses to offer, and consumers to choose, reusable, durable and repairable products. It is pointed out the need to develop a 'right to repair', restricting the built-in obsolescence of devices and boosting new business models based on renting and sharing sustainable and affordable goods and services;
- The Circular Economy Action Plan[4], providing a future-oriented agenda for a cleaner and more competitive Europe, highlights the importance of promoting the convergence of visions and interests of economic actors, consumers, citizens and civil society organisations. Between the many policies and measures, the Plan encourages the Commission to propose a sustainable product policy legislative initiative: "The core of this legislative initiative will be to widen the Ecodesign Directive beyond energy-related products so as to make the Ecodesign framework applicable to the broadest possible range of products and make it deliver on circularity" (COM(2020) 98 final). According to this legislative initiative, and, where appropriate, through complementary legislative proposals, the Commission will consider establishing sustainability principles to regulate several aspects including: improving product durability, reusability, upgradability and reparability; enabling re-manufacturing and high-quality recycling; restricting single-use and countering premature obsolescence; incen-

2. COM(2019) 640.

3. U. von der Leyen, A Union that strives for more. My agenda for Europe. Political Guidelines for the Next European Commission 2019-2024

4. COM(2020) 98.

tivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle;

– The New European Bauhaus[5], promoting relevant EU initiatives and new actions and funding possibilities, recognizes reuse, regeneration, life extension and transformation of existing buildings (and their parts) as a priority for the green challenges concerning the entire industrial ecosystem, from production to delivery and consumption.

The widespread and increasing interest for products designed to be durable, reusable, repairable, rather than simply recyclable, should not hide the difficulty of implementing these concepts, especially when dealing with buildings, notwithstanding the high impacts of the building sector (see Chapter 1).

Many questions arise from this evolving scenario: how to interpret and apply the general concept of reuse? Which is the most proper application scale for the technical feasibility and economic sustainability of reuse (element, technical unit, building, compound)? Which are the leverages and barriers for the involvement and integration of the building sector and the manufacturing sector? What are the conditions for the development of a market of reused products and of new supply chains? What are the stakeholders of the reuse processes? How to involve and make consumers aware?

About the interpretation of the general concept of reuse a first assumption should be considered: reuse should be placed in a wideperspective, articulating it in several "re-actions", all functional to a variety of circular processes. The literature review highlights many different positions about the relationship between reuse and re-manufacturing (Lieder *et al.*, 2017; Seitz and Wells, 2006; Parkinson and Thompson, 2003; Gharfalkar *et al.*, 2016; King *et al.*, 2006; Nasr *et al.*, 2006; Patyal *et al.*, 2022). The standard BS 8887-2:2009 provides an overall view and a systemic framework of all the "re-actions" strategies, valid for most of the manufacturing sectors and applicable to all products (or to some of their parts). The aim is to extend the useful life of the products and to multiply the cycles of use with limited consumption of material and energy and minimal waste generation. The standard proposes (Tab. 2.1) a hierarchy of possible "re-actions", each of one characterized by the return of a used product, focusing on its performances and warranty level compared to the original product.

5. COM(2021) 573.

Tab. 2.1 - Actions for the extension of the product life cycle according to the standard BS 8887-2:2009

Re-manufacturing	To return a used product to at least its original performance with a warranty equivalent or better than the one of the newly manufactured product. *NOTE* *From a customer viewpoint, the re-manufactured product can be considered to be the same as the new product.* *With respect to re-manufacture:* • *manufacturing effort involves dismantling the product, the restoration and replacement of components and testing of the individual parts and whole product to ensure that it is within its original design specifications;* • *performance after re-manufacture is expected to be at least to the original performance specification; and any subsequent warranty is generally at least equal to that of new product.*
Recondition	To return a used product to a satisfactory working condition by rebuilding or repairing major components that are close to failure, even where there are no reported or apparent faults in those components. *NOTE* *With respect to reconditioning:* • *manufacturing effort involves the replacement of worn or broken parts, generally less extensive than required to re-manufacture, but more than necessary for repair;* • *performance after reconditioning is expected to perform its intended role but the overall performance is likely to be inferior to that of the original model; and* • *any subsequent warranty is generally less than new or a re-manufactured product but the warranty is likely to cover the whole product (unlike repair); reconditioned products do not require a warranty equivalent to that of a newly manufactured equivalent.*
Reuse	Operation by which a product or its components, at end-of-life, are put back into use for the same purpose.
Repurpose	To utilize a product or its components with a role that it was not originally designed to perform. *NOTE 1 This action deals specifically with products and assemblies and not materials, which falls under recycling.* *NOTE 2 Augmentation of the product may be required to fulfil its new role.*

The standard BS 8887-2:2009 focuses on the three "re-actions" that can be applied to products with different levels of complexity (Fig. 2.1): *re-manufacture* (the used product is equivalent or better compared to the original one) is at the top of the hierarchy, followed by *recondition* (lower or equivalent) and *reuse* (lower or equivalent). These three "re-actions" deal with processes that do not change the original function of the product. Besides these three "re-actions", the hierarchy includes also *repurpose* as an action dealing with products whose function may be completely or partially changed.

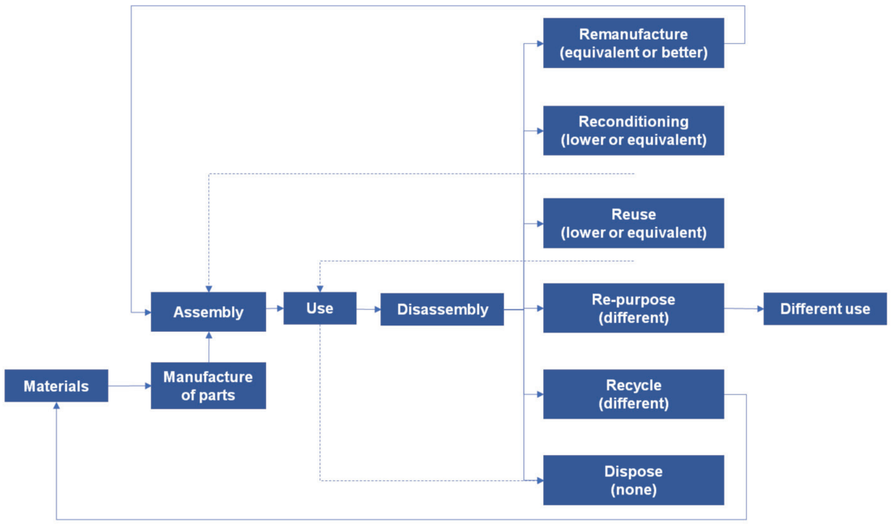

Fig. 2.1 - Product life cycle (BS 8887 2:2009)

Although the choice of a "re-action" rather than the other ones may depend on many various conditions (e.g. characteristics of the product, fields of use, market, productive and commercial aspects, consumer propensities, etc.), all the "re-actions" share the same aim: the extension of the product lifetime and environmental and economic value retention of the products considered as long-life resources. Among the various options, reuse and re-manufacturing are clearly the strategies characterized by the most effective value retention over time. However, depending on the products (their specific characteristics, the conditions at the end of their first life cycle, their market, etc.) some of the other re-actions may be more viable or appropriate (Talamo *et al.*, 2021).

2.2 Re-manufacturing as a key strategy for the building sector

The basic concept of value management during a product's entire lifecycle (Rashid *et al.*, 2013) is well represented and broadened in the holistic vision of Resource Conservative Manufacturing[6] (ResCoM) (Rashid *et al.*, 2013; Asif *et al.*, 2012). ResCoM defines the indispensable condition for resources conservation through multiple life cycles of products i.e: the deep rethinking of the relationships between materials, design, customer behaviour, enabling technologies, supply chain and business models. This means the creation of systemic interactions between the different levels identified whatever the goal is, both by slowing the resource loops through the extension of the utilization period of products, and by closing resource loops through the link between post-use and production.

A wider vision, a shift of design paradigms and an integration of levels are necessary to pursue sustainable closed-loop processes and to face the many uncertainties[7] that currently, still operating within a conventional manufacturing paradigm, are affecting the practices of the "re-actions", especially re-manufacture.

So, on one side, a system of requirements should be considered and experimented according to a new and overall view. The requirements that characterize the design of long-life and multiple lifecycle products[8] basically are: reliability, durability, maintainability, standardisation and compatibility, upgradability and adaptability, dis- and re-assembly. On the other side, end of life (EoL) strategies (Lieder *et al.*, 2017) highlight the need to implement in conjunction (Bocken *et al.*, 2016): design processes, reverse supply chain (Rashid *et al.*, 2013) and business models. The re-manufacturing industry is growing within this changing scenario: the creation of value along the life cycle of a product will be considered in relation to different time scales and innovative design paradigms will boost new supply chains.

The re-manufacturing industry today represents about 2% of the European manufacturing sector, with a revenue of about 30 billion euros

6. ResCoM is also a project co-funded by the European Commission. ResCoM project has developed a collection of methodologies and tools for the implementation of closed-loop manufacturing systems in order to support designers and manufacturers in the collection, re-manufacturing and reuse of products pursuing more profitable, resource-efficient and resilient business practices compared to the current linear manufacturing system.

7. "For example, uncertainty in the quality and timing of returns, balancing returns with demand, disassembly, materials recovered, reverse logistics, materials matching requirements, routing uncertainty and processing time uncertainty" (Rashid *et al.*, 2013).

8. 'How to design a multiple lifecycle product' (ResCoM WP 3 Deliverable 3.4 Report ResCoM Design Methodology for Multiple Lifecycle Products) TU Delft 30-06-2017.

(with a preponderance of aerospace at 42% and automotive at 25%) and a growth forecast of 50% by 2030 (Parker *et al.*, 2015). These data confirm the increasing interest for re-manufacturing considered as both a winning strategy for circular economy and a new promising business field. Several supranational initiatives demonstrate a widespread interest in re-manufacturing communities building. For instance, the European Re-manufacturing Council has the mission to represent small and large businesses from all re-manufactured product sectors, with the ambition to triple the value of Europe's re-manufacturing sector to €100 billion by 2030, bringing together businesses from every product sector, sharing knowledge and boosting supporting policies.

The European Re-manufacturing Network (ERN), funded by the European H2020 programme, is pursuing the goal of connecting practitioners, policy-makers and researchers and of collecting, sharing and spreading studies and good practices all over Europe.

The more and more numerous scientific studies on the subject of re-manufacturing are making evident the growing interest of traditional manufacturing sectors and demonstrating that re-manufacturing is increasingly acquiring specific and autonomous features and developing peculiar organizational and commercial approaches.

The building sector, although its significant environmental footprint, is still late in the practices of re-manufacturing and reuse. A cross-sectorial transfer process can start only from the awareness of the many issues that characterize the building sector and the manufacturing sector of the building products. If compared to many industrial products, such as machinery and engines, most of the building products are characterized by: low economic value and small quantity of production; the specificity of installation and use; the poor information about duration and fault rates; the difficulties to collect mass of used products sufficient to activate cost-effective industrial processes (uncertainty in continuity of supply and quantities).

According to the holistic approach of ResCoM, the search for forms of re-manufacturing and reuse appropriate for the building sector will imply rethinking both the design of building products and the processes of assembly and disassembly in light of: various business (organization, contract, supply chain) models; the ways for involving and motivating the consumers in order to boost a market demand for reused products (for instance through actions of dissemination, awareness raising and creation of specific brands); new stakeholders and skills (for instance involvement of the Third sector and the creation of networks of artisans for the re-manufacturing of small batches).

The challenge of applying re-manufacturing strategies to the building sector depends on some modifications at the same time of the design approach, of the organizational and business models and of the models of management and use of the buildings. Ensuring a greater circularity of resources also appears to be a good opportunity to overcome some rigidities, which often hinder the processes of adaptation and "updating" of spaces and buildings quickly obsolete. A "continuous improvement" process and a Life Cycle Design (LCD) approach, applied in an integrated way to the constructions, can allow to extend the lifetime of the building elements, save economic and environmental resources and ensure the adaptation of spaces.

2.3 Re-manufacturing and reuse within a product Life Cycle Design (LCD) approach

Within the framework of circular economy, considering the role of design, we refer to product Life Cycle Design (LCD) approach, even known as product Ecodesign, where re-manufacturing and reuse is framed in a wider strategy named product lifespan extension[9], which include together with re-manufacturing, reuse and repair, even maintenance, upgrade[10] and adaptation[11].

Even if properties of re-manufacturable products started to be observed during the eighties, the idea of designing products in order to facilitate re-manufacturing came to light later, due to the understanding of the relevance of early design stages in relation to consecutive barriers during re-manufacturing processes (Yang *et al.*, 2015; Hacher *et al.*, 2011; Ijomah *et al.*, 2007; Manzini and Vezzoli, 1998; Keoleian and Menerey, 1993). This opened a progressive growth of research contributions specifically focused on product Design for Re-manufacturing (DfRem), i.e. how to integrate within product development requirements that could have facilitated re-manufacturing (Yang *et al.*, 2015; Vezzoli, 2018). Successively, design tools and methods have been explored by scholars, from qualitative to quantitative ones, at different stage of product development – either

9. To be more precise, product lifespan extension together with product use intensification belong to the common strategy of product life optimization (Vezzoli, 2018).

10. Product upgrade means to "keep its validity (remain in usage) through the substitution of parts that have become (technologically or culturally) obsolete" (Vezzoli, 2018).

11. Product adaptation means to "keep validity in relation to changing environments or cultural/physical evolution of individuals" (Vezzoli, 2018).

concept development, detail engineering or embodiment – but with scarse results in the industry (Hatcher *et al.*, 2011). More recently, with the advent of Circular Economy framework, the research community increased the consideration of design for re-manufacturing, reuse and broadly lifespan extension, as a strategic asset to foster alternative and more sustainable business models. In the attempt of establishing some key concepts about product design and circular economy, among others Hollander *et al.* (2017) pointed out the increased potential and responsibility of product designers in supporting alternative business models through the design of long-lasting products.

Following, the design approaches and guidelines for re-manufacturing, reuse and broadly for lifespan extension are presented, referring to short-time architectural components in the tertiary sector.

Product Life Cycle Design and, in particular, design for lifespan extension is still affected by some barriers related to the traditional product sale supply and demand chain, where the economic profits are based, among other, on the amount of products sold, i.e. product durability potentially reduces the number of products sold, so forth even the economic revenues.

Consequently, the extension of product lifespan – thus, even re-manufacturing and reuse – could be counter-productive for manufacturers, from an economic point of view. All this considered, it makes sense to introduce the well known Sustainable Product-Service Systems (S.PSS) business models, that couple the economic interest of the provider/manufacturer with environmental benefits. In other words, S.PSS represents an opportunity to create conditions for an economically favorable product Life Cycle Design (LCD) approach. In particular, specific S.PSS win-win benefits have been identified fostering the manufacturer/provider to adopt for economic interest the LCD strategies, among which the design for product lifespan extension, so forth even design for re-manufacturing and reuse. They are defined as follows (Vezzoli *et al.*, 2018):

Sustainable Product-Service System (S.PSS) is an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the ownership of the product/s and/or the life cycle services costs/responsibilities remain by the provider/s, so that the same provider/s, for economic interest, continuously seek/s environmentally and/or socioethically beneficial new solutions.

2.4 Rethinking the supply chains for the re-manufacturing market

The articulation of the flows of materials, components, and products – i.e. the supply chain – plays a pivotal role for making re-manufacturing feasible and sustainable with a relevant impact on the overall re-manufacturing system. Hence, when conceiving a re-manufacturing system, the re-design of the supply chain cannot be overlooked, taking into proper consideration two main elements:

- the factors of complexity that characterise re-manufacturing supply chains;
- the key design variables, that can be mobilized to deal with such factors of complexity.

Moving from the first issue, compared to "traditional" manufacturing supply chains, re-manufacturing supply chains are characterized by greater complexity and uncertainty, due to some peculiar characteristics of the three main subprocesses in which a re-manufacturing supply chain can be articulated: 1) product returns management, that can be considered the front end of reverse supply chain activities, 2) re-manufacturing operations, which include reverse logistics, testing, sorting, disposition activities, product disassembly, and re-manufacturing processes, and 3) re-manufactured products market development, which consists in re-marketing activities, channel choice and coordination (Guide and Van Wassenhove, 2006; 2009).

First, the identification of the potential sources of used products / components, i.e. cores, is a relevant challenge. Re-manufactures, in fact, can retrieve used products from a variety of suppliers that include the end customers, scrap yards, core brokers and other companies. However, they have to deal with exceptional levels of uncertainty concerning both quantity and quality of these supplies (Guide and van Wassenhove, 2009). The number and the timing of the returns is typically unknown; this uncertainty is further amplified by the growing number of products with shorter life cycles, caused for instance by technological developments (Östlin *et al.*, 2009). Then, the variety and diversification of the usage patterns during the use phase can have a significant impact on the conditions of returned products, leading to high variability in the quality of the supplies (van Nunen and Zuidwijk, 2004; Sundin and Dunbäck, 2013).

Second, the production planning and control of re-manufacturing operations is inherently complex (Junior and Filho, 2012). In this respect, a major problem is the need of balancing returns and demand. In fact, if the demand of re-manufactured goods is lower than the returns – that are the necessary input for the re-manufacturing process –, the re-manufacturer will have to deal with excessive amounts of inventory, that increase production costs, holding costs, and the risk of obsolescence. On the other hand, if the demand is higher than the returns, quantities of end products will not be enough to satisfy the demand, with a negative impact on the customer satisfaction. A second challenge consists in the planning of how returns have to be collected and transported to the re-manufacturing plants – where re-manufacturing operations take place – this requires the definition of the number of collection centres, the transportation means and the frequency of collection. Furthermore, processing times are highly variable, as a consequence of the different conditions of the collected cores – even two identical objects may require to be treated differently due to their diverse initial condition.

Finally, also the marketing of re-manufactured products is a challenging task in particular due to the customer perception towards their quality. In this respect, the design of proper incentive systems, and the development of product warranties play a pivotal role in the development of marketing strategies for re-manufactured products (Govindan *et al.*, 2019).

To address the above elements of complexity, we can refer to two main design issues:

- the type of re-manufacturing supply chain;
- the type of relationships that can be developed among the actors that constitute the re-manufacturing supply chain.

Re-manufacturing systems typically comprise two separate supply chains: a forward one and a reverse one. The forward supply chain organizes the flows of products from the manufacturer to the customer, the reverse supply chain organizes the flow of returns from the customer to the re-manufacturer, as in this case, the customer servers as a supplier of used products.

Re-manufacturing supply-chains can be categorised into three types depending on who performs re-manufacturing activities in the reverse supply chain (or, in other words, who the re-manufacturer is) (Jacobsson, 2000; Guidat *et al.*, 2015). Accordingly, we can distinguish between:

- supply chain where the re-manufacturers are the original equipment manufacturers (OEMs) that execute their own re-manufacturing leveraging on their resources or collaborating with other actors;
- supply chain where the re-manufacturers are contracted re-manufac-

turers (CR) that are subcontractors of the OEMs and execute re-manufacturing for them;
– supply chain where the re-manufacturers are independent actors that work without any contractual arrangement with the OEMs, and often become competitors of the OEMs in the same market.

In literature, this last type of supply chain is sometimes indicated as an open-loop supply chain (OLSC) to stress that, in this case, third-party and independent actors have more possibilities of participating and innovating in contrast with other closed-loop supply chains (CLSC) where the OEMs have (directly or indirectly) a central role in ensuring circular flows of products and materials (Kalverkamp, 2018).

Finally, re-manufacturing supply chains are characterised by high heterogeneity in connection to the type of relationships that can be established among the actors that constitute the supply chain. For instance, Östlin *et al.* (2008) identify seven different types of relationships among re-manufacturers and customers/suppliers: ownership-based, service-contract, direct-order, deposit-based, credit-based, buy-back and voluntary-based relationships (Tab. 2.2).

Tab. 2.2 - Possible relationships in a re-manufacturing supply chain

Relationship	**Description**
Ownership-based	The product is owned by the manufacturer and operated by the customer (e.g. rental or lease).
Service-contract	The product is used by the customer based on a service-contract between a manufacturer and a customer that includes re-manufacturing.
Direct-order	The used product is returned by the customer to the re-manufacturer, who re-manufactures the product and give back it to the customer.
Deposit-based	When the customer buys a re-manufactured product, he/she has to return a similar used product.
Credit-based	The customer that returns a used product receives some credits, that grant a discount when buying a re-manufactured product.
Buy-back	The used product is bought by the re-manufacturer from a supplier (end user, scrap yard, core dealer…).
Voluntary-based	The supplier gives the used products voluntary to the re-manufacturer.

Source: Based on Östlin *et al.*, 2008

These relationships have different characteristics and are often not used individually, but simultaneously to complement each other.

Starting from this very promising scenario, which highlights the role of managerial and organizational aspects for the activation of changes along the supply chain, in the next chapters the book presents the results of the Research aimed at investigating the aspects characterizing re-manufacturing applied to others sectors (Chapter 3) and to define which criteria are transferable and applicable in the building sector (Chapters 4, 5, 6, 7).

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