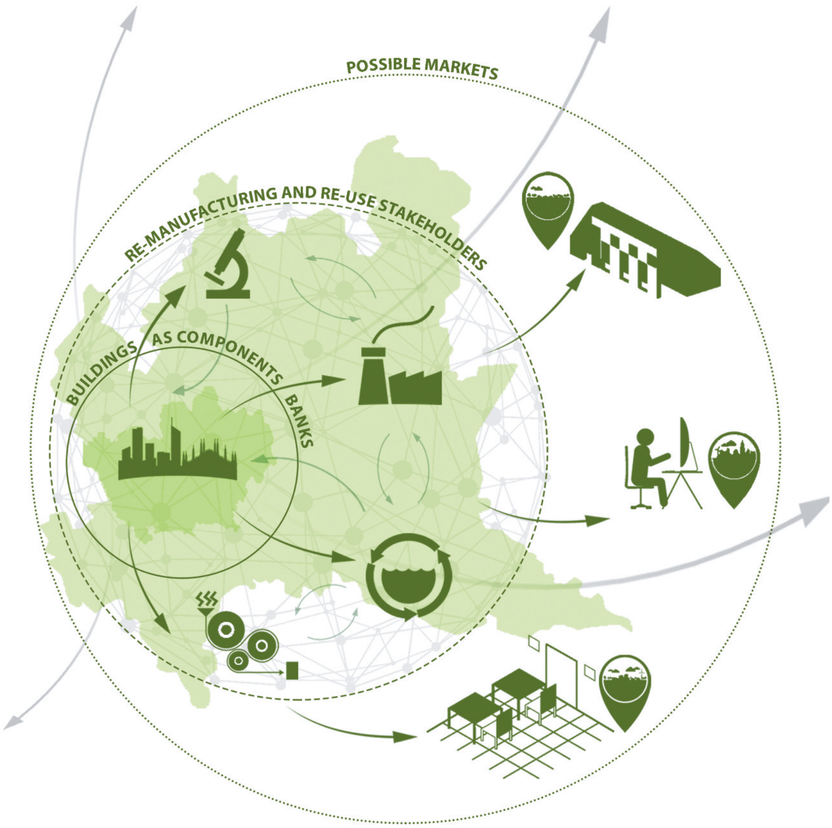
Re-manufacturing networks for tertiary architectures

Innovative organizational models towards circularity

edited by Cinzia Maria Luisa Talamo



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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").

Isbn 9788835142232

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Introduction

This book deals with re-manufacturing, recondition, reuse and repurpose considered as winning strategies for boosting regenerative circular economy in the building sector.

The book presents many of the outcomes of the research "Re-NetTA (Re-manufacturing Networks for Tertiary Architectures). New organisational models and tools for re-manufacturing and re-using short life components coming from tertiary buildings renewal". The research was funded in Italy by Fondazione Cariplo for the period 2019-2021 and developed by a multidisciplinary group composed of all the authors present in this publication.

The field of interest of the book is the building sector, focusing on various categories of tertiary buildings, characterized by short-term cycles of use.

The building sector is a fundamental lever for the activation of circular economy. European Commission identifies the construction sector as a "Priority area" involved in specific challenges in the context of circular economy: according to the Eurostat statistical data in EU-28 the main field that produces waste is construction sector, contributing to 33.5% of the total waste generated by all economic activities and households in 2014. Besides, the construction sector is an important driver for circular economy as it provides, according to European Commission data, 18 million direct jobs and contributes to about 9% of the EU GDP. The application of new circular economy strategies can create new jobs, social benefit, energy and resource efficiency and a sustainable environment.

Currently, the circular strategy more promoted in the built environment is recycling. Most of European Projects (e.g. HISER PROJECT, Resource Efficient Use of Mixed Waste, DEMOCLES, ENCORT) and particularly Life Project investigate on recycling (inter-sectoral or within the construc-

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tion sector) of construction and demolition waste and deal with specific recycling topics (e.g. LIFE-PSLOOP Polystyrene Loop; CDW recycling Innovative solution for the separation of construction and demolition waste). Often recycling implies the downcycling and requests complex and energy-consuming processes. On the contrary, if well-organized, re-manufacturing and reuse require very simple and low-impacting processes, reduce the generation of waste and maintain over time the value of the resources embodied in manufactured products – once they are removed from the buildings – by extending their useful life and their usability with the lowest possible consumption of other materials and energy and with the maximum containment of emissions in the environment.

In the perspective of circular economy, the focus of this book on tertiary buildings derives from some considerations:

- cities all over the world are characterized by high quantities of tertiary buildings with various destinations (public and private offices, accommodation facilities, retail, exhibition facilities, temporary shops, etc.);
- there is an increasing stock of unused, often obsolete, tertiary buildings, especially after the pandemic;
- tertiary buildings are more and more characterized by quick cycles of renewal and reconfiguration of interior spaces following a series of phenomena that determine a fast functional obsolescence and frequent reshaping such as: recent approaches that shift attention to the use of buildings in terms of service (such as hoteling, leasing, co-working, smart working and various declinations of sharing) determining a high degree of temporary use; shortening of leases; transformations in the Real Estate market; transformations in the models of commerce;
- this kind of buildings generate significant quantities of disused elements and systems that become waste if not reused or remanufactured. These products (in particular interiors, services, equipment and furnishings) have usually a high degree of residual performances and are characterized by being dry assembled (therefore easy to disassemble), composed of high-value raw materials, generally equipped with manufacturer technical datasheets (therefore easily traceable) and, besides, by having a high added value.

This book investigates the most promising strategies and organisational models to maintain over time the value of the environmental and economic resources integrated into manufactured products, once they have been removed from buildings. Some novel concepts for the construction sector should be introduced:

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- the integrated “re-actions” (re-manufacturing, re-condition, re-purpose, reuse, repair) as strategies for keeping building products and their embodied materials in use for longer time with significant decrease of waste, energy and water use and emissions through the reduction of manufacturing activities;
- the building as “components bank”. The building is no longer meant as the last destination of industrial products, but as a node within circular processes;
- “planned obsolescence” as a proactive strategy for addressing and optimizing the “re-actions”;
- decommissioned building products meant not as waste but as “bought and sell” items available for purchase from catalogues or other sources;
- “reverse supply chains” that is the delivery of goods (decommissioned elements) from the owners to the reuse or remanufacture operators.

These new concepts are connected with various possible approaches, innovative for the construction sector:

- from product to service, i.e. overcoming the purchase of building elements towards “pay per use” approaches which assume the presence of an operator who supplies products for defined periods and uses and who withdraws them and re-introduces them into the use network, possibly after re-manufacturing, repair, etc.;
- “disown ownership”, possibly with forms of peer to peer market, which assume the presence of networks that facilitate the sharing, renting or leasing and exchanging of products that can be remanufactured and repaired over time;
- lengthening of the life cycle of products through services, with low or zero consumption of materials and energy, based on the scheduled monitoring and updating (re-manufacturing, recondition, repair). These services may be integrated within FM (Facility Management) services related to space and maintenance management;
- assessing the reduction of impacts and the consumption of resources from the point of view of environmental (LCA), economic (LCC) and social (SLCA) sustainability in order to evaluate the effectiveness of circular economy strategies based on re-manufacturing and reuse processes.

By assuming these concepts and approaches the book introduces some challenges to the existing paradigms:

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– from the design of products, meant as "black boxes", to the design of systems that can be divided into items, identified for the different durations and for the possibility of being disassembled, remanufactured, traced and reused once isolated;
– from the sale of a product (the building element) to the supply of a service, enhancing the "extended producer responsibility" and "shared responsibility" along the supply chain through the introduction of new re-manufacturing operators;
– from the ownership of an asset to the delivery of a service (for example renting and leasing models).

Also thanks to the hints that emerged from the intense dialogues and many roundtables involving various categories of stakeholders, conducted during the *Re-NetTA* research, the book intends to identify and analyse the most important berries to the development of effective re-manufacturing practices and the possible strategies to overcome them.

The book is articulated into three parts and 15 chapters.

Part I BACKGROUND introduces the current theoretical background and identifies key strategies about circular economy and re-manufacturing processes within the construction sector, focusing on tertiary architectures. It is divided into three chapters.

Chapter 1 deals with the relationships between circular economy and building sector, proposing tertiary architectures as promising testing ground for assessing circular strategies.

Chapter 2 introduces and discusses a hierarchy of the possible "re-actions" for circularity, each of one characterized by the return of a used product, trying to highlight the fundamentals and the basic conditions for propagating re-manufacturing, recondition, reuse and repurpose.

Chapter 3 provides an overview of the most existing consolidated practices of re-manufacturing within different industries and highlights possible strategies and approaches to transfer to the building sector.

Part II PROMISING MODELS outlines, according to a proposed framework (Ch. 4), a set of promising circular organizational models to facilitate re-manufacturing practices and their application to the different categories of the tertiary sector: exhibition, office and retail. This part also reports the results of active dialogues and round-tables with several categories of operators, adopting a stakeholder perspective. The chapters 5,6,7 describe each of the three models and share the same structure: the description of the organizational model, cases and views from the

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perspective of some key stakeholders in the field-sectors, the enabling and hindering elements.

Chapter 4 proposes three promising circular organizational models and discusses some key features useful for deepening them: *rent contract as a support for re-manufacturing*; a*ll-inclusive solution to support re-manufacturing; alternative/secondary markets for re-manufactured products.*

Chapter 5 introduces the rent contract, focusing on value chain key factors that enable circular practices. Representative case studies for the tertiary sectors are discussed.

Chapter 6 presents the characteristics of an innovative organizational model proposed for the tertiary architecture based on the integration of all-inclusive services with the goal of promoting re-manufacturing practices. The investigation is developed considering the exhibition, office and retail sectors.

Chapter 7 The chapter presents the characteristics of an innovative organizational model aimed at promoting circular dynamics through the setting of a supply chain that identifies alternative/secondary markets as potential destinations for reused, re-manufactured and repurposed products.

Part III INSIGHTS provides some insights on the issue of re-manufacturing, analyzed from different perspectives with the aim of outlining a comprehensive overview of challenges and opportunities for the application of virtuous circular processes within building sector. In particular, Part III is organized in four key topics: A) Design for re-manufacturing; B) Digital Transformation; C) Environmental Sustainability; D) Stakeholder Management, regulations & policies.

Topic A "Design for Re-manufacturing" investigates the relevance of original product design in the specific context of re-manufacturing in tertiary architecture, with a focus on design strategies and guidelines.

Chapter 8 focuses on the topic of design for re-manufacturing (DfRem), presenting a set of guidelines that can facilitate product re-manufacturing processes toward more circular and sustainable organizational models in specific contexts, with particular attention on the tertiary sector.

Chapter 9 deepens the subject of design for re-manufacturing and circular processes applied to the field of textile architectures.

Topic B "Digital Transformation" explores the possibility to apply digital technologies to re-manufacturing practices, highlighting possible solutions to streamline current activities and to exploit the novel availability of real-time information and advanced data management capabilities offered by Information and Communication Technologies (ICTs).

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Chapter 10 investigates how digital technologies can support the transition to circular economy of tertiary building through the digital simulation of the disassembly and remanufacturing stages.

Chapter 11 discusses how some barriers to the spreading of re-manufacturing practices may be handle more effectively by means of the Information and Communication Technologies (ICTs), especially Internet of Things (IoT), highlighting the key role of information platforms towards stakeholder collaboration and co-operation.

Topic C "Environmental Sustainability" focuses on the environmental benefit of re-manufacturing practices, emphasizing the application of life cycle tools to support the sustainability assessment of circular practices, encouraging the materials flow monitoring and information exchange among stakeholders.

Chapter 12 focuses on the assessment of the environmental sustainability of building products derived by re-manufacturing organizational models, in order to support eco-innovative approaches for the development of long-term value and green products. In this context, the material flows associated with re-manufacturing process are mapped and analyzed in depth, providing a framework for the application of LCA to re-manufacturing processes and re-manufactured products.

Chapter 13 deals with the traceability tools (e.g. materials passports, pre-demolition audit, etc.) useful to keep information related to building components in their entire life cycle (from material extraction to the disassembly after use and the end of life).

Topic D "Stakeholder Management, Regulations & Policies" deals with the definition of regulations supporting the relationships between the stakeholders and of approaches to the management of the re-manufacturing supply chain, providing also value chain insights to foster circular processes in the building industry.

Chapter 14 introduces the Sustainable Product-Service Systems (S.PSS) discussing to which extent they can enable value chain opportunities for re-manufacturing practices in the context of tertiary architectures and focusing on the application of product-service based models attached to re-manufacturing activities in the tertiary architectures context.

Chapter 15 aims to provide an overview of the main aspects on novelty introduced by reuse and remanufacturing practices assuming as a sample the Italian regulatory framework of the building sector, in particular focusing on aspects related to negotiation (sale, donation and leasing), safety, environmental and waste management.

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Part I

Background

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1. Circular economy and tertiary architecture

by *Monica Lavagna, Carol Monticelli, Alessandra Zanelli*

1.1 Circular strategies: fragmented practices and lack of stakeholder awareness

The principles of circular economy are based on theoretical issues developed in the Sixties-Seventies (Boulding, 1966; Commoner, 1971; Stahel and Reday, 1976; Stahel, 1982), about closing the loop and the extensions of product life cycle through material exchange (reuse, recycling) and strategies planned from the beginning, with a particular focus on design.

In the 2000s, to face the problem of the increasing resource consumption and the growing cost of raw materials, some international bodies (UNEP, 2006; EMF, 2013; 2014; 2015; EEA, 2016; 2017) relaunched these principles, under the concept of circular economy, with the aim to replace the current linear economic model.

In recent years, the circular economy has become an important objective, in particular of policies (EC, 2014; 2015; 2020) and has been promoted by various environmental action plans, programs, roadmaps and local initiatives, especially in Europe (but not only). The construction sector is a "priority area", as it is the producer of the highest quantity (36%) of waste (Eurostat, 2020) and the consumer of about 50% of all extracted materials (EC, 2020).

There are many strategies for applying the circular economy, based on closing the cycles of production and consumption in the technosphere, in order to reduce the flows of resource consumptions and waste emissions, to and from the ecosphere. The strategies currently applied at European level are very diverse and fragmented, but they can be grouped into three areas (Giorgi *et al.*, 2022): i) resource and waste management, with an end-of-

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pipe approach mainly linked to solving the problems of end-of-life waste; ii) design for circularity (e.g. design for disassembly), with an upstream approach and a vision extended to the life cycle; iii) circular business models and networking of operators, with a management and value chain approach.

Current practices, especially in the construction sector, are mainly oriented towards waste management and recycling (Giorgi *et al.*, 2017), which is the least optimized solution in the hierarchy of circular actions, but also the most promoted by the current European legislative framework. Moreover, downcycling activities, such as the reuse of aggregates for the construction of road foundations, deriving from the need to solve the problem of managing construction and demolition waste at the end of the building service life, are the most practiced. This is also a consequence of a strongly focused approach on the material level, while the building level is rarely considered (Pomponi and Moncaster, 2017).

Instead, the primary objective of the circular economy, in the original inspiring principles, should be value conservation, based on the extension of product life, not simply understood as an extension of the use of materials over several lives (through recycling), but possibly as an extension of the use (through multiple use cycles) of products and construction systems as they are (reuse) or with few adaptations (re-manufacturing), maintaining their value over time. Examples of these kinds of applications in the built environment are only pilot cases (CE100, 2016; ARUP, 2016) and not current practice.

The difficulty for the construction sector to prolong the maintenance of the economic value is the main reason that hinders the implementation of more effective circularity strategies. The practice of downcycling is caused by the fact that demolition activities at the end of the building life return materials that are mostly inert, of little value and difficult to recycle, due to the constructive characteristics of the existing building stock. The potential to identify a residual economic value in the building products is generally poor, due both to the low value of the building materials, and to the degradation state of the elements at the end of the building's life (being generally very long). This discourages disassembly operations, which would favour the potential reuse of products, but are very expensive because they are manual, favouring demolition. Moreover, disassembly is a scenario that is difficult to apply to buildings that had not been designed and built to be disassembled (and, therefore, not characterized by reversible constructive solutions).

Despite being a circularity strategy, recycling can become a legitimation for accelerating consumption, without guaranteeing a solution to the

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scarcity of raw materials for the construction sector, and with unsustainable energy and environmental costs.

Reuse and re-manufacturing are rarely practiced in the construction sector and are more widespread in industrial sectors, where end-of-life products still have good residual performances and high economic value, and service life cycles (of use) are short. In the construction sector, these practices are hampered by the low economic value of the products and by the long times of use (typically decades), which discourage operators from taking on the management of the useful life of the products and the end of life.

However, there are also areas of temporary use in the construction sector, in particular in tertiary buildings (offices, reception facilities, exhibition areas, commercial spaces, temporary shops), characterized by functional and/or aesthetic obsolescence (of image/branding), that lead to disposal of products which still have a high residual value and which could become interesting opportunities for experimenting reuse and re-manufacturing (Talamo *et al.*, 2021).

Implementing these practices, however, requires a control of the entire process along the life cycle and appropriate networking of operators.

Circular practices in the construction sector are currently very fragmented and there are still few supply chains and organizational models that permanently involve operators in circular practices. This derives from the fact that the flows of products, that can be reused or regenerated, are not constant (especially if we refer to those disposed by the existing assets and which have not been designed to be reused), so the activation of a stable supply chain becomes difficult. The variability of the products, the fragmentation of supply (linked to the individual construction/demolition sites) and the variety of possible operators involved or available, make complex the logistics and the management of processes and responsibilities. The consequence is to manage the reusable products and constructive systems case by case, thus failing to activate stable supply chains.

The lack of circular supply chains is also motivated by the lack of awareness on the side of operators of the potential for generating value from circular practices, in particular related to reuse and re-manufacturing, and the re-evaluation of resources that would otherwise be wasted. The construction of new organisational and business models based on circularity, which modify ownership relationships, transaction methods, and extend the responsibility of the producer to the entire life cycle, creating a lasting relationship with the customer, can demonstrate to operators the economic advantages of circularity and open up new market opportunities.

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1.2 Rapid obsolescence and temporary use: opportunities for circularity in tertiary buildings

Many industrial sectors are developing practices of circularity, based on re-manufacturing and reuse, for items characterised by short life spans, and enabling virtuous organizations of relationships between the operators of the entire production-use-reuse-regeneration process (Atta *et al.*, 2020; see Chapter 3). Starting from the need to experiment virtuous circular paths for building elements through re-manufacturing and reuse, considered as winning and low environmental impact strategies in the perspective of a regenerative circular economy (CER, 2020), the main objective is to foresee the range of possible winning applications in the field.

In the construction sector, the tertiary sector (public and private offices, accommodation facilities, commercial structures, exhibition spaces, shops) is characterised by: i) the strong presence of prefabricated and dry assembled building elements and products, ii) products and materials with high economic and performance value, iii) products often replaced after short life cycles (10-15 years) (Peters *et al.*, 2017), due to the frequent renewal of the fit-out (for functional reasons, spatial layout or corporate identity) typically implemented in such specific contexts. These features are similar to the ones that facilitate the application of reuse and re-manufacturing in the industrial sectors.

Additionally, in recent times some trends, which determine an acceleration of the modifications and the replacements inside tertiary buildings, have been consolidated. In particular, the use of buildings as a service (hoteling, temporary shops, co-working and various forms of sharing), corresponding to new use models and to a high degree of temporary use of the spaces, is generating frequent renewals as a consequence of recent changes in usage patterns. This process is empowered by the shortening of leases, the transformation of the Real Estate market and business models and, last but not least, the most recent requirements of organisational and spatial transformability and rapid and reversible rearrangement upon the exiting pandemic emergency. In the last twenty years, the workspaces have evolved from individual offices to open spaces, to accomplish the need for collaboration. The rise of smart working has further modified the use of office spaces. This opened the way for the hybrid use of shared spaces like hoteling, hot desking (non-reservation-based hoteling) and free address seating. After the pandemic period, the design of offices and other tertiary spaces is still changing with different rules and needs. The consequence are frequent changes in space layout.

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The commercial spaces have also evolved over the last twenty years, with the spread of temporary forms such as temporary shops and "pop up" store. Due to the short leases, retail is also characterized by frequent change in the commercial destination of shops, which involves substantial renovations of the interiors in relation to the type of commercial activity and branding image. Finally, shops typically tend to renew their image frequently, to attract attention.

In the current practice, these renovations mean the demolition and the disposal in landfills of elements (finishes, internal partitions, flooring, false ceilings, fittings, systems and furnishings), which are still in good condition and have a high percentage of residual performances. These are building products that could be recovered, reused or re-manufactured. The typical partitions for tertiary interior design are characterised by modular products, special joints and dry and easy assembly, that guarantee their integrity during disassembly and a durability overcoming the first cycle of use.

The environmental advantage of re-manufacturing emerges especially for short-term buildings or their elements, where the dismantled products can ensure a satisfying level of residual performances: the functional obsolescence is rarely corresponding to the physical decay and this aspect should be verified at the end of the functional life cycles of the products themselves.

The following observations underline the reasons for focusing on buildings of the tertiary sector as a possible sector of interest for re-manufacturing strategies:

- the huge number of buildings used for various tertiary destinations (public and private offices, accommodation facilities, exhibition facilities, retail, temporary shops, etc.);
- the presence of an unused tertiary building stock waiting to be revitalized, whose number increased during the pandemic emergency of the last two years, due to the paradigmatic change of the "non-use" of the offices and their management;
- the frequent cycles of renewal and reconfiguration of the interior spaces following a series of needs, that determine a fast functional obsolescence and frequent reshaping;
- the consequent availability of significant quantities of disused elements and products (in particular interior finishing materials, panels, tiles, services, equipment and furnishings). Most of these elements, typically designed and produced for tertiary building, are dry assembled (therefore easily to disassemble), composed of high-value (high embodied

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energy content) materials, generally supplied with manufacturer technical datasheets and manuals (therefore easily traceable);
- the presence in this sector of operators (e.g. facility managers) who deal with the management of spaces, the monitoring of interventions during the use phase and the planning of the end-of-life (e.g. for restyling), and who can become key players in conjunction with the re-manufacturing operators;
- the predisposition of this sector to experiment product-service formulas applied to building elements and products, taking into account the short cycles of use and the interest of clients for leasing than ownership (e.g., successful practices relating to furnishings).

1.3 The challenge to implement circular models in the context of tertiary architectures renewals

The application of circularity in the construction sector requires a change of perception: the costliness of raw materials led to the shifting of the focus of the supply chain from the ecosphere to the technosphere. This means that materials stored in buildings are potential resources, waiting to be reused at the end of their life. Consequently, resources should be monitored throughout their life cycle, in a cradle-to-cradle perspective.

Several studies expressed this concept both at city level and at building level. Hence, the birth of the concept of urban mining, which means to thinking of the cities and buildings as a mine of materials. Resources are stored in the anthropogenic stock embedded in our buildings. The upgrading of this vision is to consider not only the building materials, but also the building products and elements that can be reused.

In line with this concept, the European project "Building as Material Bank" (Peters *et al.*, 2017) suggests that buildings can be seen as "banks" of products and materials. This concept open to new strategies and business models for lengthening the service life of building products, preserving their value over time. To allow these changes, the design approach has to consider more than one life cycle of the products/elements, towards reuse, re-manufacturing and repurpose.

A good practice we can pursue is to create an inventory of materials and products available within buildings, whose economic value is real-time updating, following the market's variations. One of the most virtuous initiatives of survey under development is the Madaster platform conceived by Turntoo (Rau, 2019): it contributes to spread awareness of the value of

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building products over time and of the benefits (also economic) coming from their management at the first end-of-usage towards reuse.

However, the activation of these processes means the satisfaction of some necessary conditions, related to the overcoming of the current technical, organizational/managerial, regulatory, information and cultural barriers.

First of all, there are flows of waste materials and elements which come out from building not designed for disassembly and reuse/regeneration: they have high potentials to be regenerated, but their heterogeneity and non-continuity create considerable problems, from a technical point of view, in the reworking activities. These last ones have to be carried out on a case-by-case basis. Furthermore, this aspect hinders the activation of a stable supply chain. The immediate foreseen consequence for driving this rework towards is a shift back to an artisanal and non-industrial processes, for the ability to manage the re-manufacturing with an higher level of flexibility.

Secondly, the difficulties during the recovering of the products stored in the current buildings derive from the current use of non-reversible construction techniques, which necessarily involve demolition at the end-of-life. Designing them in the logic of dry assembly and constructive reversibility (design for disassembly), in order to enable the recovery of parts without breakages or irreparable losses, helps to overcome this barrier.

A third important aspect is the management of information during the life cycle of the products. The loss of information related to the properties of the product and the lack of a register of the actions on the product over time leads to difficulties in reuse at the end of the first life. The technical information of products, related to characteristics and performances, has to be integrated with technical specifications (defined by the manufacturer) concerning the whole life cycle, related to the installing and assembling process, the maintenance needs and the disassembly process, where it is possible. These information have to be stocked and implemented over time, in order to detail new specifications about the products, related to the actual conditions of assembly-use-disassembly (e.g. the number of maintenance interventions during the lifetime, the replacements of some parts, the repainting). For such purposes, tools as Building Information Modelling and Material Passport are potential for facilitating the re-manufacturing chain in order to collect and manage information over time.

Linked to this aspect, the guarantee of performance after the re-manufacturing phase is the main critical point for the circular process based on reuse/re-manufacturing/repurposing: the operator have to re-ensure a new

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certification of a product not knowing precisely the degradation stage after the first usage cycle. A possibility is the material "re-characterization" and testing of its performances, but it is a much more expensive process in comparison to the recycling industrial process, where the production process is checked. One possible leverage for overcoming this problem, although probably not enough to solve the problem, could be the traceability and the registration of the material properties and the technical specification of the product and of the maintenance actions, monitored over the multiple life cycles.

The regulatory framework plays an important role in this respect. While on the one hand the European directives are oriented towards circularity, there are still many regulatory barriers that hinder the recovery of materials and products at the end of their life. Furthermore, there is still a lack of a regulatory framework dedicated to second-life products (in particular certification schemes, guarantees and the transfer of ownership). Finally, the strong regulatory restrictions on performance of buildings often hinder reuse (due to the lack of knowledge on the residual performance of the products), imposing "downcycling" of the function and application of the reused product. If this latter aspect cannot be overcome, the regulatory framework should instead be updated to allow the application of circular practices.

The ownership and thus responsibility of products and elements are other relevant aspect to be considerered. The current product sales practice and the lack of responsibility of the producers with respect to the useful life and end of life does not stimulate the design of durable products, designed to be reused, because the interest of the producer is to guarantee himself the continuity of production and sale on the market. To overcome this situation, a possible approach is the introduction of new contractual opportunities among manufacturer and end user (product-service formula): the producer retains ownership of the product during the entire life cycle (with the extension of producer responsibility and a "take-back" formula at the end of life), providing the customer with building products as a service.

This perspective requires the activation of new supply chain organizations and the development of new organizational models, which provide for the involvement of the producer/distributor of the product, but which can then expand to new operators who deal with re-manufacturing and the second life of the product.

Starting to filling the gap, to apply new business models developed on the product-service or on the leasing/renting model is necessary to define the relationship among producers-installers-users-maintenance technicians-dismantlers (e.g. related to logistic, technical skills, management skills,

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responsibility, ownership of the product). This leads to the need to define new organizational models and possible re-manufacturing network.

One of the conditions for structuring possible new re-manufacturing networks could be the identification of new interface figures among the many operators of the circular process (production, use, disposal, re-manufacturing, market of re-manufactured products). This aspect allows to generate new professional figures, skills and jobs.

Finally, the cultural barrier is the last one. The second-hand market has fluctuating successes in other sectors. Specifically in the construction sector, this sensitivity is still very variable. The momentum of this market would certainly be strengthened by awareness-raising actions on some win-win key points: for the demand, the reduction of costs related to the "ownership" of building components related to temporary uses, thanks to temporary access (leasing) to customizable fit-outs (building product as a service); for the supply, both the reduction of production costs through the reuse or regeneration of materials and products, and new business opportunities related to rental rather than sale.

Among all the aspects dealt with, the economic lever is certainly the one that can drive change. For this reason, the research work presented in this book focuses on this aspect (value retention) and on the need for new organizational models of the supply chain.

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2. *Reuse and re-manufacturing as key strategies towards circularity*

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.

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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.

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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.

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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

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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.

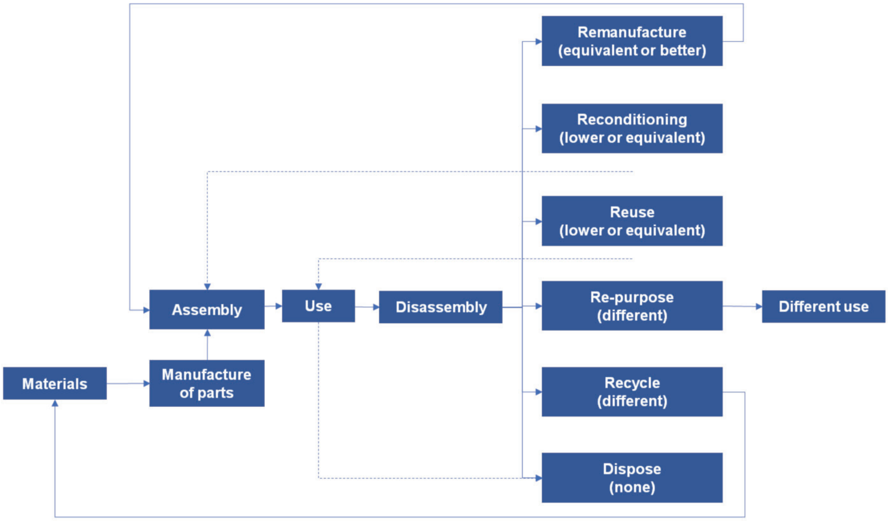

Fig. 2.1 - Product life cycle (BS 8887 2:2009)

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).

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

The basic concept of value management during a product's entire life-cycle (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.

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(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).

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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).

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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.

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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

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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-

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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

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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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3. Re-manufacturing evolution within industrial sectors and transferable criteria for the construction sector

by *Anna Dalla Valle, Nazly Atta, Serena Giorgi, Luca Macrì, Sara Ratti, Salvatore Viscuso*

3.1 The spread of re-manufacturing practices across the industrial manufacturing sectors

Re-manufacturing is an industrial practice intended for returning a used product to at least its original performance, releasing it with equivalent or better warranty than the newly manufactured product (see Chapter 2). Despite this practice now represents a possible strategy towards circular economy, its origin is attributable to more than 80 years ago. Indeed, at the time of World War II the great need to reuse automotive and truck parts lunched the industry. The intensive exploitation of resources to build military vehicles highlighted how material and energy savings are key enabler for re-manufacturing activities. Today, the lack of resources, the increase in price and the commitment to green transition further evidence a growing emphasis on re-manufacturing, in order to maximise the exploitation of resource efficiency potential (Lee *et al.*, 2017; Nasr *et al.*, 2017; Lange, 2017).

However, it is important to note that, even if performed in a variety of form for decades, re-manufacturing is now fully implemented only in specific industrial fields and geographical areas. The oldest and well-established re-manufacturing industry is placed in the US country, marketing a wide variety of re-manufactured products, accepted as cheap alternatives to the new equivalents (Lund, 2012). Here, the United States International Trade Commission (USITC) is the body responsible for collecting import-export data on the US re-manufacturing industry, according to the major twelve industries. They concern: aerospace, consumer goods, electronics, heavy equipment, IT products, train, machinery, medical devices, automotive parts, office furniture, restaurant instrument and tires (USITC, 2012). In the other countries, re-manufacturing is implemented in heterogeneous ways, depending on the field area and the application context (Guidat

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et al., 2017). For instance, it results at the preliminary stage in China, although the strong economy growth of the last decades and the interest covered within the political agenda (Wei *et al.*, 2015). The industrial scale and annual production value of Chinese re-manufacturing enterprises is improving with the new policies as well as capital and technical support from the government, but technical barriers, inefficiency and lack of unified standards still exist (Cao *et al.*, 2020).

In EU communities, re-manufacturing is applied in the industrial fields similar to those in the US, mainly focusing on some business industries and slowly spreading into others. In particular, the European Re-manufacturing Network (ERN) is in charge of supervising the re-manufacturing industry according to nine industrial sectors: aerospace, vehicle, electronics, furniture, heavy equipment, machinery, ship, medical device and railway (Butzer and Schötz, 2016). By the market analyses (Parker *et al.*, 2015), the re-manufacturing industry constitutes 2% of the European manufacturing sector, with an annual turnover of about 30 billion euros, mainly covered by aerospace (42%) and automotive (25%) sectors. They jointly produce more than two-thirds of the entire European turnover in the re-manufacturing industry. Low annual turnovers (range from 1 to 4 billion euros) are achieved in the heavy-duty and commercial vehicles, electrical and electronic equipment, mechanical engineering and medical equipment industries. Lastly, rail, furniture and marine sectors play a marginal role, reaching together a share of 2.5% of the total re-manufacturing turnover. Nevertheless, the European re-manufacturing industry is expected to grow by more than 50% to 46 billion euros by 2030 and it is supposed to triple in case of more favourable political and economic conditions (Parker *et al.*, 2015). This transformation scenario, however, needs important promotion actions by various stakeholders, including policy-makers, industrial companies, research and academic communities as well as public audience, in support of the involved business parties. Encouraging targeted recommendations (Karvonen *et al.*, 2017) and networks creation turns out to be pivotal for promoting and expanding re-manufacturing activities in Europe (Guidat *et al.*, 2015).

Deepening the re-manufacturing market of EU by regions (Parker *et al.*, 2015), Germany, UK (and Ireland), France and Italy emerge as key drivers, by accounting up to 70% of re-manufacturing value. Specifically, Germany leads Europe in terms of turnover in all sectors except for marine and furniture. Concerning marine sector, it is overtaken by Eastern regions (including Bulgaria, Estonia, Latvia, Lithuania, Hungary, Poland, Romania and Slovakia), while in furniture it is equivalent to Italy. In all cases, re-manufacturing industry is characterized by a majority of micro-

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enterprises and small enterprises (SMEs), often operating as independent re-manufacturers (Parker *et al.*, 2015). However, it is worth mentioning that data on re-manufacturing sector are hard to source especially when Original Equipment Manufacturers overlap with re-manufacturers, practicing re-manufacturing as aftermarket service.

To provide insights into re-manufacturing, the leading industries are examined in the next paragraphs by means of a sample of current practices. The business industries are picked out starting from the categorizations provided by both US and EU bodies (USITC, 2012; Parker *et al.*, 2015), selecting the most representative in terms of market share. In particular, they fall into the following main sectors: aerospace (Par. 3.2); automotive (Par. 3.3); electrical and electronic equipment (Par. 3.4); heavy-duty and off-road equipment (Par. 3.5); and machinery sector (Par. 3.6). Moreover, the emerging industries, like fashion, marine, transport and consumable goods, are clustered together as "Other sectors" (Par. 3.7). For each selected business sector, the most representative re-manufacturing practices are presented, based on the available scientific papers, official whitepapers, company reports, enterprise websites and networks (e.g. European Re-manufacturing Network).

The focus is on the specific organizational and business approaches underlying the closed-loop supply chain models, intended as the process of designing and controlling systems aimed at maximizing the creation of value along the life cycle of products (Moroni-Cutovoi, 2021). Note that they include Sustainable Product Service System (S.PSS) and they deal with re-manufacturing in its broad sense, extended to the wide range of reprocessing activities (e.g. reuse, repair, reconditioning, replacement, refurbishment, overhaul). System maps are used to provide an effective and comprehensive overview of the different practices, highlighting the involved actors, the contractual terms, the resource flows and the operations carried out during re-manufacturing process. All practices maintain the same function of the original product.

3.2 Aerospace sector

The aerospace industry deals with vehicular flight within and beyond Earth atmosphere (Amir and Weiss, 2020). It is thus engaged in the research, development and production of flight vehicles, comprising all aircraft and spacecraft but excluding space-related services such as telecommunications. On one hand, it includes the manufacturing of space items, enclosing spacecraft, spacecraft launch vehicles, satellites, planetary probes, orbital stations and shuttles. On the other, it covers non-

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space items, like passenger and military airplanes, helicopters, gliders and balloons. In addition, it comprehends the manufacturing of their parts and accessories, used in civil or military applications (OECD, 2007).

As well-know, to operate in this sector implies significant costs to sustain, conferring to products, engines and airframes an intrinsic high value. Indeed, they are engineering products, manufactured with advanced and sophisticated materials and with high levels of skills and technologies, calling for constant maintenance activities to ensure safety. Since maintenance, intended as the product re-processing operations, plays an established role, it is commonly practiced in different ways, according to the involved parties, to the contractual terms and the derived organizational models. In the event that product ownership and related responsibilities and risks are in aircraft owner hands (customers), the high costs for spare parts and aircraft elements make customers necessarily enter in service agreements for maintenance services. These service activities can be externalized and committed to third parties or strategically internalized, dedicating for instance one business section specifically to engineering and maintenance (Air France KLM Group, 2016; 2019). Here, operators are particularly encouraged to find more and more advanced solutions aimed at extending items lifespan in safe and proven ways.

In this context, the key stakeholders involved into the value supply chain are: the aircraft manufacturer (supplier); the aircraft owner (customer); and the service provider (re-manufacturer). Note that in some case customer and re-manufacturer can correspond to the same company (Air France KLM Group, 2016; 2019), while in others they are independent players. Typically, re-manufacturers provide overhaul services for airframe, components and engines, by binding service agreement contracts with the aircraft owners. Moreover, depending on customer relationships, besides offering maintenance services, they can make specific design interventions aimed at extending elements lifespan. Fig. 3.1 shows the related system map, considered as the standard practice of aerospace sector:

1. aircraft frames and engines are entrusted to manufacturer/service provider by aircraft owners;
2. aircraft owners keep the property of products and pay fixed price to have lifecycle services;
3. during use, the service provider performs predictive maintenance and repair activities as required;
4. if needed, products are also overhauled by the company;
5. once re-manufactured, aircraft frames and engines return to aircraft owners.

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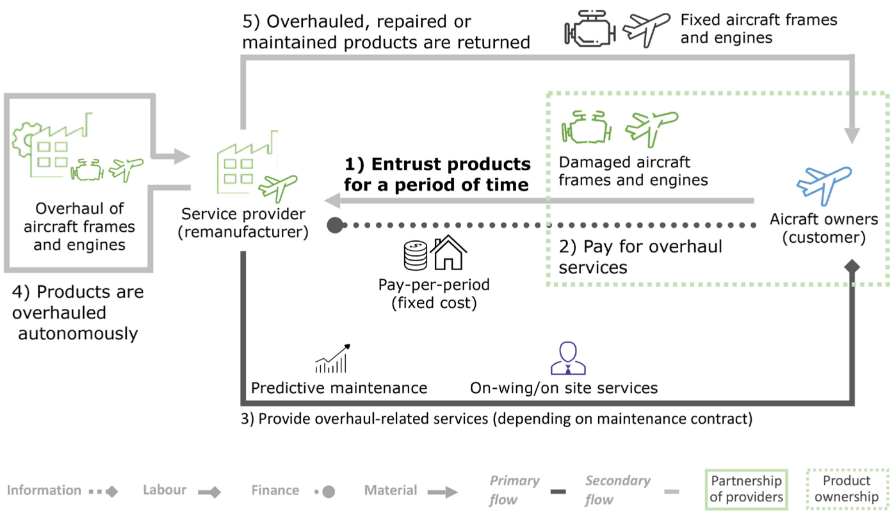

Fig. 3.1 - System map of aerospace practice – sample 1

However, the high value of aircraft elements activates initiatives oriented to extend products lifespan, experimenting alternative and innovative organizational models. This happens for instance when aircraft owners do not want to deal with maintenance services, entering in specific contracts entrusted directly to aircraft manufacturers. In fact, manufacturers can decide to sell products together with total care service, providing an all-inclusive lifelong program in order to ensure product performance according to customer requirements (Rolls-Royce, 2022; Buller *et al.*, 1994; Kerley *et al.*, 2011; Smith-Gillespie *et al.*, 2019). This type of offer is plainly used for certain products, carefully designed in order to preserve performances in use and facilitate maintenance. For this purpose, a strategic design feature is the modular configuration, creating for example engines with different thrust based on the same compressor. It means that the core is designed for high-thrust engines but used also in low-thrust engines, improving product flexibility both during manufacturing and re-processing. Moreover, materials are deliberately selected to extend performance durability, products are conceived with distinct structural and non-structural elements and product monitoring technologies are implemented to carefully plan maintenance operations.

In this perspective, the organizational model includes two main actors: the airline companies as aircraft owner (customer) and the aircraft manufacturers, responsible also for all life cycle services (manufacturer/

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re-manufacturer). The service operates on the basis of pay-per-hour of engine flight payment mechanism, including secured cost of operating engines as well as maintenance, repair and take-back services provided by the manufacturer/re-manufacturer. In practice (Fig. 3.2):

1. the engine is sold by manufacturer to the airline company, which acquires its ownership;
2. after the installation on the aircraft (included in the offer), the manufacturer/re-manufacturer provides all the necessary scheduled and unscheduled interventions;
3. the aircraft provider receives payment-per-hour of engine flight (more time engines are operative, higher is the profit of the provider);
4. at the end of the contract, the manufacturer/re-manufacturer takes the engine back;
5. products are properly disassembled for reuse and/or material recovery and recycling.

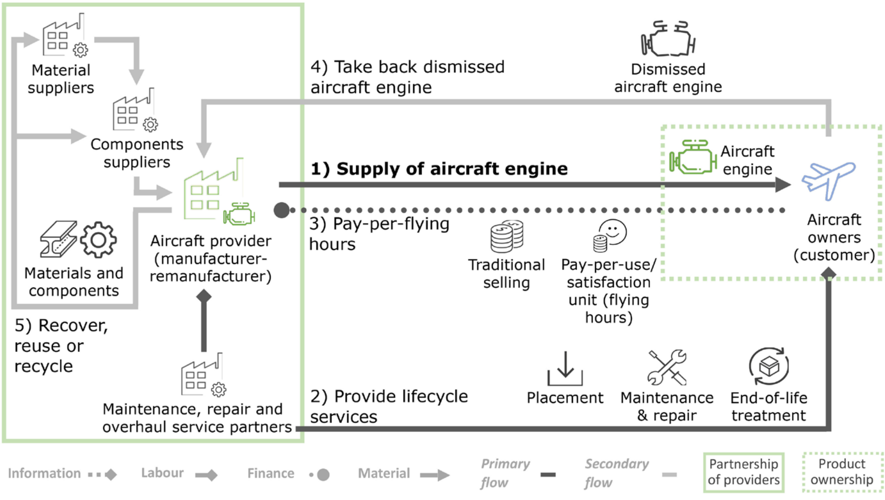

Fig. 3.2 - System map of aerospace practice – sample 2

In both aerospace practices, the re-manufacturing steps are typically as follows: (i) inspection of the whole; (ii) disassembly; (iii) cleaning; (iv) inspection of products; (v) reconditioning; (vi) reassembly; (vii) validation tests and certifications. During the inspection, products are assessed visually and with non-destructive methods (e.g. ultrasonic or eddy current

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inspections), dividing elements according to their level of functionality (service, scrap or requiring rework). Elements that need re-manufacturing are transferred to repair facilities, while materials for recycling/recovering are given back to material suppliers, usually for re-melting. The whole process is conducted efficiently and cost effectively, in compliance with the specific quality standards, allowing individual repair modules alongside the full overhaul services. The high technical level and the importance of safety standards encourage the development of life cycle services and thus the attempt to implement actions oriented to lengthen product lifespan. Re-manufacturing strictly depends on the product at issue and on its performance level.

3.3 Automotive sector

Automotive industry embraces all companies and activities involved in the manufacture of motor vehicles, including engines and bodies, but excluding tires, batteries and fuel (Bell Rae and Binder, 2020). The principal products are passenger automobiles and light trucks, including pickups, vans and sport utility vehicles. Although crucial for trade, commercial vehicles, as delivery trucks and large transport trucks, turn out to be secondary products for automotive. Moreover, note that this sector includes vehicle manufacturing as well as parts and accessories production for motor vehicles and their engines (EC, 2007).

Contrary to aerospace, re-manufacturing in automotive sector is mainly performed by specific independent partners, used to work with a wide portfolio of Original Equipment Manufacturers (OEMs), as appropriate, at national or international level. In this way, re-manufacturers are not responsible for the design of products to be reprocessed, since they derive from external dealers or OEM. This implies that unsuitable product design could affect the feasibility of re-manufacturing process. Anyhow, re-manufacturers have as priority strategy to operate for product lifespan extension, trying to iron out the original flaws and design to increase durability and to preserve performances, avoiding additional costs for OEM. Indeed, the design and manufacturing phases are under OEM control as well as the repair interventions within the warranty period, in case of malfunctions of products in use.

Considering as basic stakeholders, the end-users, OEM and/or local dealers, and the re-manufacturer, the latter is focused on specific products, e.g. automatic dual clutch transmissions (ATP Industries Group, 2016; 2022) or starter motors and alternators (Autoelectro, 2016; 2022).

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Consequently, OEMs or local dealers can potentially enter into service agreements with different re-manufacturers, ensuring the collection of cores to be re-manufactured which are then sold back to OEMs. As disclosed by the related system map (Fig. 3.3):

1. final users buy new cars from OEMs or local dealers;
2. at the end of use, vehicle OEMs or dealers collect dismissed cars from the end-users through service contract;
3. dismissed products are sent to specific re-manufacturer;
4. re-manufacturing operations are performed as necessary;
5. the re-manufactured products are sent back to OEM;
6. the OEM or local dealer sells cars with re-manufactured cores to end-users by applying a surcharge to ensure the returning of cores for future re-manufacturing.

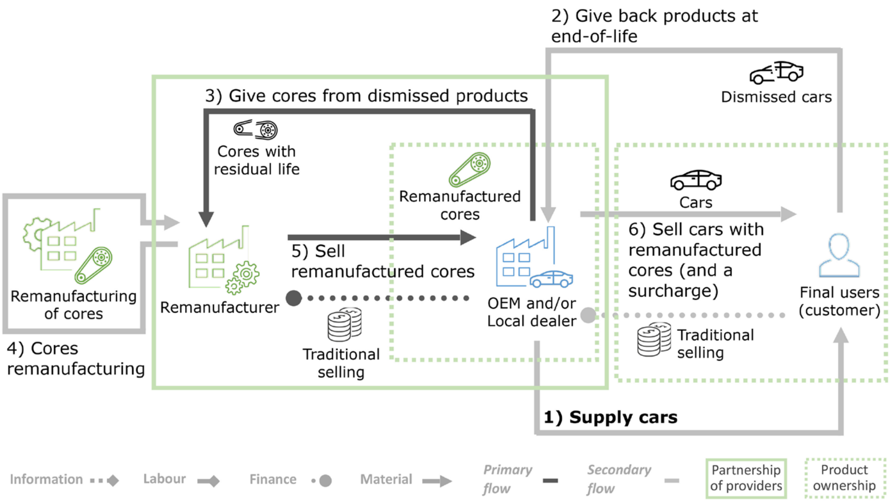

Fig. 3.3 - System map of automotive practice – sample 1

It is worth underlying that the deposit-based system established between the provider and customer (ATP Industries Group, 2016; 2022; Autoelectro, 2016; 2022), it is strategical for closed loop supply chain. Indeed, the customer being obliged to pay a surcharge at the product purchasing, it is encouraged to return the core to get back the surcharge at the end of product use. In this way, it is possible to implement re-manufacturing activities for automotive products by following

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these typical steps: (i) sorting; (ii) inspection and initial diagnosis; (iii) disassembly; (iv) record original serial number; (v) remove of elements; (vi) cleaning; (vii) inspection and internal checking; (viii) renewing and replacement of wear and faulty parts; (ix) test assembly; (x) test full unit to original equipment specification. During re-manufacturing process, re-manufacturers strive in fact to select and assembly elements according to the latest quality specifications, to preserve performance to the greatest extent possible through innovative solutions (e.g. start and stop technology). On one side, the advantage to customers is that they get reworked products of equivalent or superior quality to the original but at a lower price and with still 2-year warranty. On the other side, dealing with products with high warranty costs, re-manufacturing represents an opportunity of cost savings for manufacturers, inducing them to partner with core re-manufacturers.

3.4 Electrical and electronic equipment

The electrical and electronic equipment industry rests on assets that need electric currents or electromagnetic fields to operate and on equipment for the generation, transfer and measurement of such currents and fields (EC, 2022). To simplify, if a product has a battery or needs a power supply to work properly, it means that it embeds electrical and electronic equipment.

The value chain of electrical and electronic equipment is usually characterized by three parties: the end-users (customers), the original manufacturer and the re-manufacturer. In addition to these stakeholders, commercial dealers can as appropriate act as intermediaries to reach the end market, made up of both corporates and household users. According to the profile of customers, different contractual terms may be offered. In Business-to-Consumer (B2C) channel, providers may be interested in offering not only products to end customers, but also in establishing continuous relationships with them through product reconditioning services. Whereas, in Business-to-Business (B2B) channel, facility management unit may enter in a facility contract with the providers for setting a circular management of its electric system, ranging for instance from printing to lighting systems. In all distribution channels, an efficient and responsive product collection system is generally granted by providers.

In order to deepen the closed loop supply chain of electrical and electronic equipment, printing systems are taken as representative case for re-manufacturing, since standing for a firmly established practice

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(APD International, 2016; 2017; Armor, 2016; 2022; Ricoh, 2016; 2022). The conventional organizational model is based on OEMs value chain (Fig. 3.4):

1. printers are sold or leased to end customers;
2. printer contract usually includes lifecycle services included;
3. damaged or dismissed products are collected by OEM;
4. used electro-mechanical modules are transferred to re-manufacturer;
5. the re-manufacturer takes responsibility for the re-manufacturing process, returning modules to their original value or higher;
6. re-manufactured products get back to OEMs;
7. manufacturer and re-manufacturer constantly communicate information for developing re-manufactured solutions that are more and more reliable;
8. printers with re-manufactured modules are provided from OEMs to final customers.

Focusing on the downstream value chain, note that if in some case, re-manufacturer is independent and is in contract directly with OEMs (APD International, 2016; 2017), in others it is in partnership with local commercial dealers (Armor, 2016; 2022). Anyway, the organizational model works out the same way.

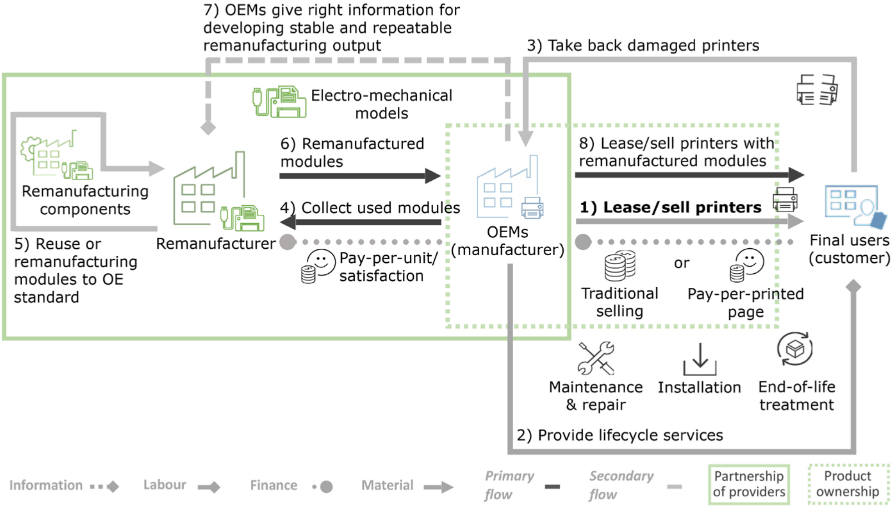

Fig. 3.4 - System map of electrical and electronic equipment practice – sample 1

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Advanced solutions are achieved when OEM is also re-manufacturer (Ricoh, 2016; 2022), pursuing product lifespan extension as main design strategy, with particular attention on facilitating maintenance, repair, re-manufacturing and reuse. Here, especially for corporate facility management units, the printer company can offer innovative "Pay-per-Page" program (Ricoh, 2016; 2022). The integrated printing service contract provides for a printing and copying service, paid by the customer with a price based on the number of delivered pages and copies. The contract does not include the ownership transfer of the printer machine, but rather it covers: consultancy (preliminary assessment of company needs); substitution of old printers with new ones; collection of spare parts and consumables; technical assistance and maintenance.

The same approach is currently experienced in other business area, dealing for instance with lighting systems, turning into "Pay-per-Lux" program (Philips Lighting, 2021; 2022). In sum, it works as follow (Fig. 3.5):

1. the company offer starts with the design of the light infrastructure based on the needs expressed by customers;
2. the customized lighting system is consequently installed, providing lighting as a performance, paid by clients in accordance with the specific amount of energy consumption;
3. during usage, the service company pays energy bills;
4. the lighting provider ensures in addition the life cycle services included in the contract: design, installation, but also repair, maintenance and potentially upgrade;
5. the lighting company takes also responsibility for taking back products at their end-of-life;
6. finally, serviceable elements are reused or recycled.

This organizational model is classified as Sustainable Product-Service System, transforming the original product offering into a service-oriented offering, thanks to the ownership retention by the provider.

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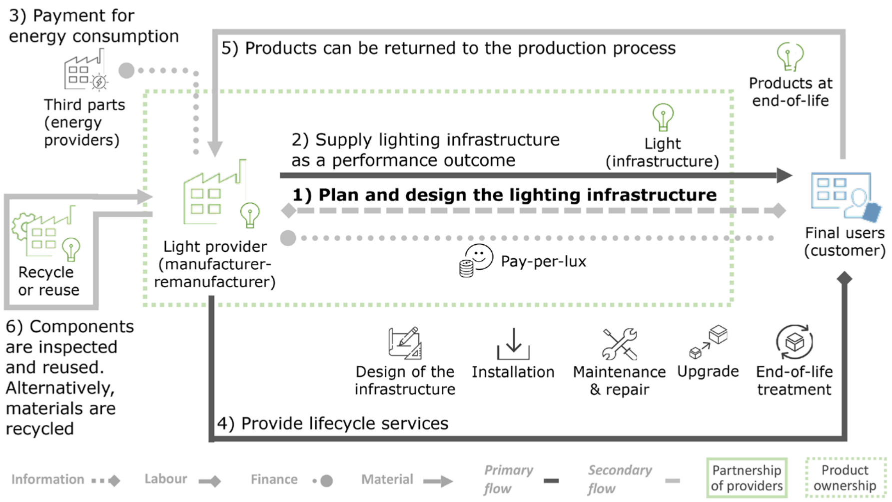

Fig. 3.5 - System map of electrical and electronic equipment practice – sample 2

Concerning re-manufacturing into electrical and electronic equipment industry, the typical process is: (i) inspection of cores to determine if they are viable for re-manufacturing; (ii) erasing data; (iii) breakdown of the re-manufacturable cores; (iv) cleaning; (v) assessment of elements for reuse or replacement with new parts; (vi) reassembling of cores; (vii) software installation; (viii) testing to ensure that the re-manufactured product meets original performance; (ix) packing the approved re-manufactured products per customer requirements and labelling appropriately for full traceability before dispatch. Note that a variety of operations and controls are targeted for each product. In particular, due to the intrinsic features of the products at issue, they could be protected by patents and/or contain chip sets made of many different materials (Armor, 2016; 2022), making more challenging the re-manufacturing and calling for the implementation of specific production lines. Conversely, tracking system and self-monitoring software could be integrated (Ricoh, 2016; 2022; Philips Lighting, 2021; 2022), to advice the need of intervention and to enable preventive maintenance and collection for secondary use. This is crucial especially within S.PSS organizational model for avoiding extra asset costs.

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3.5 Heavy-duty and off-road equipment

The heavy-duty and off-road equipment industry includes vehicles with products created to work in- and off-road environment and designed to operate at low speeds, making them unsuitable for normal highway operation (CFR, 1977). They refer to a wide range of vehicles, purposefully built to perform a wide variety of industrial tasks, sharing many features with on-road vehicles constructed primarily to transport people and goods at high speeds. Notwithstanding, off-road heavy equipment function in the broad scope of non-transportation industry, covering earth moving, mining, agriculture, construction, forestry, landscaping and material handling (Duffy *et al.*, 2019).

Given the specificities of the sector, the related Original Equipment Manufacturers usually perform also re-manufacturing activities (manufacturer/re-manufacturer). They are key stakeholders of the supply chain as well as companies within automotive industry and commercial vehicle manufacturers (customers). For activating reverse logistic, companies sell products to customer on prior payment of a deposit, so that at the end of product use, the core is returned to re-manufacturer and deposit is fully refunded. The simpler practice (Fig. 3.6), associated for instance to diesel engines and components (AGCO Power, 2016; 2022), operates as follows:

1. products are sold to vehicles manufacturers with a deposit;
2. the business offer arranges various additional service, including the product recovery;
3. products are take-back at the end-of-life, refunding consequently the deposit to customers;
4. re-manufacturers are used to get additional engines also from third parts suppliers;
5. all the collected products fall into the re-manufacturing or reuse process.

Finally, re-manufactured products are placed again on the market at a reduced price. Note that since the same company is in charge of both manufacturing and re-manufacturing, depending on the business size, it can have dedicated plants. This may entail the transfer of products to the re-manufacturing plant, but the exploitation for the assembly completion of re-manufactured products of the same production lines of new products (Knorr-Bremse, 2016; 2022). Indeed, by assuming the dual role, the company has the possibility to exploit internal production processes for re-manufacturing activities, take advantages of the existing market shares and the possible synergies of resources.

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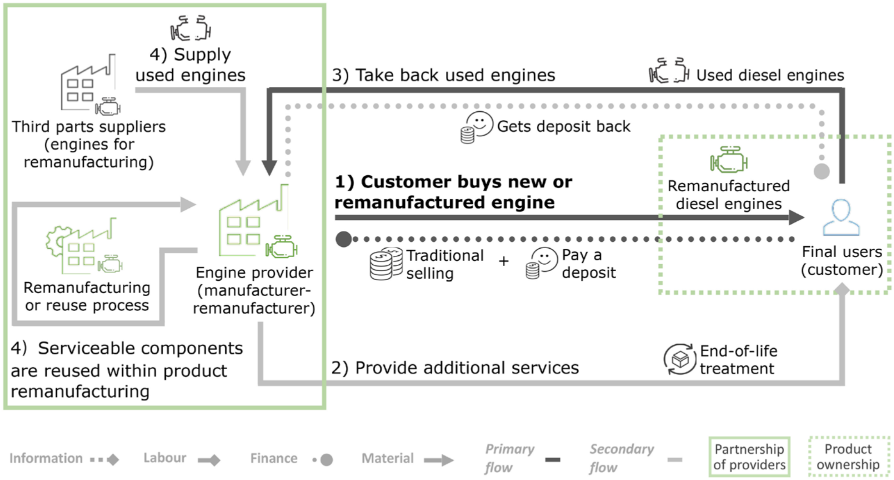

Fig. 3.6 – System map of heavy-duty and off-road equipment practice – sample 1

Turning the attention to extremely complex equipment with high economic value, such as tunnel boring systems, the re-manufacturing practice turns out like in Fig. 3.7:

1. Tunnel Boring Machines (TBM) are sold to customers;
2. TBM are repurchased after use by the leading supplier;
3. once recovered, products with residual life are identified, analysed and stored in the company warehouse;
4. when new request for TBM is made by new customer, general technical requirements are set;
5. project requirements are clearly communicated to the company;
6. customized TBM is designed and produced combining re-manufactured elements and tailored ones;
7. the product is transferred to the customer with a traditional sale, at a reduced price.

Note that although some machine products are custom-designed for individual project requirements, many other like hydraulic pumps or electronic motors are designed and selected to maximize standardisation. TBM are thus designed considering common products and modular platforms that are successively coupled with tailored parts. Moreover, it is important to stress that the company tries to integrate

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re-manufactured elements from the current stock in the new TBM to reduce the offered price to the customer (Herrenknecht AG, 2016; 2022). Due to the different types and sizes of products, the re-manufacturing process requires different loops of cleaning, disassembling and product analysing steps.

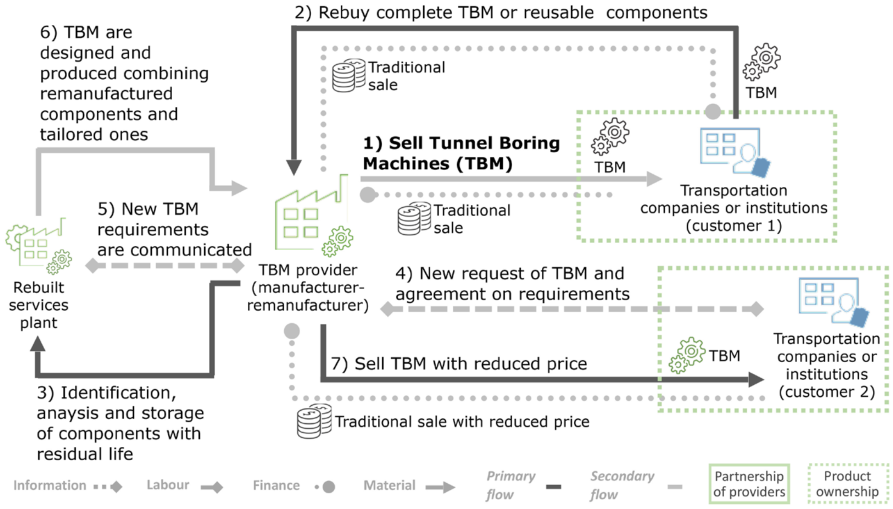

Fig. 3.7 – System map of heavy-duty and off-road equipment practice – sample 2

In this context, the high intrinsic value of products triggers the development of technical practices and business opportunities for extending their utilization. Here, re-manufacturing process is commonly carried out as follows: (i) each part is completely disassembled, (ii) cleaned and (iii) inspected; (iv) their individual elements are, if possible, upgraded to the latest OEM engineering specifications, (v) fully tested and (vi) ready to install. Otherwise, if individual elements are considered at the end-of-life, they are replaced with new items. In addition, besides the comprehensive quality check of the incoming cores as well as of the single parts within the reconditioning, a visual quality check is performed by the committed operators within each re-manufacturing process step.

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3.6 Machinery sector

The machinery industry consists of all companies engaged in the manufacturing of basic power and hand tools, hardware, small-scale machinery and other industrial products. Machinery are an assembly of products, at least one of which moves, joined together for specific applications and usually powered by energy but also human effort (EC, 2006). It encompasses a vast variety of products for heavy equipment, including agricultural, construction and mining equipment, industrial machinery, commercial and service industry machinery, HVAC and refrigeration equipment, metalworking machinery, engines and turbines, and other general-purpose machinery. All machinery aims to reduce or eliminate the amount of human work required to accomplish a task.

As in previous industrial sectors, the high intrinsic value of products triggers the development of technical practices and business opportunities for extending their utilization. The main involved stakeholders are: product re-manufacturers, in some cases coincident with manufacturer; contractors/dealer as intermediaries to reach the end-market; and final users (customers), including as appropriate supermarkets, shops, offices and/or private clients. Re-manufacturing is usually performed on products in stock, implying that the old product is substituted with an available re-manufactured one. To secure the core return, the customer is asked to pay a charge that will be fully refunded when the core will be returned. Therefore, this system is mainly deposit-based: all product supplied from stock are sold on an exchange basis and re-manufacturer need the old (broken) product returned in exchange (ACES, 2016; 2022; HCME, 2016; 2022). However, other alternative systems may occur. Direct-orders take place when clients want their own product returned, when a direct replacement is not available from stock or when re-manufacturing process is activated only if a new buyer is ensured (ES Power AB, 2015; 2016). Moreover, buy-back systems happen occasionally with worn out plant or surplus elements and voluntary-based systems when worn out compressors are offered and purchased to boost stocks (e.g. when a plant room has become obsolete and the equipment is sold off).

Dealing with machinery practice, it is important to discern between medium-scale products, such as refrigerant compressors (ACES, 2016; 2022) and hydraulic pumps (HCME, 2016; 2022), and big-scale products, like wind turbines (ES Power AB, 2015; 2016; Siemens Gamesa, 2022). In both cases, re-manufacturing can be carried out as an independent activity (ACES, 2016; 2022; ES Power AB, 2015; 2016) or as an integral part of the same manufacturing company (HCME, 2016; 2022; Siemens Gamesa,

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2022). The goal is to extend product lifespan, bringing cores to the same high standard and warranty of new ones. When re-manufacturers, do not design original products and elements, since acting as service providers for what concern re-manufacturing and replacement, they used to track every re-manufactured product throughout its lifecycle. This is achieved by the stamp of a unique number on the body casting, storing the code in the company database with associated all its technical details in order to become a reference for any future process (ACES, 2016; 2022). About medium-scale products practice (Fig. 3.8):

1. re-manufacturer and contractor firstly agree on sourcing modalities in relation to the product to re-manufacture or replace;
2. among different contract possibilities, most of the times re-manufacturer acquires old products from contractors;
3. depending on product conditions, a surcharge could be applied;
4. products are stocked waiting to be re-manufactured for future demands;
5. in exchange, the re-manufacturer provides contractors with the available re-manufactured products (in case of lack of availability, the old product sourced by customer is re-manufactured directly);
6. the re-manufacturing company keep providing the agreed life cycle services to contractors;
7. contractors supply product systems to final users.

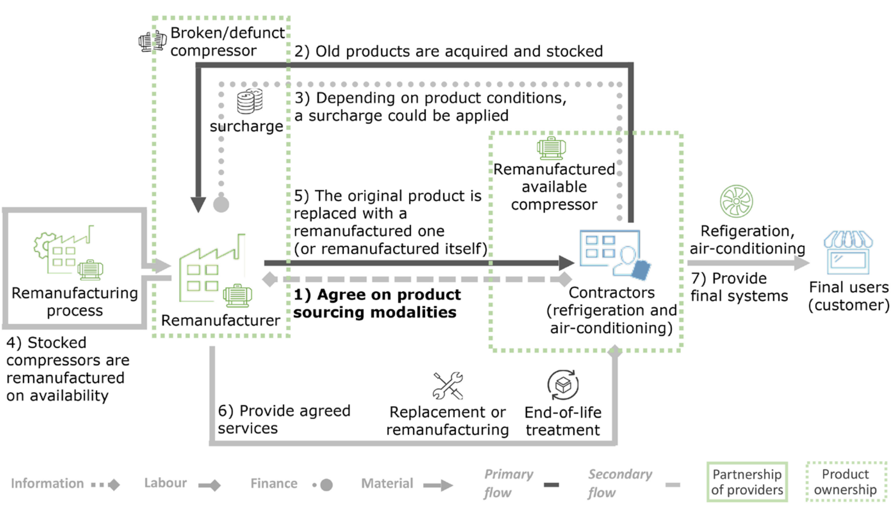

Fig. 3.8 - System map of machinery practice – sample 1

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Concerning big-scale products, as wind turbines, it is interesting to note how re-manufacturing is performed not only to the leading manufacturers (Siemens Gamesa, 2022) but also for instance by electricity supplier (ES Power AB, 2015; 2016). Here, the company operates and sells electricity from its own wind turbines and at the same time provides total solutions for operation, service and maintenance to other wind power owners. Since they have insight everything from service and maintenance costs to revenue from electricity sales, the company has the chance to continuously test new ideas and methods not previously used in wind power. Turbines are thus brought back to the highest level of performance and designed for appropriate lifespan. The organizational model (Fig. 3.9) is as follows:

1. a contract is signed with the original turbine owners that want to sell their old turbines;
2. a new owner has to be found before activating re-manufacturing process;
3. once negotiations are completed, the re-manufacturer takes care of services, like the old windmill inspection;
4. the re-manufacturer is in charge of the dismantling of wind turbines;
5. re-manufacturing process is partially performed on site, whereas specific products, such as generator and gearbox, are managed and re-manufactured by sub-suppliers;
6. the re-manufactured windmill is transported from re-manufacturer to the new customer, which acquires its full ownership.

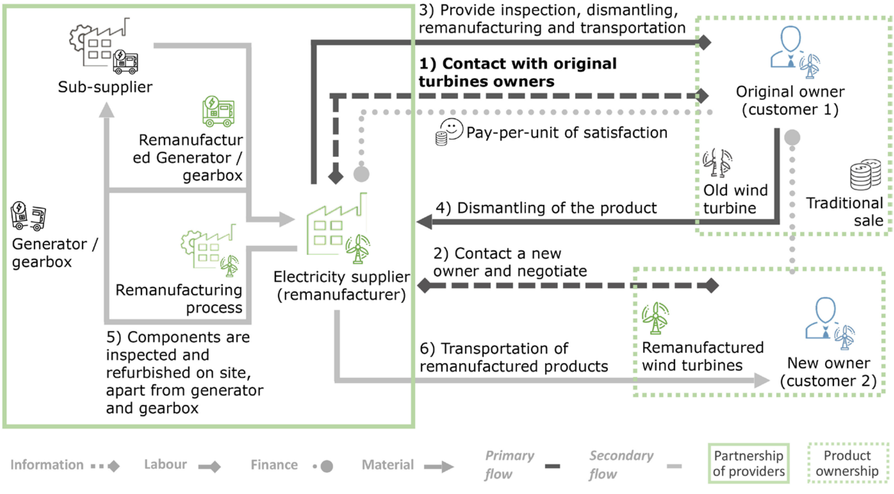

Fig. 3.9 – System map of machinery practice – sample 2

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To simplify, the re-manufacturing process of machinery industry is breakdown in the following phases: (i) complete strip down; (ii) inspection of parts; (iii) replace and recycle; (iv) cleaning; (v) reassembly; and (vi) testing. In some cases, products follow the exact procedure, allowing especially for high-pressure elements to repeat the process multiple times, before the material is recycled. Moreover, note that in case of big-scale products some steps are performed on site, including for instance the disassembly and checking phases. In particular, since old wind turbine towers are often welded onto the foundation, when rebuilding the tower, it is necessary to apply a new bottom ring. Nevertheless, the case of turbines is peculiar because of customer sustains high capital investments and the sale of products is restricted to a limited number of times per customer. This imply that service agreements and constant contacts are crucial for wind turbine manufacturers for providing additional services and securing customer retention. For this purpose, being energy cost the driver for customer profitability, energy efficiency represents a key success factor for wind turbines. Innovation and the latest technology results thus at the core of turbine providers business, promoting the research and development of solutions that improve turbine performances. Accordingly, in this specific application context, re-manufacturing is generally better perceived by the market as a value-adding activity compared to the existing product (Siemens Gamesa, 2022). For the remaining, customer perception concerning the quality level of re-manufactured cores is still highly dependent on price, which is lower inducing customer to perceive a lower quality item compared to a new one.

3.7 Other sectors

This section includes the industrial sectors that only recently have started to experiencing re-manufacturing, ranging from fashion to transport and consumable goods. Contrary to the well-established re-manufacturing industries, these practices represent matter of interest because of the handling of products with significant lower economic value. A sample of representative practices is thus following presented.

The first is related to the baby prams fully designed by the original manufacturer to have an extended lifespan, including strategies for facilitating maintenance, repair, upgrade and re-manufacturing (Mont *et al.*, 2006). In particular, design specifications concern: textiles products to replace just worn out parts (e.g. through zippers); the handle that is wrapped in order be replaced separately; and the selection of long-lasting

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air pumped wheels in order to simplify maintenance between customers. Besides design, pram retailers play a key role for activating and making reverse supply chain economically sustainable. Indeed, the business proposition is based on a leasing system of baby prams between pram retailers and end-customer, having the chance to extend it throughout the pram usage time. In this way, consumer does not purchase the item, but rather pays a constant fee for the utilization period. The return of the product is secured by the contract, enabling re-manufacturing process and the offering of re-manufactured baby prams at a lower leasing fee compared to original one. Contractual terms regarding baby pram manufacturer and retailers includes a sharing of both leasing fee value and the costs associated to pram reconditioning activity. In this context, as shown in Fig. 3.10:

1. the company supplies new prams to local partner retailers;
2. retailers lease products to individual customers;
3. after the use period, prams are returned to retailers due to the leasing contract specifications;
4. the manufacturer company provides technical training to local retailers for re-manufacturing;
5. information is continuously shared about products updates and feedbacks from the re-manufacturing process to improve its efficiency;
6. thanks to the acquired information, local dealers autonomously take care of reconditioning prams and make them ready for new customers.

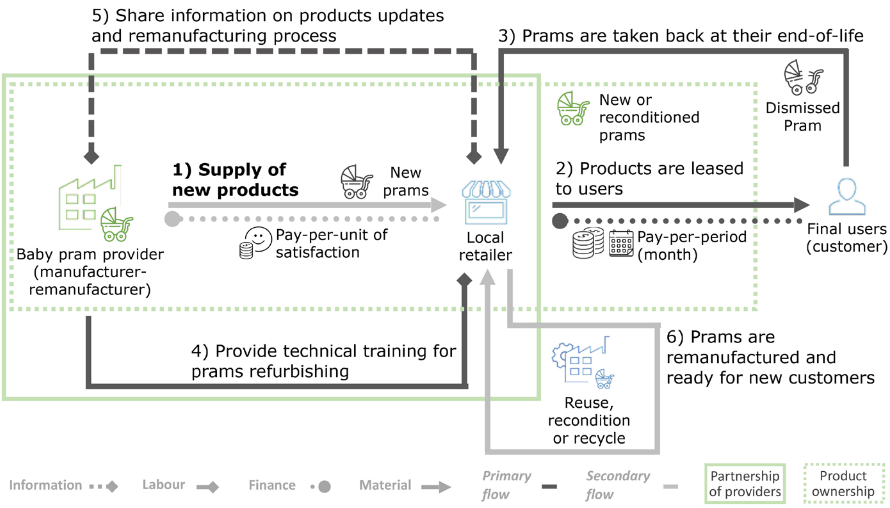

Fig. 3.10 – System map of other emerging practice – sample 1

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Another interesting practice pertain to technical shoes for outdoor activities, including mountain running, trekking and the skimountaineerging. Since performance is particularly important and vulnerable to overuse and sole get ruined faster than the rest of the product, the company activate a re-soling service for customers, which consists of the replacement of worn soles with new high-performance ones through a training program with several local artisans (La Sportiva, 2022). The original shoe manufacturer enters into partnership with authorized local artisans, offering re-manufacturing services to shoes owners (customer). End-customers for re-manufactured products are therefore indirectly reached through local commercial channel, specialized in shoe handcraft and repairing. Re-soling is proposed as an additional service for shoes customers and it is implemented by supplying brand material to local artisans for the reconditioning of shoes in a certified and authorized way. The original shoe manufacturer then establishes a purchasing contract with local artisans, and these offer authentic reconditioning services to consumers, under direct payment. The related system map (Fig. 3.11) is summarized as follows:

1. the original manufacturer takes care of training local artisans (e.g. cobblers and shoemakers) that are part of its network;
2. shoes are traditionally sold to customers;
3. final users acquire full ownership rights;
4. when soles appear overused and out of performance, customers have the opportunity to bring shoes to local shops;
5. the damaged parts are replaced;
6. customers pay the artisan for the service and gets the product back.

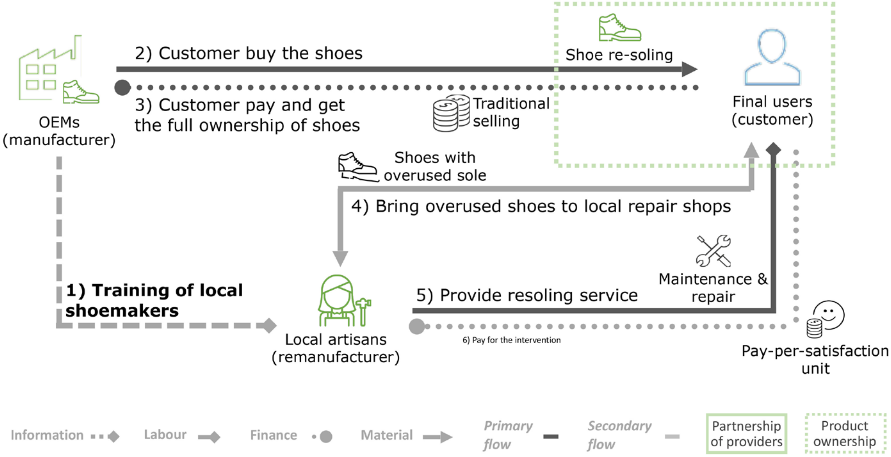

Fig. 3.11 – System map of other emerging practice – sample 2

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Finally, bike sharing is a practice worthy of attention (Sampieri, 2021; Ma *et al.*, 2018), involving the provider of shared urban mobility product-service but also municipalities as key partners for activating business in urban area and end-users (Fig. 3.12). In view of this, the design core intent is to extend product lifespan as much as possible, with specific focus on preserving performances in use and easing maintenance. Materials are so carefully chosen to meet high resistance properties and products are designed with strong geometries and volumes (e.g. frame and spoke thickness, full-section tires). The number of elements in sub-assemblies is minimised (e.g. breaks, gearshift) and removal is simplified. Moreover, the integrated geo-localization system combined with the app through which users report malfunctions allow to accelerate on-site interventions and proper collection of products at their end-of-life. Below a synopsis of the model:

1. bikes are serviceable to customers via a smartphone application, intended to manage products rent;
2. the provider handles the set of life cycle services included into the contract. As happens for other re-manufacturing practices related to various industrial sectors, bikes are not sold to customers and they are offered for a limited time decided by the customer. There is no purchase of any product, but rather the usage of the bike is paid through a fee that could be ride-based, time-based or upon a month subscription. Risks and responsibilities for bike status are kept by the service provider;
3. at the end of life, disposed bicycles are take back for closing the loop.

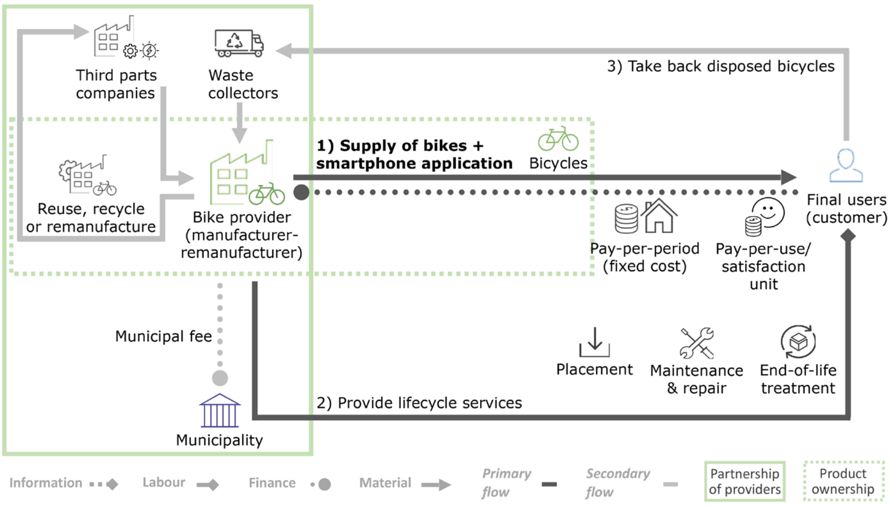

Fig. 3.12 – System map of other emerging practice – sample 3

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These practices related to the emerging re-manufacturing industrial sectors evidence how closed loop supply chains and S.PSS models (Mont *et al.*, 2006; La Sportiva, 2022) are starting to spread also in business field characterized by low-value products. Unlike the most mature industries, here, re-manufacturing does not seem to have a standardized process consisting of structured and well-established phases. It is commonly intended as recondition and repair of damaged parts and substitution with spare parts for putting back onto the market new high-performance products. Given the presence of a large second-hand market, this turns out to be a significant threat for the industrial sectors in which margins are low and with product useful life still long at the end of use-cycle. However, the possibility to enlarge existing market by subtracting customers from the second-hand market represents for companies an interesting business opportunity. The challenge is to overcome reputational barriers from the point of view of both users and industrial companies. On one hand, by users, because of they generally perceive re-manufactured products with lower quality compared to the original ones. On the other, by industrial companies, because of they could deem the offer of business proposition based on recovered products as potential damage to the brand image. Moreover, it is worth mentioning that considerable efforts are needed as appropriate for making re-manufacturing profitable, calling as appropriate to the arrangement and implementation of training programmes for local artisans (La Sportiva case, 2022).

3.8 Lesson learned and transferable criteria for the construction sector

The in-depth analysis of the sample of re-manufacturing practices established across the most varied industrial sectors (Par. 3.2, 3.3, 3.4, 3.5, 3.6, 3.7) allows to identify the enabling factors to activate re-manufacturing models. Accordingly, the question of what and how is transferable to the construction industry is posed, taking into account the most distinctive features of the sector.

The application contexts with the increased chance of success for the implementation of re-manufacturing emerge as characterized by:

1. durable and high-value products (e.g. the cost of an airplane engine is not comparable with the cost of a plasterboard panel);
2. stable technological cycles, exceeding the service life and enabling thus to carry out multiple use cycles during the useful life, before being discarded and possibly recycled;

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3. available restoration technology and at sustainable costs, assessing the cost-effectiveness of the organizational model at issue;
4. products suitable for being provided as "product-service", shifting customer from "consumer" of a product to "user" of a service by paying for it with contractual formulas based on performance (e.g. pay-per-use or pay-per-period). It concerns the product potentiality to be leased or delivered as a service rather than as hardware (Yang, 2018).

These reasons prove why re-manufacturing activities are worldwide concentrated in aerospace, automotive, electrical, heavy-duty and machinery sectors, being only recently implemented into other industries (Parker *et al.*, 2015). Moreover, it is worth underling that re-manufacturing primarily focuses on durables goods for professional use, having to date little impact on consumer goods, since the related purchase decision is strongly affected by fashion design and status issues. However, the emerging industries in the field of re-manufacturing (Par. 3.7) provide evidence of how re-manufacturing is feasible and practicable also in industries distinguished by low-value products as core business, offering thus good chance also to construction products. Here, to secure the recovery of products for closing the loop supply chain, the establishment of Sustainable Product Service Systems (S.PSS) is of strategic importance (Gallo, 2012). The key idea is that costumers access the service provided by the product without having the property of it. In this way, when the product is no longer able to deliver its performance, it is recovered to be used by other costumers, satisfying shared goals of longevity, durability and performance (Gaiardelli *et al.*, 2014; Salwin *et al.*, 2018; Vezzoli *et al.*, 2014). Note that in recent years, following the most established re-manufacturing practices, also some manufacturers of construction products start experiencing S.PSS models, involving for instance carpet products (Desso, 2016; 2022).

In addition, current trends reveal how re-manufacturing is an activity implemented not as an End of Life (EoL) sustainable strategy but especially during the life cycle of a product, when the economic value of a product is high and improvements will be able to offer a significant increase in performances (D'Adamo and Rosa, 2016). Nevertheless, concerning the construction industry, several studies and researches highlight how the most widespread circular strategy is still recycling applied to materials and products according to the logic of down-cycling (Ghaffar *et al.*, 2020). The issue is that, unlike other industrial sectors, most of the building products have limited residual performance and limited economic value at the end of their life. The attention is thus directed toward products

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characterised by short use cycles, enabling the arrangement of network of relationships between the operators of the entire production-use-regeneration process.

In this perspective, tertiary architectures (including public and private offices, accommodation facilities, commercial structures, exhibition spaces and shops) is a promising testing ground, due to the frequent renewal of fit-out typically implemented for the most varied purposes. Frequent renewals are mostly applied to ensure the functionality of spaces, the effectiveness of layout and the renewing of corporate image. Moreover, it is recently promoted by the novel organizational models intended to offer the same buildings in terms of service, as occur for hotelling, temporary shops, co-working and the many different forms of space sharing. The high degree of temporary use of spaces is associated with the reduction of lease contracts, the transformation of real estate market and business models as well as the adjustment to meet pandemic emergency needs. All these factors imply in current practice the demolition and disposal in landfills of products, which still have good condition since adopted only for a short use period. For this reason, to comply with resource circularity, the set of tertiary finishes, internal partitions, flooring, false ceilings, plant systems and furnishings could be diverted from disposal to be subject to reuse or re-manufacturing. In fact, such construction products are distinguished by reversible technologies and assembly methods, that guarantee their integrity during disassembly and a durability beyond the single use cycle, generally embedding high residual performance.

As happens within the other industrial sectors, construction products, intended as the ensemble of different elements, could be handle and managed for part substitution and element reconditioning, by following the recognized re-manufacturing process. It is typically divided into: (i) inspection of the whole; (ii) disassembly; (iii) cleaning; (iv) element inspection; (v) reprocessing according to the element type and its performance level; (vi) assembly; (vii) validation and certification tests. However, it is crucial to implement and put in practice re-manufacturing process taking a wider perspective to the whole organizational model. In particular, the product suitability for re-manufacturing has to be assessed by accounting eight criteria (Steinhilper, 2001; Özer, 2012), defined for the most varied industries and transferable to the construction sector:

- technical criteria, i.e. state of returned products, type and variety of materials and parts suitable for disassembly and re-manufacturing;
- quantitative criteria, i.e. amount of returning products, timely and regional availability, correlated with transportation distances and costs;

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– value criteria, i.e. value of re-manufactured products, value added from material/production/assembly;
– time criteria, i.e. maximum product life time, single-use cycle time, potential frequency of products recovery;
– innovation criteria, i.e. technical progress regarding new products and re-manufactured products;
– disposal criteria, i.e. efforts and cost of alternative processes to recycle the products and possible hazardous elements, including cost of re-manufacturing (that must be at least comparable to the cost of other alternatives);
– market criteria, i.e. interference with new manufacturing (competition or cooperation with OEMs), demand of re-manufactured products (same or different market);
– other criteria, i.e. consumer behaviour, liabilities, patents and intellectual property rights.

To trigger within the construction sector an effective transition towards resource circularity, a change in supply chain relationships and interrelationships between operators is needed. This is activated not only by the raising awareness of environmental issues, but also through the economic lever. In this context, the involved stakeholders (including users, manufacturers, re-manufacturer, dealer and intermediate) must be supported with appropriate tools capable of demonstrating how the environmental benefits can be combined with economic advantages. Win-win solutions have to be created for the various subjects of the supply chains and re-manufacturing networks.

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Part II

Promising Models

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4. *Organizational models for reuse and re-manufacturing in the building sector*

by *Nazly Atta, Anna Dalla Valle, Serena Giorgi, Luca Macrì, Sara Ratti, Salvatore Viscuso*

4.1 The need of new organizational models to implement reuse and re-manufacturing within building sector

The increasing need for sustainable processes within manufacturing and construction sectors to mitigate the negative impacts on the environment and meet the needs of future generations led in the past decades to the development of circular strategies. Among these virtuous practices, down-cycling and recycling have been the most investigated with proven benefits especially in the industrial fields (Özer, 2012; Parker *et al*., 2015). However, despite their undeniable value, these practices turn out to have higher environmental impacts than other end-of-life strategies (Özer, 2012; Parker *et al*., 2015; Paterson *et al*., 2017; Talamo *et al*., 2021). Hence, going beyond down-cycling towards more sustainable practices, in the last few years the interest focused on re-manufacturing, meant as a process whereby used products, having reached the end of their use-life or useful-life, are restored for starting a second lifecycle (Gutowski *et al*., 2011). In particular, re-manufacturing is generally intended as the process that restore used products to the "like-new" functional state, by renovating and/or replacing components with minimum consumption of materials and energy (Gunasekara *et al*., 2018; Bernat, 2019; Cheng *et al*., 2021). In this way, re-manufacturing acts as a strategy for closing the loop between disposal and supply chains, extending the service lifespan of products, preserving embedded resources and limiting environmental impacts (Gutowski *et al*., 2011). Moreover, the "like-new" feature of re-manufacturing implies that re-manufactured products usually have a warranty at least equal to the original one (Ijomah, 2008), ensuring quality products with high performance (Parker *et al*., 2015; Özer, 2012; Paterson *et al*., 2017). Also due to these reasons, today re-manufacturing represents

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a well-established practice in several sectors (Benoy *et al.*, 2014), such as Aerospace, Automotive, Electronics, Machinery, Marine, Rail (USITC, 2012; Parker *et al.*, 2015; Butzer and Schötz, 2016; Gunasekara *et al.*, 2018) with proven economic and environmental benefits, as shown in the previous chapter (see Chapter 3). Indeed, these industrial sectors show an intrinsic aptitude for re-manufacturing, since characterized by:

- durable products, usually made up of high-value components;
- stable technology-cycles of products, longer than their use-cycles;
- available regeneration technology to perform product re-manufacturing;
- propensity of products to be leased or delivered "as a service" rather than "as a hardware" (Yang *et al.*, 2018).

Also due to these features, within these sectors re-manufacturing represents a practice implemented not only as a circular strategy to carry out at the end of the useful life of a product, but also during the product service life, when both the performance and the economic value of the product are still significantly high and, therefore, when reprocessing activities are able to deliver a high-quality re-manufactured product with limited efforts (Ardente *et al.*, 2018; D'Adamo and Rosa, 2016). For these benefits, in the recent past, industrial companies have consolidated re-manufacturing practices within their businesses, gaining added value and competitive advantages (Cao *et al.*, 2020; Sundin *et al.*, 2020; Golinska-Dawson *et al.*, 2021). Alongside industrial operators, also the EU recognizes the value of re-manufacturing as a promising approach to close product loops, reducing waste and emissions (Boorsma *et al.*, 2019) in several production fields, with particular reference to the construction sector (European Commission, 2020). In fact, according to the European Commission (2020), "Construction and Buildings" is a field that urgently requires widespread and coordinated actions towards circularity and sustainability (European Commission, 2020). As stated by the EU, the application of re-manufacturing strategies to the construction sector represents a shared priority at European level which must directly engage all member states (COM 2015/ 614; European Commission, 2020). Indeed, in the last two decades the contribution of the construction sector to greenhouse gas emissions counted as approximately the 40% of the totality of emissions on the global scale (Yan *et al.*, 2010). Moreover, according to Eurostat (2016), the construction sector in past years generated more than a third of the total amount of waste produced by the totality of economic activities and households (Eurostat, 2016). This is mainly due to the "take-make-dispose" models that characterize the construction sector. Indeed, the latter mostly

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adopts linear models, which start with the extraction of raw materials from the environment – then processed into construction materials – and end with their disposal at the building end-of-life (Benachio *et al.*, 2020; Elisha, 2020). This linearity can be attributed to different causes, including the following two:

– materials and products are assembled on the construction site, mostly employing wet construction technologies, hence embedded in ways that cannot be disassembled or deconstructed at the end of the building life. Therefore, the end of this linear process can only be the demolition of the building and the transfer to landfill of its components and materials that become waste to be disposed of. In this last stage of the building process, materials and components cannot be recognizable as functional entities – thus distinguishable potential resources – since they were assembled for a one-time use only and not to be reuse/reworked (Benachio *et al.*, 2020);
– generally the lifespan of buildings is very long, exceeding 60 years (CSHub@MIT, 2016) and, therefore, it is difficult to envision it as a closed cycle. This idea of "long and durable" life of buildings, on the one hand, often implies corrective approaches to the management of building elements, leaving them to perform their functions until they are no longer able and only then performing interventions (e.g. punctual repairs and replacements of parts) to correct the occurred anomalies and degradations, without any strategic planning of preventive maintenance services. On the other hand, it hinders the spreading of "design for disassembly" and "design for re-manufacturing" practices which could support a "lifecyle-oriented" design, opting for components and systems that will be more easily removable / repairable / reusable / re-workable during the life cycle of the building, as well as at the end of its useful life.

By intervening in the early stages of the building process with appropriate strategies aimed at extending the useful life of products, lengthening their first lifecycle and/or guaranteeing over time multiple reiterated lifecycles, the generation of construction waste could be limited (COM 2015/ 614; European Commission, 2020) overcoming this linear view of the building process.

To achieve these objectives, Re-NetTA (Re-manufacturing Networks for Tertiary Architectures) project proposes new circular approaches in the construction sector, following a gradual approach according to some procedural steps:

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1. identify which of the fields of the building sector is the most promising and characterize the related offer of products to be (potentially) re-manufactured (Par. 4.2);
2. define the paradigm shifts that have allowed other sectors to make the leap towards circular processes (Par. 4.3);
3. outline the key features of the circular models already in use in other sectors, adjusting them to the specificity of the construction sector, also with the support of stakeholders (Par. 4.4);
4. on the basis of the defined key features, develop new circular organizational models for the construction sector (Par. 4.5), to be tested and validated in the fields defined in point 1, with the support of stakeholders (see Chapters 5, 6, 7).

The support of stakeholders is concretized through a series of roundtables and focus groups, organized by sector (exhibition, office, retail). The stakeholder sample involved 27 interviewed actors and, in particular, 16 companies contributed significantly – through an active involvement within workshops and roundtables – to the development and evaluation of the organizational models.

The majority of the stakeholders belong to the reference geographical area of Re-NetTA project, i.e. Lombardy region, and they have been identified according to two alternative selection criteria:

– representativeness of the sector, i.e. relevance of the actor within the sector on the basis of market shares and turnover;
– level of innovation, originality and maturity of practices (compared to the traditional scenario).

The sample includes for-profit companies, third sector actors (i.e. cooperatives) and trade associations. As emerges from the following list, the roundtables and focus groups are organized by sector and according to the principle of complementarity of the stakeholder roles to cover the whole supply chain. Consequently, the subjects involved for the tertiary subsectors include:

– exhibition: designers, outfitters, manufacturers and sellers;
– office: renters, outfitters, manufacturers, general contractors, trade associations, maintainers;
– retail: sellers, designers, manufacturers, general contractors, third sector stakeholders in reverse logistics and manufacturing operations.

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4.2 Tertiary architectures as promising field for re-manufacturing

In the context of the construction sector, re-manufacturing represents a regenerative circular process aimed at maintaining overtime the intrinsic economic and environmental value of products even when they are removed from buildings. To this end, re-manufacturing aims to extend the useful life and usability of products generating the least possible consumptions and emissions (Talamo *et al.*, 2019) and reducing the production of scraps and waste from maintenance, renewal and demolition interventions. In light of this premise, among the different building sectors, the tertiary field (including exhibition, retail, office, hosting, etc.) seems to be one of the most favourable for the start up of re-manufacturing practices since it is characterized by:

- short renewal times and frequent reconfigurations of interior spaces (OMI, 2017) that determine the accelerated obsolescence of equipments/interior fittings. Moreover, the recent approaches that envision the use of buildings in terms of service (such as hoteling, space-sharing, co-working, smart working, etc.) imply a high degree of temporariness in product use patterns as well as the shortening of lease contracts;
- availability of significant quantities of disused components (e.g. interiors, equipments and furnishings) with high residual performance (Rose and Stegemann, 2018). These components, typically developed for tertiary buildings, are usually characterized by being composed of high-value raw materials, being dry assembled (therefore easily to disassemble) and having a high added value.

As a promising strategy characterized by processes that use less energy and materials than recycling, re-manufacturing has the potential to avoid the transformation of this kind of components into waste. Hence, presenting key outcomes of Re-NetTA project, the following paragraph introduces the main paradigm shifts towards circularity in the field of tertiary architectures and, starting by the definition of a set of key features able to describe circular models, it sets the stage for the proposal of new organizational models for building product life extension based on re-manufacturing.

4.3 Paradigm shifts towards circularity in the building sector

The analysis of re-manufacturing best practices from the different industrial sectors (see Chapter 3) leads to the identification of some recurring innovative approaches aimed at extending the useful life of products.

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These approaches can promote the development of new organizational models within the tertiary architecture field, shaping new win-win relationships among stakeholders, laying the foundations for the development of virtuous circular practices.

In particular, the first approach follows the logic of the "disown ownership" (Dalla Valle *et al.*, 2021), implying a paradigm shift towards practices oriented to the offer of products "as a service" instead of the sale. According to this new approach, the ownership of products is retained by the provider and not transferred to the customer as in the case of sales. Hence, the customer is no longer the buyer of a physical good but it becomes the purchaser of a service. From being the "owner" of a product, the customer becomes the "user" of it, paying for the "availability to use" of the product itself. Consequently, also the payment method switches from a single-payment to new formulas based on pay-per-use, pay-per-period or pay-per-performance systems (Bocken *et al.*, 2018; Sousa-Zomer *et al.*, 2018).

The second approach refers to the concept of "servitization", namely the transition from the pure sale of a product to the sale of a "product plus service" solution that actually gives rise to a long-lasting relationship between customer and supplier, transforming the transaction into a system capable of selling together with the product also a set of value services integrated into the product itself. In this regard, it is important to highlight that services are not simply an addition to the sale of a product, but they become a central element of the offer itself, contributing to extend the product useful life and allowing the customer to always have a high-performing product (Della Mura, 2020). In this case, ordinary maintenance becomes part of the range of offered services, as part of the product useful-life extension strategies. Furthermore, in this regard, by tracing and keeping a history of the interventions undergone by the product, at the end of the service-life the re-manufacturer will be able to evaluate the residual performance and the re-manufacturing potential of the product.

The third approach is based on the concept of industrial symbiosis, identifying new business opportunities by exploiting cross- and inter-sectoral synergies following the logic of "waste-resource" (Talamo and Migliore, 2017). Industrial symbiosis gathers traditionally-separate industries in a collective and cooperative approach, aimed at gaining competitive advantage, that involves the exchange of materials and products between industries even belonging to different sectors. This approach is grounded on the concept of "network", hence on the collaboration between operators in order to exploit synergistic possibilities in a waste-resource perspective. Accordingly, the waste of one sector becomes a resource for

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another, creating long-term synergistic interconnections able to optimize the management of resources.

The fourth approach focuses on the product design, shifting the attention upstream of the process by proposing "design for re-manufacturing" strategies, aimed at facilitating the re-manufacturing process by product design so that disassembly, cleaning, reprocessing and reassembly activities are facilitated during the product lifespan. According to these strategies, in order to guarantee a greater propensity for reworking and high durability of the products, it is necessary to opt for design solutions oriented towards modularity, ease to dis/assembly and ease to find spare parts on the market.

4.4 Key features of circular processes

On the basis of the introduced paradigm shifts, an interpretative framework able to describe circular models (Tab. 4.1) is proposed. The framework consists of nine key features (described below), further articulated into multiple possible configurations. The key features are here intended as a set of key elements that characterize circular organizational models based on re-manufacturing practices. Following the business process, they are: original product design; product procurement; product collection; re-manufacturing actors; re-manufactured product design; product-service distribution; product ownership; revenue system; market destination and segment.

Tab. 4.1 - Key features of circular models based on re-manufacturing

Key features		**Possible configurations**	
A	Original product design	A1	Product designed for re-manufacturing
		A2	Product not designed for re-manufacturing
		A3	Product not designed for re-manufacturing but with facilitating features (e.g. modularity, standard dimensions)
B	Product procurement	B1	Surcharge-based mechanism
		B2	Buy-back mechanism
		B3	Direct- order mechanism
		B4	Service contract mechanism
		B5	Leasing mechanism

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Tab. 4.1 - continued

Key features		**Possible configurations**	
C	Product collection	C1	Enabled by "collectors" activity
		C2	Performed autonomously by re-manufacturer
		C3	Hybrid solutions
D	Re-manufacturing actors	D1	Original Equipment Re-manufacturer
		D2	Contracted Re-manufacturer
		D3	Independent Re-manufacturer
E	Re-manufactured product design	E1	Product re-designed for re-manufacturing
		E2	Product not re-designed for re-manufacturing but with facilitating features
		E3	Product not re-designed for re-manufacturing
F	Product-service distribution	F1	With a partner intermediation
		F2	With a dealer intermediation
		F3	Performed autonomously by re-manufacturers
G	Product ownership	G1	Ownership is transferred to the customer
		G2	Ownership is retained by the provider
		G3	Ownership is transferred to the customer with provider's extended responsibilities
H	Revenue system	H1	Traditional single payment
		H2	Deposit-based single payment (with surcharge)
		H3	Performance payment (e.g. Pay-per-use/-period, etc.)
I	Market destination and segment	I1	Same market destination and segment of the original product
		I2	Same market destination of the original product but different market segment
		I3	Different market destination from original product

Source: Adapted from Dalla Valle *et al.*, 2021

In particular, the aim of the proposed framework is twofold (Dalla Valle *et al.*, 2021). On one side, already-existing organizational models can be represented and described as combinations of the proposed key features; while on the other side, the proposed framework opens up opportunities for outlining innovative circular models based on re-manufacturing, starting from novel combinations of the proposed key features configurations (Tab. 4.1).

The proposed key features – and related configurations – are below described in detail following the business flow, from product design to time-to-market.

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A. *Original Product Design*

This key element refers to the design features of the original product and its propensity to receive rework and partial replacements over time. In this stage, as highlighted in Chapter 3, one of the main strategy for circularity is represented by "Design for Re-manufacturing" (DfRem) (Prendeville and Bocken, 2017; Hazir and Sundin, 2020). Following this strategy, the re-manufacturing interventions performed at the end of the first product use-cycle are favored thanks to upstream choices related to the development and design of the original product (e.g. dis/assemblability, modularity, spare pat availability, etc.) (Yang *et al.*, 2015, Hatcher and Ijomah, 2011, Abuzied *et al.*, 2020). Focusing on the Original Product Design, Tab. 4.2 describes the three different options of the key feature configuration.

Tab. 4.2 - Original Product Design – possible configurations

A. Original product design		
A1	Product designed for re-manufacturing	Products are intentionally and specifically designed according to criteria and characteristics that are able to facilitate the future product re-manufacturing after the first use cycle (e.g. facilitated disassembly, interchangeable components, modular structures, durable materials, etc.).
A2	Product not designed for re-manufacturing but with facilitating features	Re-manufacturing is facilitated by some component features that – although not intentionally designed for re-manufacturing – are able to facilitate some steps of the re-manufacturing process (e.g. standard dimensions, availability of spare parts on the market, dry assembly, etc.).
A3	Product not designed for re-manufacturing	Original products not intentionally designed to be re-manufactured and they do not own design features that are able to facilitate re-manufacturing interventions.

B. *Product Procurement*

This feature focuses on the strategies to secure the procurement of physical cores to be re-manufactured. The strategies to procure products to be re-manufactured (Tab. 4.3) are mainly based on the "reverse supply chain" logic as key trigger of circular business models, promoting contractual mechanisms between re-manufacturer and product-holder oriented to grant or promote the return of cores after use.

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Tab. 4.3 - Product Procurement – possible configurations

B. Product procurement		
B1	Surcharge-based mechanism	At the sale the customer pays a surcharge that will be fully paid back at the return of the sold product at the end of its use.
B2	Buy-back mechanism	The customer receives an economic incentive for the return of the used product at the end of its utilization.
B3	Direct-order mechanism	The re-manufacturing operation is activated by a direct order for a substitution of the used product with a re-manufactured one that guarantees the same or an upgraded performance compared to the old one.
B4	Service contract mechanism	The customer pays for a product&service solutions, including re-manufacturing activities, setting the stage for the return of cores, thus easing the circular practice.
B5	Leasing-based contracts	By maintaining the product ownership in provider hands, a leasing scheme obliges the return of the product from the customer, thus enabling circular offerings.

C. *Product Collection*

The key feature focuses on the actors and modalities of the physical collection of materials/products to be re-manufactured. Compared to a linear model, the management of the retrieval of post-use product represents an additional activity to implement, that can either trigger or undermine the feasibility and the economic sustainability of a circular business opportunity (Prendeville and Bocken, 2017). Tab. 4.4 clustered the possible product-retrieval configurations in three macro-categories, based on the level of responsibility of the re-manufacturer within the logistics management of cores to be re-manufactured.

Tab. 4.4 - Product Collection – possible configurations

C. Product collection		
C1	Enabled by "collectors" activity	The post-use products are retrieved by "collectors", namely logistics operators acting as reference points for picking and stocking specific post-use goods, thus easing the possibility for re-manufacturing firms to get the cores.
C2	Performed autonomously by re-manufacturer	Where the market proximity and the logistics infrastructure are present, the re-manufacturer can manage autonomously the physical retrieval of cores.
C3	Hybrid solutions	The core collection is jointly managed by the re-manufacturer and the dealers, i.e. intermediate points between production and end-market, representing collection points for customers that return post-use products and for re-manufacturers that obtain the cores for re-manufacturing processes.

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D. *Re-manufacturing actors*

It refers to the types and roles of the actors that perform re-manufacturing on products, studied based on the relationship with the original equipment manufacturers (Östlin *et al.*, 2008; Duberg *et al.*, 2020). These roles are defined in Tab. 4.5 according to three types of re-manufacturer.

Tab. 4.5 - Re-manufacturing actors – possible configurations

D. Re-manufacturing actors		
D1	Original Equipment Re-manufacturer	Original Equipment Re-manufacturer (OER) is represented by a firm responsible for re-manufacturing its own manufactured product, exploiting potential manufacturing processes, existing market share and resource synergies.
D2	Contracted Re-manufacturer	Contracted re-manufacturer is represented by a firm responsible for re-manufacturing activity and bound by contract with the original equipment manufacturer.
D3	Independent Re-manufacturer	In this case the independent re-manufacturer is a firm with little or no contact with the original equipment manufacturer. Factors like proximity to the market and resources and skills linked to re-manufacturing processes are strategic for contracted and independent re-manufacturing businesses.

E. *Re-manufactured product design*

This key feature refers to the implementation of the strategy of Design for Re-manufacturing (DfRem) within the re-work interventions on post-use products (Tab. 4.6). Regardless of the original design, new design solutions for the re-manufactured products can be introduced in order to positively affect their successive performances.

Tab. 4.6 - Re-manufactured product design – possible configurations

E. Re-manufactured product design		
E1	Product re-designed for re-manufacturing	Specific design choices are implemented within the re-manufacturing process in order to facilitate future re-manufacturing interventions.
E2	Product not re-designed for re-manufacturing but with facilitating features	The re-manufacturing process introduces new features to the product that are not directly facilitating successive re-manufacturing practices but that are able to ease some steps of the process.
E3	Product not re-designed for re-manufacturing	The interventions carried out through the re-manufacturing process are not aimed at introducing features to ease future re-interventions, but simply to restore the product performance according to market requirements and opportunities.

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F. *Product-service distribution*

This key feature focuses on the structure of the network aimed at distributing re-manufactured products and services on the market. The way in which products and/or services are delivered to the customers represents a key aspect that characterizes downstream choices to reach the final market. Tab. 4.7 proposes different product distribution configurations.

Tab. 4.7 - Product-service distribution – possible configurations

F. Product-service distribution		
F1	With a partner intermediation	The re-manufacturer works in direct relationship with an external partner that not only supports the delivery of re-manufactured products to the final market but it also collaborates with the re-manufacturer to offer product-related services to customers throughout the whole product use-cycle.
F2	With a dealer intermediation	The re-manufacturer relies on a commercial third-party, acting as an intermediation for the delivery of re-manufactured products to the final market. This solution is used in case of lack of final market proximity.
F3	Performed autonomously by re-manufacturers	The re-manufacturer can directly access to the final market through an internalized distribution system. Hence, the re-manufacturer manages the delivery of re-manufactured products and related use-cycle services with its own capabilities.

G. *Product ownership*

This feature deals with the "right of property" on the re-manufactured products after they have been delivered to the customer. Surveying the sample of best practices (see Chapter 3), it emerges the presence of multiple transaction types that determine different rights of ownership over the re-manufactured product. From the different alternatives of product ownership transfer (Tab. 4.8), diverse levels of responsibility of the providers over the product delivery emerge.

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Tab. 4.8 – Product ownership – possible configurations

G. Product ownership		
G1	Ownership is transferred to the customer	The ownership is completely transferred from the manufacturer/provider to the customer, through a traditional sale offer.
G2	Ownership is retained by the provider	The ownership – and usually lifecycle responsibilities – is retained by the manufacturer/provider, which interest appeared to shift from the quantity of sold products toward the extension of their lifespan.
G3	Ownership is transferred to the customer with provider's extended responsibilities	Hybrid configuration represented by the extension of manufacturer/provider responsibilities, although the product ownership is transferred to customers, e.g. extended warranties or after-sale included services.

H. *Revenue system*

This concept refers to the contract relationship between the customer and the provider and to the related modality of payment for the purchase of re-manufactured products. In addition to the traditional single payment, Tab. 4.9 highlights innovative payment systems oriented towards circular business models.

Tab. 4.9 – Revenue system – possible configurations

H. Revenue system		
H1	Traditional single payment	Simple sale transition based on a single payment for the purchase of a product.
H2	Deposit-based single payment (with surcharge)	Within a sale transition based on a single payment, a percentage is considered as a deposit, that is refunded if the customer bring back the product after the use.
H3	Performance payment (e.g. Pay-per-use, Pay-per-period, etc.)	Payment modalities that do not necessarily imply a sale transition and that could be deferred in time. They are quantified on the basis of the performance accessed by the customer (e.g. pay-per-use, pay-per-time, pay-per-period).

I. *Market destination and segment*

This feature refers to the market destination of the re-manufactured product and its customer typologies, defined in relation to original product. The market destination explains the market targeted by the re-manufacturer, while the market segment represents the category of customers of

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the re-manufactured product. As highlighted in Tab. 4.10, the assessment of the market of the re-manufactured product is affected by both product-specific and market-specific factors.

Tab. 4.10 - Market destination and segment – possible configurations

I. Market destination and segment		
I1	Same market destination and segment of the original product	The market destination of the re-manufactured product is the same as the original one when both products have the same function, and thus they are demanded by the same market. The specific market segment targeted by the re-manufacturer is the same as the original product if not significant differences in terms of product value are perceived by the market, and thus the same client of original product is willing to accept the re-manufactured product as well. These two options, if combined, describe the first identified cluster.
I2	Same market destination of the original product but different market segment	The re-manufactured product is perceived differently from the original product customers (e.g. same function but lower performance), and so it is targeted to a different market segment.
I3	Different market destination from original product	The re-manufactured product is repurposed (i.e. different function than the original product) to target a new market, not competing with the original product.

4.5 New organizational models for the building sector

On the bases of the above-introduced key features, the present paragraph aims to propose three circular organizational models for the construction sector. The three proposed models – understood as a set of interconnected strategic and operational solutions (Osterwalder and Pigneur, 2010) – are based on re-manufacturing and reuse practices in order to promote circularity within the construction sector and, in particular, in the field of tertiary architectures. Based on the paradigm shifts defined in Par. 4.3 and by means of the key features identified in Par. 4.4, the three proposed circular models are:

1. *Rent contract as a support for re-manufacturing*;
2. *All-inclusive solution to support re-manufacturing*;
3. *Alternative/secondary markets for re-manufactured products.*

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In particular, these models have been – firstly – outlined starting from combinations of the key features on the basis of the best practices on-going in the construction sector but especially in other industrial sectors where re-manufacturing appears more mature and structured (Benoy *et al.*, 2014). Secondly, they have been developed through the active involvement of the main stakeholder categories (e.g. investors and clients, manufacturers, construction companies, installers, facility managers) of the tertiary architecture field by means of roundtable sessions and focus groups.

4.5.1 Rent contract as a support for re-manufacturing

The first model "Rent contract as a support for re-manufacturing" proposes the rent contract as a strategy for promoting re-manufacturing practices to lengthen product life-spans. Rented products with end-of-use residual performance are re-manufactured in order to start a subsequent new use-cycle, overcoming the "single use" approach towards a "multiple-use" one (Fig. 4.1).

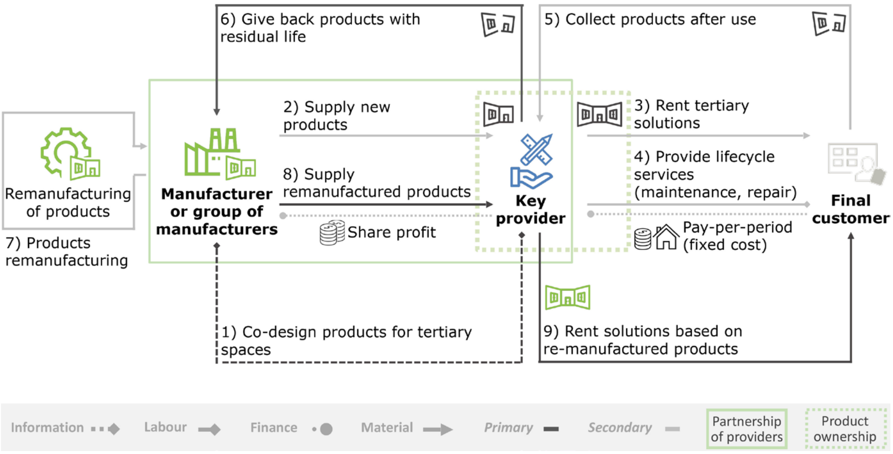

Fig. 4.1 – Rent contract as a support for re-manufacturing – organizational model (Dalla Valle et al., 2021)

Following this approach, the original manufacturer co-design the products in collaboration with an external party – the provider – who is in charge of offering them for rent to customers (Tab. 4.11). Moreover, the provider has

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also the responsibility of collecting the used products at the end of the rent contracts in order to return them to the original manufacturer, who carries out the re-manufacturing activity. Thus, used products are brought back to the original performance in order to be offered again for rent by the provider to new customers, activating in this way a circular value chain.

Tab. 4.11 - OM1 key features

Key features of OM1 " Rent contract as a support for re-manufacturing"				
Key features		**Possible configurations**		**OM1**
A	**Original product design**	**A1**	**Product designed for re-manufacturing**	
		A2	Product not designed for re-manufacturing	
		A3	Product not designed for re-manufacturing but with facilitating features	
B	**Product procurement**	B1	Surcharge-based mechanism	
		B2	Buy-back mechanism	
		B3	Direct- order mechanism	
		B4	Service contract mechanism	
		B5	**Leasing mechanism**	
C	**Product collection**	**C1**	**Enabled by "collectors" activity**	
		C2	Performed autonomously by re-manufacturer	
		C3	Hybrid solutions	
D	**Re-manufacturing actors**	**D1**	**Original Equipment Re-manufacturer**	
		D2	Contracted Re-manufacturer	
		D3	Independent Re-manufacturer	
E	**Re-manufactured product design**	**E1**	**Product re-designed for re-manufacturing**	
		E2	Product not re-designed for re-manufacturing but with facilitating features	
		E3	Product not re-designed for re-manufacturing	
F	**Product-service distribution**	**F1**	**With a partner intermediation**	
		F2	With a dealer intermediation	
		F3	Performed autonomously by re-manufacturers	
G	**Product ownership**	G1	Ownership is transferred to the customer	
		G2	**Ownership is retained by the provider**	
		G3	Ownership is transferred to the customer with provider's extended responsibilities	

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Tab. 4.11 - continued

Key features of OM1 " Rent contract as a support for re-manufacturing"				
Key features		**Possible configurations**		**OM1**
H	**Revenue system**	**H1**	**Traditional single payment**	■
		H2	Deposit-based single payment (with surcharge)	
		H3	Performance payment (Pay-per-use, Pay-per-period)	
I	**Market destination and segment**	**I1**	**Same market destination and segment of the original product**	■
		I2	Same market destination of the original product but different market segment	
		I3	Different market destination from original product	

The offer of products for rent, without any transfer of ownership to the customers, is aimed at sensitizing both manufacturers and providers towards the co-design and manufacturing of products characterized by high durability and maintainability, facilitating multiple reiterative product use-cycles before reaching the end-of-life (i.e. not sufficient residual performance for recovery). Retaining the resources embedded into products and guaranteeing multiple use-cycles, this model may lead to both environmental and economic benefits over time.

4.5.2 All-inclusive solution to support re-manufacturing

The second organizational model "All-inclusive solution to support re-manufacturing" involves the sale of the product together with a set of life-extension services performed during the product use phase (Fig. 4.2). Hence, the customer pays for the product and the related services aimed at extending its useful life, including for instance: cleaning, repair, maintenance, replacement and re-manufacturing.

As shown in Fig. 4.2, this model is based on the close partnership between the provider (product supplier) and the re-manufacturer (service supplier). The provider supplies the product to the customer, while the re-manufacturer provides overtime the services connected to the product. This win-win partnership brings benefits to both parties. Indeed, on one side the provider, in order to offer all-inclusive solutions on the market, needs the support of a re-manufacturer with technical know-how and operational

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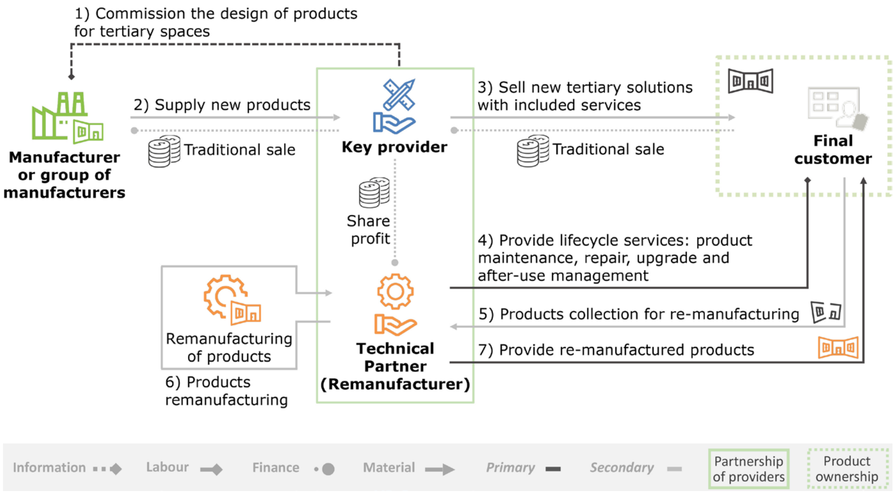

Fig. 4.2 - All-inclusive solution to support re-manufacturing – organizational model (Dalla Valle et al., 2021)

skills in the field of repair, maintenance and re-manufacturing. On the other side the re-manufacturer, in order to intercept a greater share of customers, exploits the partnership with the provider, taking advantage from its marketing connections and product commercializing activities performed for promoting the all-inclusive solutions (Tab. 4.12).

Tab. 4.12 - OM2 key features

Key features of OM2 "All-inclusive solution to support re-manufacturing"				
Key features		**Possible configurations**		**OM2**
A	**Original product design**	**A1**	**Product designed for re-manufacturing**	■
		A2	Product not designed for re-manufacturing	
		A3	Product not designed for re-manufacturing but with facilitating features	
B	**Product procurement**	B1	Surcharge-based mechanism	
		B2	Buy-back mechanism	
		B3	Direct- order mechanism	
		B4	**Service contract mechanism**	■
		B5	Leasing mechanism	

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Tab. 4.12 -continued

Key features of OM2 "All-inclusive solution to support re-manufacturing"				
Key features		**Possible configurations**		**OM2**
C	**Product collection**	C1	Enabled by "collectors" activity	
		C2	Performed autonomously by re-manufacturer	
		C3	**Hybrid solutions**	
D	**Re-manufac-turing actors**	D1	Original Equipment Re-manufacturer	
		D2	**Contracted Re-manufacturer**	
		D3	Independent Re-manufacturer	
E	**Re-manufactured product design**	**E1**	**Product re-designed for re-manufacturing**	
		E2	Product not re-designed for re-manufacturing but with facilitating features	
		E3	Product not re-designed for re-manufacturing	
F	**Product-service distribution**	**F1**	**With a partner intermediation**	
		F2	With a dealer intermediation	
		F3	Performed autonomously by re-manufacturers	
G	**Product ownership**	G1	Ownership is transferred to the customer	
		G2	**Ownership is retained by the provider**	
		G3	Ownership is transferred to the customer with provider's extended responsibilities	
H	**Revenue system**	H1	Traditional single payment	
		H2	Deposit-based single payment (with surcharge)	
		H3	**Performance payment (Pay-per-use, Pay-per-period)**	
I	**Market destination and segment**	**I1**	**Same market destination and segment of the original product**	
		I2	Same market destination of the original product but different market segment	
		I3	Different market destination from original product	

With regard to Tab. 4.12, it is important to stress how the present model differs from the first one in terms of product life-extension strategy. Indeed, the first model aims to guarantee multiple subsequent reiterative use-cycles of the same product even by different customers. Differently, this model has the goal of extending as much as possible

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the first product use-cycle by promoting long-term relationship with the same customer. This latter approach (the so-called "loyalty strategy") aims at matching the duration of use with the useful life of the product (thus minimizing the waste of residual performance), favouring the creation of win-win long-term commercial relationships between the provider plus the re-manufacturer (supply side) and the customer (demand side).

4.5.3 Alternative/secondary markets for re-manufactured products

The third proposed organizational model is based on: (i) product-reuse for the subsequent sell on secondary markets with respect to the original one (primary market), as well as on (ii) the strategy of repurposing, involving the change of the original function of the post-use product for its subsequent placing in a different market (Fig. 4.3). This model promotes reuse and repurposing as strategies towards industrial symbiosis by preventing waste generation through the reuse or refunctionalization of post-use products of a market into reworked product (or potential resources) for sale (or production) processes within another segment of the same market or within a different market.

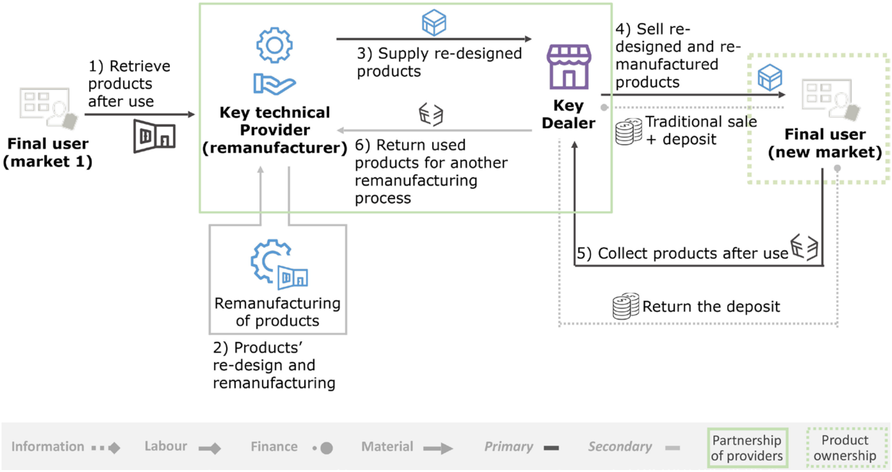

Fig. 4.3 - Alternative/secondary markets for re-manufactured products – organizational model (Dalla Valle et al., 2021)

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According to this model, the recovery of post-use products is carried out by an independent re-manufacturer, who performs the required operational interventions (Tab. 4.13). In partnership with the re-manufacturer, the dealer is the market intermediary who deals with the distribution of re-manufactured products to end customers with a sale that includes a deposit. This deposit-based payment system is useful in order to incentivize the end user to return the products after use, guaranteeing the circularity of the model. The dealer then returns to the re-manufacturer the post-use products collected from the clients (after returning the related deposits). The re-manufacturer, closing the circle, carries out the reworking activities on the products for the starting of a new use-cycle.

Tab. 4.13 - OM3 key features

Key features of OM3 "Alternative/secondary markets for re-manufactured products"				
Key features		**Possible configurations**		**OM3**
A	**Original product design**	A1	Product designed for re-manufacturing	
		A2	Product not designed for re-manufacturing	
		A3	**Product not designed for re-manufacturing but with facilitating features**	
B	**Product procurement**	B1	Surcharge-based mechanism	
		B2	Buy-back mechanism	
		B3	Direct- order mechanism	
		B4	Service contract mechanism	
		B5	Leasing mechanism	
C	**Product collection**	**C1**	**Enabled by "collectors" activity**	
		C2	Performed autonomously by re-manufacturer	
		C3	Hybrid solutions	
D	**Re-manufacturing actors**	D1	Original Equipment Re-manufacturer	
		D2	Contracted Re-manufacturer	
		D3	**Independent Re-manufacturer**	
E	**Re-manufactured product design**	**E1**	**Product re-designed for re-manufacturing**	
		E2	Product not re-designed for re-manufacturing but with facilitating features	
		E3	Product not re-designed for re-manufacturing	

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Tab. 4.13 -continued

Key features of OM3 “Alternative/secondary markets for re-manufactured products”				
Key features		**Possible configurations**		**OM3**
F	**Product-service distribution**	F1	With a partner intermediation	
		F2	**With a dealer intermediation**	
		F3	Performed autonomously by re-manufacturers	
G	**Product ownership**	**G1**	**Ownership is transferred to the customer**	
		G2	Ownership is retained by the provider	
		G3	Ownership is transferred to the customer with provider’s extended responsibilities	
H	**Revenue system**	H1	Traditional single payment	
		H2	**Deposit-based single payment (with surcharge)**	
		H3	Performance payment (Pay-per-use, Pay-per-period)	
I	**Market destination and segment**	I1	Same market destination and segment of the original product	
		I2	**Same market destination of the original product but different market segment**	
		I3	**Different market destination from original product**	

The innovative nature of this model implies a strong commitment by the involved stakeholders, both on the supply and demand side. Indeed, on the supply side, collaboration and coordination efforts are required to the re-manufacturer and the dealer in order to effectively handle the logistic activities and to assess market opportunities for promising product re-design and repurpose. On the demand side, an effort of foresight on the issue of circularity is required to the clients, accepting both the deposit-based payment system and the reconverted and regenerated products.

Concluding, the introduced key features of innovative circular approaches and the three innovative organizational models based on re-manufacturing represent a contribution towards the development of networks of heterogeneous operators (e.g. clients, designers, providers, manufacturer, artisans, dealer, third sector, etc.) able to identify and exploit new synergies needed in order to establish the market conditions required for the activation of circular practices based on re-manufac-

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turing within the construction field. In the next Chapters (5, 6 and 7), the proposed organizational models are explored and discussed with respect to three main fields of the tertiary sector, namely: exhibition, office and retail.

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5. *Organizational models for re-manufacturing: the rent contract*

by *Salvatore Viscuso, Nazly Atta, Anna Dalla Valle, Serena Giorgi, Luca Macrì, Sara Ratti*

5.1 The rent contract: innovative contractual forms based on payment for use as drivers for the spread of circular processes

The present chapter presents the characteristics of a model based on the integration of pay-per-period services to promote re-manufacturing practices. The chapter is structured as follows: the first paragraph (Par. 5.1) describes the organizational model that can encourage reverse logistics and the following re-manufacturing practices; secondly, the cases and views of the stakeholders from the different field sectors will be introduced (Par. 5.2, 5.3, 5.4); then paragraph 5.5 deepens the role of involved actors for activating rent services, while the final section (Par. 5.6) outlines the encountered enabling and hindering elements.

The organizational model presented in this chapter originates from the combination of two key elements: the procurement of rentable products (i.e. furniture and electronics) and a collaboration between two or more supply chain actors (contractors, manufacturers, carriers, installers, customers, etc.) involved in the repairing/regenerating/reinstalling processes after each use.

Among the diverse potential scenarios that could reduce the waste of building strip-outs, the interviews investigated the case in which the manufacturer is also a re-manufacturer. This model is already applied to some niche markets such as luxury exhibitions and events, where the ownership of products and construction systems is maintained by the contractors that offer them to the customers through rent contract solutions.

In this organizational model, three main stakeholders are involved. A key actor is a manufacturer that also performs the role of the re-manufacturer, implementing re-manufacturing processes for product recovery. Another relevant actor is the outfitter, who is in close partnership with the manufacturer through supply agreements to develop fitting solutions for its

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customers. Lastly, the third main actor is the final customer, who is both the main beneficiary of the re-manufactured solution and the source of product provision to be re-manufactured post-consumer.

The following system map (Fig. 5.1) schematizes a potential contracted chain for pay-per-period services. The manufacturer produces the elements to assemble on-site and then the outfitter rents these products delivered as a whole 'kit' plus maintenance and repair services (during the rent contract duration) to a final customer. The product ownership is retained by the manufacturer. Products that have concluded the first cycle of use are selected and retrieved by the outfitter that collects the products and takes them back to the manufacturer. The manufacturer (or re-manufacturer) is now in charge of performing the re-manufacturing of the received products (closing the circular loop), recovering them in a condition of good functionality and performance so they can be re-injected into the market again by the outfitter renting them to clients.

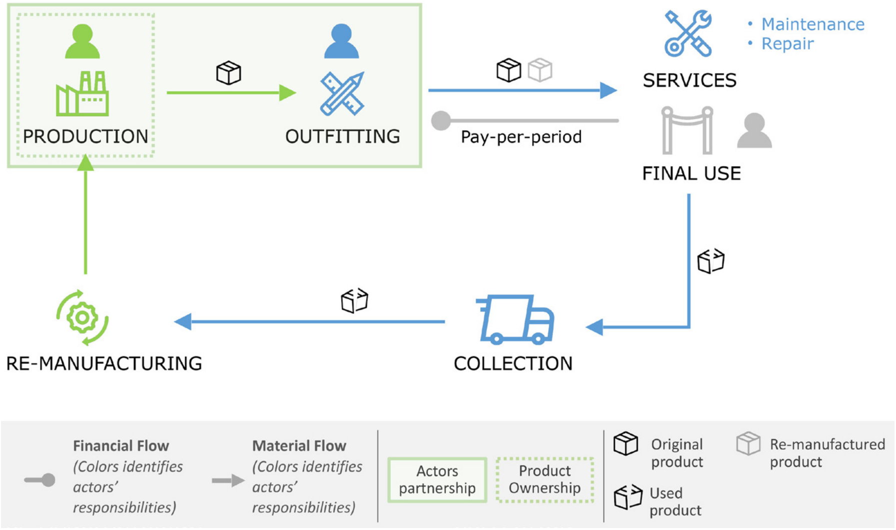

Fig. 5.1 - System map of organizational model "Rent contract as support for re-manufacturing"

Due to the strict partnership between the producer and the outfitter for the offer set-ups through a rent contract (retaining their ownership), the longer products last, the higher the profitability of a single set-up. Thus, it is economically beneficial for the producer and the outfitter to activate

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re-manufacturing practices aimed at extending products' lifespan (and to design products accordingly), e.g., for moving the re-manufactured element from an office/exhibiting/retail location to the new one. In order to incentivize that, the presented organizational model involves an outfitter's business proposition based on key supplier relationships with highly skilled manufacturers that can perform re-manufacturing on their specific products competitively. The fact that re-manufacturing activity is assumed to be at an upstream supply chain level requires the reworked object to be not intensively treated for customization purposes.

5.2 The rent contract in the field of office buildings: cases and the view of the stakeholders

During the roundtables, the interviewed stakeholders from the office sectors involved in the Re-NetTA project (general contractors and manufacturers), declared the frequency of restyling of the workspaces to achieve marketing and rebranding images every 2/3 years, even if components (movable walls, furniture, dry assembled interior fittings, etc.) have a duration of performance at least 10/15 years. Benchmark studies show that strip-out works during office refurbishment create 63 tons of material per 1000 m^2. The primary material components are plasterboard, carpet, ceiling tiles, glass, metals, and furniture. The research also indicates that many of these materials have existing or emerging diversion pathways which are currently unknown or underutilized by the industry because of time, cost, or logistics. With careful separation and aggregation, materials can have a viable second life in another tenancy or be reprocessed into something new, creating business opportunities and jobs in the local economy, whilst significantly improving environmental outcomes and avoiding landfill and their expense.

Moreover, after the Covid-19 pandemic, corporate demand for reconfiguration of interior spaces, which promises a near future of numerous demolition and construction processes in the office sector, producing high numbers of waste and high demand for new building components. In this context, this sector acquires high potential for the experimentation of re-action on waste/materials with high residual value in output, and for the design of new reversible components that respond to the new market demand for flexibility and easy reconfiguration.

The producers interviewed highlighted the potential for reuse of components coming out of office restyling processes, towards a reuse destination in other sectors (e.g., residential), however, there are still no consoli-

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dated dynamics of recovery, repair, or re-manufacturing of components towards a destination for reuse.

The questions, taken up during the roundtables, focused on the feasible collaboration with the manufacturer, for activating a reverse logistic chain to reuse and/or reprocess the products. The list of questions is following reported. For instance, is it possible to activate a continuous collaboration with a manufacturer to provide a rental service for office fit-outs? Or maybe the market is not ready enough to buy-rent re-manufactured products?

In general terms, the discussion with stakeholders clearly revealed the state of the art in that sector, the current waste management, barriers, and opportunities for new types of procurements with manufacturers and suppliers.

The main challenge is due to the property issue. Pay-per-period services are difficult to be applied: generally, the manufacturers sell – not rent – the products to the outfitters due to the high customization/branding requested in this field. Generally, the ownership of the fit-out material remains to the customer, especially in the case of important brands or companies that occupy large spaces.

In case of rapid technological and/or functional material obsolescence (e.g., furniture and led walls in modules, film, in transparency), rent or leasing solutions can represent a suitable option for the customer, because this type of service enables access to good-quality products at a convenient cost. For instance, diverse companies usually offer rental services for luxury furniture as subcontractors to the outfitters or directly to the owner of the office. Independently from the ownership, the reverse chain should be activated by a professional figure that is still absent, a "collector" with cross-sectoral knowledge, that transforms the material or even provides the (re)manufacturer or who can reuse it.

Customization/branding represents a barrier to possible re-manufacturing processes, while the recycling process still represents the most common system to manage the disposal of materials. For instance, a large amount of wood finishes cannot be reused for its low resistance, e.g., wooden honeycomb. Normally, the manufacturer recycles it for generating new products, such as MDF or OSB; due to the high customization of the current office design trends, only some emblematic elements (e.g. some structural timber, or hi-performance glazing partition) can be conserved by the demolishers to be reused – and eventually repaired or adjusted – for future works.

If we refer again to the wooden industry, recently many international players in the sector are adopting the FSC certification to trace the wooden elements for more cycles (from solid wood to chipboard). FSC is a global forest certification system established for forests and forest products. In

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addition to its global certification standard, FSC develops national standards in selected countries. These standards are closely aligned to the global certification standard and its criteria but are adapted to local context conditions. Italy adopted the standard in 2017.

The widespread adoption of voluntary certifications for recycled materials shows that customers demand green solutions, but they also want to communicate this green choice through the stand itself. Communication is obviously primary, so people often prefer to do good marketing about their company's green policies (maybe linked to their core business) than a real sustainable office design. Because of this "greenwashing" attitude, there are customers who are really interested in choosing a sustainable productive chain, even if costs increase, but they always ask to certify the sustainability rate for their marketing policies.

In general, the market accepts the re-manufactured products if workability, technical/aesthetical specifications, and quality are preserved, and if their usability is not inferior to the new products. The second criterion is the final cost of re-manufactured products. Especially for the Italian market, the outfitter should demonstrate an economic advantage in using re-manufactured products, without losing the final quality of the stand. If the re-manufactured material is more expensive than the new one, it will not be used because the customers obviously prefer to spend less.

5.3 The rent contract in the field of exhibition fittings: cases and the view of the stakeholders

Contrary to the office sector, the distinctive trait of the participant stakeholders involved in events and exhibitions is that they represent outfitter companies that retain the ownership of the set-up products, basing their business on the multi-use of products, regardless of customer demands. The interviewed actors (outfitter suppliers and manufacturers) confirmed the high quantity of waste in output from the exhibition sector. For example, in Lombardy, only Fiera Milano, despite its attention to waste reduction, in 2019 produced 10,320,775 kg of total non-hazardous waste, constituted by more than 67% of building components with high potential reusability (Fiera Milano, 2019). These total wastes are generated even though outfitting suppliers are currently trying to get more use cycles for the components they rent for corporate outfitting so that they can have more revenue by renting the same component multiple times.

Generally, exhibition outfitters share their know-how with many furniture suppliers and subcontractors, especially in the case of high-custom-

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ized orders. However, a manufacturing company has not the possibility to start a co-design together with the outfitter because the exhibition market represents an imperceptible segment for wooden, metal, and plastic production sectors.

Creativity in design can activate reusing processes, e.g., applying removable films on PVC boards. For instance, if the design for reusing/repurposing is required by the customer to decrease costs, the planning starts for other needs, such as truck size and space optimization during transport. In any case, it's not possible for any outfitter to directly manage the recovery of end-of-life products and return them to the original manufacturer.

Referring to the possibility of in-house re-manufacturing (carried out by an outfitter), it is important to underline that design patents or trademarks protect many products, thus prohibiting the re-manufacturing process. The outfitter can only ask for some tailored options directly from the original manufacturer (a particular branded cover for the chairs), or he can combine autonomously raw materials coming from diverse suppliers to realize custom furniture.

Another example of customization is represented by temporary communication/wayfinding boards. Panels consist of rigid frames made of aluminum poles, plastic connectors, and new jerseys as the basement. The Lab agreed with the manufacturers on the custom production of tailored new jerseys with different weights and colors, so as to choose the right solution for each installation and for each set of boundary conditions.

Referring to the proposal of a consortium to implement a re-manufacturing network, in the exhibition and retail sector, suppliers and subcontractors are affiliated to the respective sectorial chains (alu, timber, PVC), organized per ATECO codes, and the cross interaction and collaboration between them is difficult to be represented and managed from a single confederation. In terms of reverse logistics, there are already circular chains (MDF and other wooden materials), but sometimes the waste collection does not cover the demand for secondary raw material. The recycling process is organized in intermediate steps and managed by specific consortiums and associations of for-profit companies. During the fairs, the chain work quite well: after the exhibitions, the consortium provides a box for collecting separate waste material without paying additional fees. It is complex to imagine direct recycling, re-manufacturing, or reusing managed by the original manufacturer.

From the regulation point of view, the requirement to use only fireproof materials for the exhibition structures in a fair or a museum –

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adopted five years ago at the European level – is not compatible with the sustainability issues. About MDF and other wooden chipboards, finishing a process like painting (e.g., for the mandatory fireproof treatment) can transform these materials into special waste that cannot be recycled. This regulatory issue also increases disposal costs, so reusing/re-manufacturing could represent a valid approach to optimize the chain. In some cases, raw material comes from non-community countries, and it is impossible to interact with the original manufacturers for a green production stock, e.g., without toxic painting.

Otherwise, the sector of eco-design and production is now well present in the exhibition sector. Today most European manufacturers, customers, and fair technical offices are sensible to reversible technologies and innovative productions. There is also an ISO standard for promoting a more responsible consumption in fairs and exhibition events: ISO 20121:2012 "Event Sustainability Management Systems". The standard has been developed starting from the remarks of many different stakeholders, including representatives from the event industry, to make it practical and useful. It addresses all stages of an event supply chain and includes monitoring and measuring guidelines. In Italy, none is certified with this standard, which is common at the European level.

5.4 The rent contract in the field of retail: cases and the view of the stakeholders

Referring to the retail sector, the interviewed stakeholders (trade associations and suppliers) describe that market segment as an area in which the know-how of the exhibition sector could be transferred. In fact, in the retail sector, there is currently neither a global vision of waste output nor a tendency to reuse materials.

Even if the market sensibility to sustainable practices is progressing for years, the main barriers to re-manufacturing are represented by the customization and customer branding. For instance, bamboo is a cheap and ecological material, it is a naturally regenerating source, but it is considered a poor element from an aesthetical point of view, and it is not accepted in luxury sectors such as automotive, fashion, and jewels companies. In addition, synthetic fabrics are not biodegradable like natural fiber, but they are better than cotton textiles in terms of manufacturability and usability.

The interviews clarified that in the retail sector, the manufacturers need to specialize in a particular core business to guarantee the survival of

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the company itself. The specialization in a specific market segment cannot be compatible with the direct management of waste and the regeneration of secondary materials, because it is not economically competitive compared to the procurement of new material.

However, co-design can be feasible in large companies where volumes of dismantling materials are considerable (e.g., for the fit-out of international-branded showrooms). Designers must both use materials that are more durable and adopt modular solutions, such as aluminum structures, flexible platforms, and communication panels. On the contrary, any use of wooden honeycomb could generate waste after the first phase of disassembly. The design of the communication panels plays an important role because the customer must adapt the communication boards for diverse events with little changes. In addition, carpets are reused many cycles after washing, especially branded carpets. It is certainly possible to collaborate with manufacturers: for instance, some manufacturer collects carpet tiles at the end of their life cycle to recycle them and generate new products of lower quality, thus applying a downgrading for other installation targets.

5.5 The involved actors: roles, skills, relationships, new markets

The debate with stakeholders that the collaboration could allow to highlight the mutual potential for the activation of new circular organizational models and the way to overcome together the current barriers. Within the round table events, all the participants (producers, designers, contractors, policymakers, and investors) are potentially interested in opening new potential markets in other sectors (e.g., from the tertiary sector to the residential one) for second-life products.

Stakeholders require the definition of new professional figures and the co-creation of modular and reversible product technologies that facilitate assembly and disassembly activities and reduce their costs, to enable re-action processes. The manufacturers are interested in developing building components that can be easily disassembled (Design for disassembly), to respond in a more competitive way to the demands of the Italian regulation (Ministerial Decree 11 October 2017). Consequently, they are obviously interested in relocating or even repurposing the dismantled products (also for charitable or educational purposes), in order to avoid landfill costs.

To give an idea of a potential macro-regional chain that could be easily established, in Lombardy, many social cooperatives, fab labs, and

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numerous local art-craft activities already have adequate machinery to be able to re-manufacture the elements. Consortia or joint ventures can overcome technical barriers (towards co-designing and co-creating re-manufacturable solutions), legislative barriers (towards the official request to policymakers of new innovative incentives), and social barriers (towards the identification of secondary markets).

Co-design and co-creation should be included as an upstream activity of the organizational model: the outfitter is considered co-responsible for the design of the products in partnership with the manufacturer, arranging them for the re-manufacturing operations. In this way, the partnership plays a crucial role in launching the proposed organizational and organizational model, because it is in charge not only, as it often happens, of the design of the exhibition stands, but also of the recovery and re-manufacturing activities.

Moreover, the survey of current practice points out that outfitters are often prepared and equipped in terms of machinery, expertise, and skills for processing products, thus the collaboration with the manufacturers can also foresee the re-manufacturing of products at the outfitter's warehouse, without transporting them to the manufacturing site.

Based on the considerations obtained during the roundtables, the organizational model has been implemented as explained in Fig. 5.2.

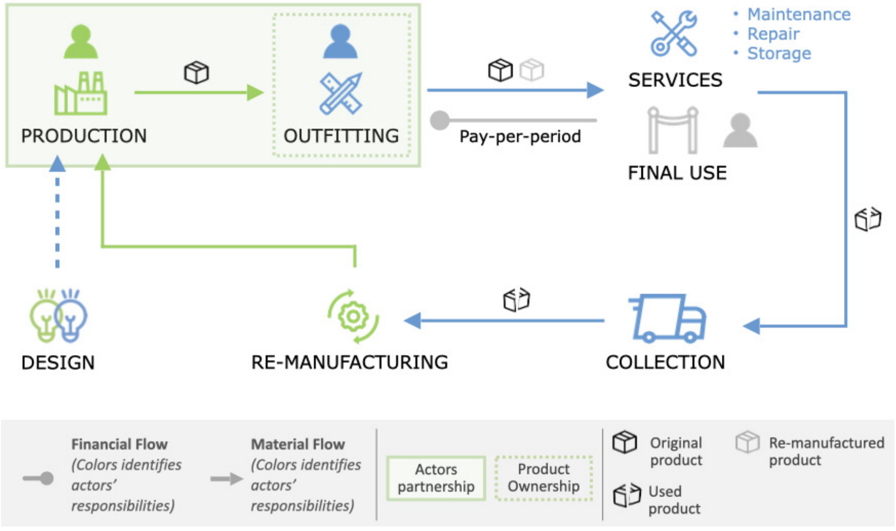

Fig. 5.2 - System map of organizational model "Rent contract as support for re-manufacturing" as modified after the stakeholder feedback

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5.6 Perspectives, leverages and barriers

The Re-NetTA research has identified the various barriers to the larger adoption of pay-per-period contracts. Despite the continuous material flow of wastes from the strip-out activities in the Milanese and Lombardy areas, product certifications – that define responsibilities in terms of quality and performance – are not yet economically advantageous. It is necessary to define procedural and regulatory aspects regarding the second use of products and increase the traceability level of information throughout the whole product life cycle.

To sum up, the main barriers, opportunities, and needs, resulting from the research on potential organizational models with pay-per-period contracts, are listed below:

1. Barriers:
   - the certification for fireproof and structural resistance of products, often with different national requirements;
   - the reaching of an agreement with manufacturers of finished products to adjust products in order to comply with fire requirements;
   - design patents and trademarks.
2. Opportunities:
   - the outfitter retains the ownership of the products used for the exhibition set-ups;
   - re-manufacturing as standard practice to allow multi-use products, namely the attainment of several rental cycles in the first market through the establishment of a network of actors;
   - from re-manufacturing to repurposing of certain products, namely once considered unsuitable for the market, the products acquire a new function, for extending their use within the outfitter company;
   - the achievement of a secondary market for some products, namely once considered no longer reusable within the active stock, the products take different paths (e.g. outlet store, students maquette).
3. Needs:
   - a strategic action of the European Community aimed at bringing the fire resistance classes into alignment across the whole European countries;
   - to meet ISO certification on eco-sustainability for making the outfitter company competitive in the tenders, especially of large multinationals.

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6. *Organizational models for re-manufacturing: all-inclusive services integrating partnered re-manufacturers*

by *Sara Ratti, Nazly Atta, Anna Dalla Valle, Serena Giorgi, Luca Macrì, Salvatore Viscuso*

6.1 All-inclusive services: from product-service logic towards new forms of partnerships for the extension of product useful life

The present chapter presents the characteristics of an innovative organizational model proposed for the tertiary architecture based on the integration of all-inclusive services with the goal of promoting re-manufacturing practices.

The organizational model presented in this chapter originates from the combination of two key elements: the offering of a product-service solution and a collaboration between two or more supply chain actors. Specifically, the organizational model based on all-inclusive services integrating partnered re-manufacturers implies the sale of the product to the customer, who will benefit from a set of services during the product use phase, aimed at extending the product useful life. The possible services might include cleaning, repair, maintenance, replacement and re-manufacturing. Relevant supply chain relationships are established between the provider, i.e. the product supplier and the re-manufacturer, i.e. the supplier of technical services associated to the product. The re-manufacturer will provide the required services oriented to protect and potentially extend the product life cycle during the use phase. He has a direct or indirect relationship with the user, offering his technical-operational skills and competences in the field of maintenance and re-manufacturing operations and he holds a business partnership with the product provider, who has commercial and distribution resources and competences to reach and engage the market users. The overview of the organizational model based on all-inclusive services and partnered re-manufacturers is presented in Fig. 6.1.

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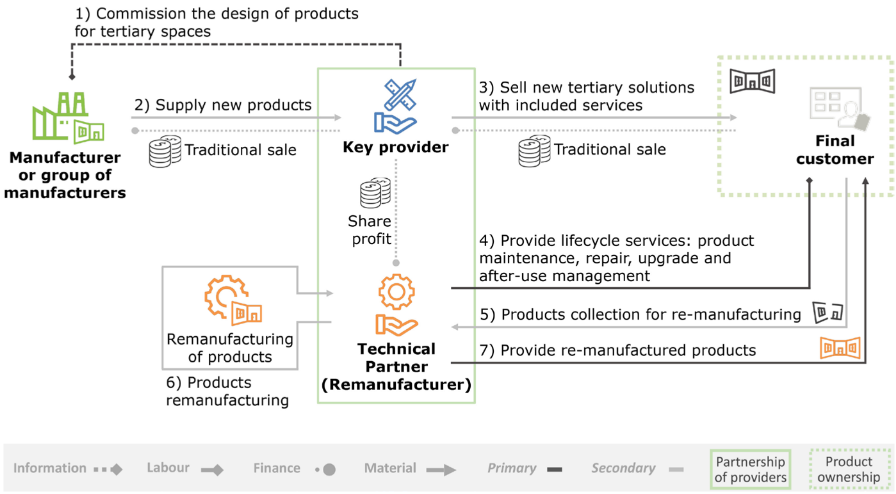

Fig. 6.1 – System map of the organizational model based on all-inclusive services and partnered re-manufacturers

While the model based on a rent contract, presented in Chapter 5, was oriented to facilitate a number of use-cycles of a given product distributed to a set of customers, the model presented in this chapter aims at extending the single product use cycle as long as possible, making the single customer, who also retains the product ownership benefit from these mechanisms in environmental and potentially economical terms. Indeed, by combining the use length and the product useful life (which turns into the minimization of the waste of residual performance), the proposed model promotes the generation of long-lasting win-win business relationships between the provider and the re-manufacturer and the customer (loyalty strategy).

Based on the key features, introduced in Chapter 4, the proposed model, based on all-inclusive services and partnered re-manufacturers, considers a specific combination of key options, summarized as follows:

– Original product design for re-manufacturing;
– Product procurement based on a service contract mechanism;
– Product collection through hybrid solutions;
– Presence of contracted re-manufacturers;
– Product re-designed for re-manufacturing;
– Product-service distribution performed with a partner intermediation;

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– Product ownership retained in provider hands;
– Market destination same as the original product;
– Revenue configuration based on performance payments.

The following three sections are dedicated to the introduction of cases and views of stakeholders operating in the industries addressed in the study, which are specifically office buildings (Par. 6.2), exhibition (Par. 6.3) and retail (Par. 6.4) sectors.

6.2 All-inclusive services in the field of office buildings: cases and the view of the stakeholders

One of the potential application fields of the innovative organizational model based on all-inclusive services investigated in the research study was the office buildings. The activation of contacts in the field was conducted, considering the need and interest of the research to interact with an extended set of stakeholders operating along the supply chain. Indeed, the engaged stakeholders from previous interactions expressed the value of mutual understanding and collaboration with other value chain actors to enable business models. Hence business players from the upstream and downstream supply chain were engaged with the goal to gain a more comprehensive understanding of the sub-industry and to enrich the spectrum of perspectives on potential implementation of re-manufacturing opportunities. Consistently, the investigated cases and engaged stakeholders for the validation of the proposed business models were represented by a manufacturer, a general contractor and a trade association. The research project included the direct engagement of these selected stakeholders with the goal to gain multiple perspectives from field actors regarding the applicability of the proposed organizational model based on all-inclusive services. Specifically, the applicability of the proposed business model was investigated by focusing on possible existing specific re-manufacturer skills and competences among the office supply chain actors and focusing on the viability of the re-manufactured product, considering the existing sector regulations and market dynamics.

The involved stakeholder offered a comprehensive overview of the actor perspectives, representing concerns and views from the production, commercial and regulatory sides. In this sense, the main points raised by the office building sector representatives in relation with the business model based on all-inclusive services are associated to the shared

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opinion of an existing supply chain network not sufficiently ready to offer the required technical competences and business skills to consider the re-manufactured product viable on the market and the reverse logistic network economically sustainable.

The stakeholders expressed the shared view on the lack of a re-manufacturing player and solid supply chain in the office buildings Italian industry. Indeed, the as-is supply chain network does not appear properly able to embrace circular practices in substitution of current large-scale practices for the office systems fit-out and office system building. The factors undermining the viability of circular practices by existing players are mainly associated to the economic convenience, to the lack of a solid logistics and production network that would guarantee the cost abatement of the closed-loop supply chain in substitution of the current linear one. Given this shared perspective on the existing supply chain, all stakeholders agreed that a new player role would be welcome within the supply chain with the aim to foster the activation of circular practices, not potentially promoted by existing commercial players (e.g. general contractors) and manufacturers, who do not own the specific know-how and competences in re-manufacturing processes. The new player should be able to introduce a competitive business proposition of circular solutions for the office system. Consistently, a robust and structured reverse supply chain should be put in place, in order to ensure the cost convenience and the diffusion of these practices at an industrial level. These result to be the critical absent elements in the as-is supply chain network.

Moreover, a further emerging issue is represented by the Italian regulatory framework. Existing regulatory frameworks associated to office building sector result relatively stringent, and they cover a fundamental importance in the market viability of office building components. For instance, safety-related aspects attached to the structural component characteristics are critical in assessing the quality of the products. The stringent regulatory system is also in a rapid evolution and this factor should be considered when developing a new business offer.

6.3 All-inclusive services in the field of exhibition fittings: cases and the view of the stakeholders

This chapter collects the reflections and suggestions gained through the interaction of representative stakeholders regarding the potential of an organizational model based on all-inclusive services oriented to promote re-manufacturing practices in the field of exhibition fittings.

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Industrial cases from the Italian exhibition fittings sector have been identified and selected based on multiple criteria, considering the geographical location of activities, the experience and relevance within the specific market and potential sustainability-oriented approaches already in place in the existing business propositions.

Different stakeholders have been selected by means of preliminary documental analysis and direct interviews with managers.

The stakeholders involved in the direct engagement phase represented multiple roles within the exhibition fitting supply chain such as designers, manufacturers and outfitters, so to gather different perspectives in relation to the applicability of the proposed organizational models.

The research study included two separate subsequent interaction sessions with representative stakeholders from the exhibition fittings sector. This occurred with the purpose of a vertical investigation of potential application of certain proposed organizational archetypes that promote circular – re-manufacturing especially – practices. Hence, the research implied the opportunity to propose two versions of the organizational model based on all-inclusive services: the first version, presented in the following paragraph, originates from the preliminary application of a general business model to the exhibition market, while the second version is the result of the adjustment of the first version, in light of the key preliminary views and insights raised by the representative stakeholders engaged in the first interaction phase.

The organizational model proposing a product solution integrated with a set of all-inclusive services provided by an external re-manufacturer is proposed for the exhibition fittings reality, considering some different changes from the archetype described in 6.1. Specifically, a first archetype version proposed that the outfitter, by covering the key role of product provider, retains the ownership of the fitting solution, which is offered to the customer with an extended set of services oriented to extend useful life of the existing fitting solution. Hence, differently from the organizational archetype, the first version adjusted for exhibition fittings industry leverages the short duration and the high frequency of fitting components usage for the attempt of a product-service business solution, on which the outfitter can maintain the control and hence favour an environmental-friendly business management.

According to the model, different fitting products are supplied by producers to the outfitter, who integrates them in the final fitting solution. The fitting solution is delivered to the customer through an inclusive service contract agreement, which is meant to provide the customer with a set of activities as maintenance, repairing and adaptation of the fitting solution

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together with a structured regeneration activity that aims at recovering the value of the product. The contract with the customer is based on an all-inclusive transaction: the single payment accounts for all the services provided among the fair-fitting lifecycle. After the use, the specific used product of the fitting solution is retrieved and brought to a contracted re-manufacturer that, in line with the supply agreement, provides the outfitter with a regenerated product to be integrated in next fitting solutions.

The specific organizational model based on all-inclusive services and partnered re-manufacturers proposed for exhibition fittings industry is displayed in detail in Fig. 6.2.

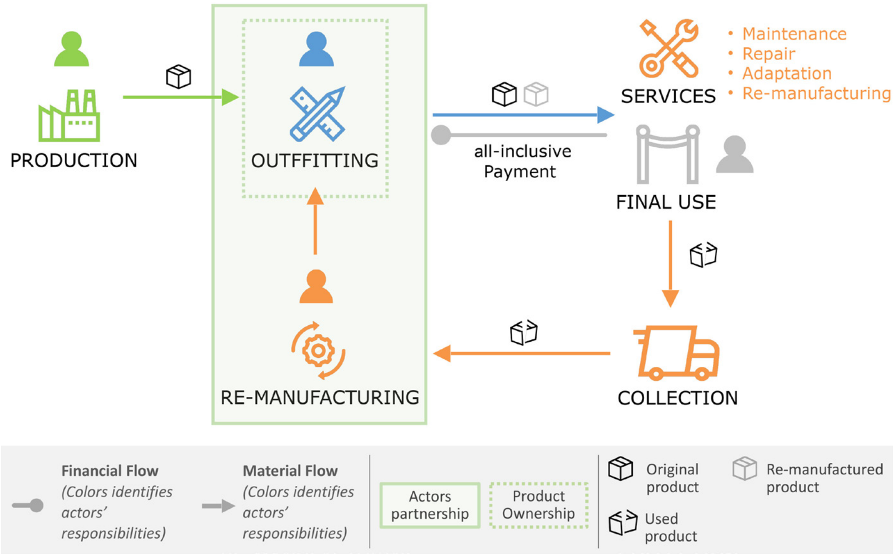

Fig. 6.2 – System map of the first version of organizational model based on all-inclusive services and partnered re-manufacturers proposed for exhibition fittings industry

A first interaction session with the representative stakeholders led to the collection and understanding of the actors perspectives regarding the proposed organizational model displayed in Fig. 6.2.

In general terms, the engaged stakeholders shared the position that key mechanisms proposed in the proposed model are already in place within the exhibition sector, although relevant considerations emerged.

– *Facilitation of customer retention*. The major strength of the model is that it allows the stand outfitter to make long-term plans with

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customers, usually not proposed in practice by the same outfitter but resulting from an active input of customers. Indeed, many set-up companies are characterized by a little turnover of customers, as most of them remain consistent for several years. This setting opens the chance to develop and favour collaboration between exhibition outfitters and customers, providing the opportunity to enter into long-term contracts, also through the intermediation of architects, responsible for the design phase.

- *Product ownership retained by customers.* Concerning the ownership structure proposed in the model, the cases investigated in the field report different experiences associated to the ownership of exhibition stands and comprised products. Most of the engaged stakeholders sell the stand to customer, who becomes the owner. This setting works for two main reasons. On one hand, the customer is able to monitor the stock of products managed and stored by the appointed outfitter in a warehouse, making full use of them for most events and partial use for specific locations. On the other, through the partnership of stakeholders, the outfitter is involved in multiannual contracts, under the same conditions established for conventional agreements. This type of contract allows the exhibition outfitter to plan together with architects, the use of the available material, optimizing as much as possible reuse and re-manufacturing of the existing products. Differently, ownership is retained in the hands of provider when the market solution includes a rental activity, that implies that all the set-up products are multi-use from the outset and are re-manufactured to be used always by different customers.
- *Product modularity versus customization.* In this context, regardless of the different methods and customer targets that plainly determine the selection and application of the set-up materials, an open issue emerges especially when, as in the proposed model, the ownership of the stand products is retained by outfitter: modularity versus customization of products. When both structural and decorative products are created ad-hoc for a customer, resulting therefore highly personalized, it is hard to reuse them for other customers and therefore to extend their lifespan. This imply a great challenge also from a technical and design perspective, for ensuring that the created product is as modular as possible but at the same time as customizable as possible.
- *Multidisciplinary approach for design.* The involved stakeholders claimed to be able to handle the design of most products required by customers, having incorporated over time the necessary skills and competences. The few remaining cases are characterized by extravagant demands from customers, requiring the collaboration and expe-

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rience of external experts in the development of specific products. Moreover, the dynamic and varied nature of customer demand lead outfitters to deal with suppliers to have a support in design and technical issues. A multidisciplinary approach in the re-design of the products emerges to be a relevant characteristic to consider in those supply-chain relationships promoting circular practices.

– *Outfitter in-house re-manufacturing activities.* Investigating the existing supply chain of exhibition fittings industry, possible re-manufacturing activities are generally performed in-house by the same exhibition outfitter and not provided by external suppliers as depicted by the presented model. In this way, the outfitter is in charge of the set-up, collection and re-manufacturing services, where basically everything that arrives at the exhibition site also returns to the warehouse to be re-manufactured and reused, by minimizing waste during the disassembly phase.
– *Interest for collaboration with external re-manufacturers.* The interviewed stakeholders showed interest in collaborating with specific partners to carry out re-manufacturing activities, when appropriate and useful for peculiar products. This is the case for instance of communication banners in PVC, since the international market calls for alternative materials. For this reason, some companies do not use anymore PVC banners for the layout graphics, as they are replaced with a completely recyclable eco-friendly textile with sublimation printing. This alternative solution costs more than PVC but embeds exceptional qualities for the textile lightness (particularly important factor for banners that reach hundreds of square meters and are handled by two people), for the quick-assembly and in terms of brilliance. Given that banners are hardly reused for several events, since it changes the language, the message to communicate, the location, etc., at the end of the event an external partner recovers and return them into the production process through a re-manufacturing process. Despite the higher price, the customer recognizes the qualities of the product, appreciating and valuing them.
– *New professional profile for re-manufacturing.* By recognizing the lack of technical skills, economic and physical resources in the existing supply chain players in order to perform re-manufacturing activities, actors from the exhibition fitting sector call for the emergence of a new professional profile.
– *Need of shared rules for re-manufacturing.* The challenge is to develop procedural and methodological guidelines in order to understand the real possibilities of re-manufacturing on the basis of what achieved at

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the architectural scale, regardless the player who performs the re-manufacturing activity. Indeed, given that during re-manufacturing products may differ in terms of properties, shape, function and use, the definition of shared rules that allow to design and operate for ensuring continuity in the re-manufacturing processes would be extremely valuable.

– *Business potential of re-manufactured products.* With reference to re-manufacturing as part of the all-inclusive service contract offered by the exhibition outfitter to the customer, it is important to note that this solution implies additional costs compared to those incurred by standard services, with the risk of forcing out of the market. With the customer need to amortize the cost, a multi-annual amortisation plan is a common strategy. This mechanism implies that the outfitter, representing in this case the manufacturer, assumes responsibilities over the solution production, aiming at maintaining a high finishing level over a period of 5 years, selecting thus suitable materials for this durability. Also in some cases circular practices become conditions to participate and compete in certain tenders, since as anticipated requested by customers, or to be able to create some exhibition set-ups.
– *Product certification.* Concerning regulatory aspects and product certifications, outfitters consider fireproof issue as a significant constraint, because of fire resistance classes vary from country to country and the European classes are unclear and not generally recognized from individual countries. In this regard, they solicit the European Community to take decisive action in the management of the matter.
– *Time as crucial issue.* Barriers for the suitability of the proposed organizational model emerged in association with the exhibition context time factor. Indeed, outfitters must comply with fairs regulations and procedures that might provide for the demolition of stands, for time and cost reduction reasons, neglecting environmental issues. Beyond costs, an eco-sustainable disassembly takes time to be carry out and often trade fair calendars do not take this into account. In this perspective, event planners represent additional stakeholders that must be involved to put in practice reuse and re-manufacturing processes, providing thus the timing necessary for appropriate assembly, use and disassembly.
– *Covid-19 impacts in exhibition sector.* The issue of timing assumes further relevance in a post-Covid-19 reality. Indeed, the concentration of events, that were progressively postponed to the last quarter of 2020 year, led to an intensive work period for outfitters and to a revision of customers investment budget in fairs. In this context, companies set the priority to achieve an economically sustainable setting, necessarily leaving in the background the environmental goals.

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– *Solutions for secondary market channels.* The set of products that after several use cycles are no longer considered reusable, can take different paths. Experiences shared by engaged stakeholders proved that secondary market channels (such as outlets) are used for medium- and high-end products from tables, chairs, decorations up to panelling and vertical partitions. This phenomenon is now growing as a result of e-commerce delivery, allowing also to foreign people to buy products.

In light of the insightful views regarding the first version of the organizational model based on all-inclusive service and partnered re-manufacturers, a revision of this brought to the adjusted version, characterized by two main revisited elements.

First, design is included as a key activity of the model: the outfitter is considered responsible for the design of the products used to build exhibition set-ups, arranging them for the re-manufacturing operations, performed as appropriate internally or in collaboration with one or more external partners. In this way, the outfitter plays a crucial role in launching the proposed organizational and business model, since design is placed upstream the system map. It is in charge of the design not only, as it usually happens, of the exhibition set-ups but also of the related products, being interested in the recovery and re-manufacturing activities.

Secondly, a revision of responsibilities over the services included in the product-service solution led to the partition of the services to the outfitter and to the re-manufacturer, according to the phase of the process. The set of services that occur before and during the event, such as maintenance, repair and storage, are provided by the outfitter, while the re-manufacturing activities are demanded to specific re-manufacturer. This change has been made because the survey of current practice points out that outfitters are often prepared and equipped in terms of machinery, expertise and skills for processing products.

Fig. 6.3 shows the details of the second version of the organizational model based on all-inclusive services and partnered re-manufacturers for exhibition sector.

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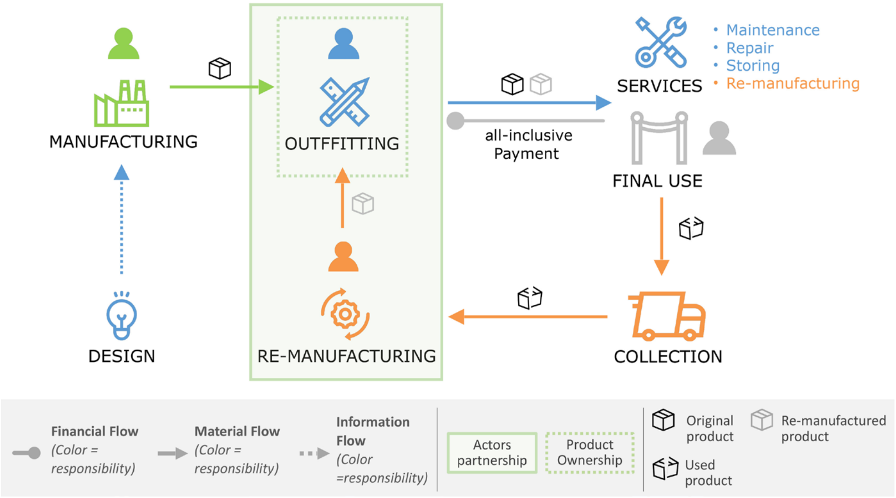

Fig. 6.3 – System map of the second version of organizational model based on all-inclusive services and partnered re-manufacturers proposed for exhibition fittings industry

6.4 All-inclusive services in the field of retail: cases and the view of the stakeholders

This paragraph presents the insights emerging from the research investigation regarding an organizational model based on all-inclusive services applied in the retail arena of tertiary architectures with the purpose to promote re-manufacturing practices.

The proposition of a re-manufacturing-oriented business model based on a product-service solution with all-inclusive services and partnerships with external re-manufacturers was accurately adjusted and re-framed for the building sector of retail spaces. Specifically, in the proposed organizational setting, the contractor (fit-out) sells retail systems including services for extending the useful life of the constituted elements and commissioning the re-manufacturing processes to external partners (Fig. 6.4).

Based on the lesson learnt from previous interaction with key stakeholders, the original proposed organizational model based on all-inclusive services was integrated with an upstream core activity: design phase. Indeed, design phase was introduced with the objective to facilitate circular processes, especially in a closed-loop product value chain, as proposed in this model, in which the single customer is the recipient of the physical component or product as "new" and as "re-manufactured". In this mechanism, design for re-manufacturing could play a relevant enabler.

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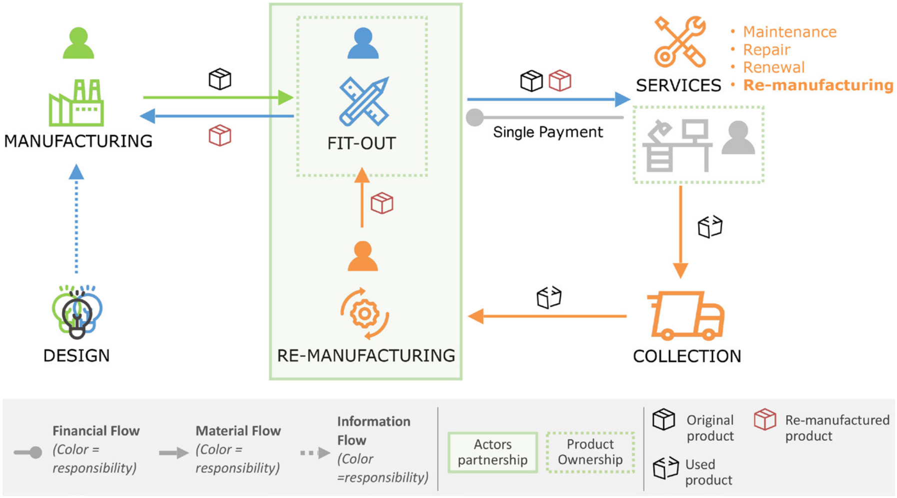

Fig. 6.4 - System map of the organizational model based on all-inclusive services and partnered re-manufacturers proposed for the building sector for retail spaces

Another focal aspect to mention is related to the ownership over the product. As in the original proposition of the model, the contractor sells the product coupled with a set of services and the customer acquires the ownership over the physical product.

The engaged stakeholders have been identified starting from the assumption that the third sector might cover a key role in developing and enhancing circular practices for the retail sector. Indeed, the design of corporate social responsibility strategies often implies the activation of collaboration agreement with non-profit organizations, that can ensure the experience and knowledge of third sector activities. To this end, stakeholders engaged in the research interaction phase have been selected involving both traditional actors from the retail sector and operators from the third sector. Specifically, the representative stakeholders were a major player acting as both designer, manufacturer and general contractors of its own retail stores; a general contractor serving franchising retail stores and two third-sector actors engaged in reverse logistics and manufacturing operations.

Stakeholders coming from the two environments – retail and third sector – have been invited to express their views regarding the different roles in the supply chain and different features (e.g. organization, size, interests, markets, core business, etc.) proposed in the organizational archetype based on all-inclusive services.

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Field actors explained some industry and market-related elements that emerge as relevant issues to consider in relation to possible business proposition combining a product-service offer and re-manufacturing.

From a market point of view, product customization trend is confirmed to be a critical reality also in retail context of construction sector. Indeed, this dynamic might not facilitate customer demand to accept re-manufactured goods, rather than new solutions. On the other side, customization could be a primary barrier to activate a closed-loop value chain oriented to design products so that they can be subject easily to some processes in a post-consumer phase.

From a supply chain point view, the retail network results complex in terms of responsibilities upon products whose ownership and origin do not belong to the re-manufacturer player. In these cases, technical actors face barriers in terms of performance assessment and certification. This element, regarding the model proposing a closed-loop value chain, could be a potential trigger for experimenting this setting that relies on a design-for-re-manufacturing, a tight connection among the players (provider with designer and provider with the customer) and products on which information are more transparent and available. On the other side, the issue of product information availability opens to the need of monitoring the conditions of products during their useful life, that is a resource-consuming and poorly practiced activity, but necessary for tracking product information for new future uses.

6.5 The involved actors: roles, skills, relationships, new markets

This section aims at summarizing key concepts emerging from the research of the distinguished sector-specific experiences in association with the organizational model that is oriented to enable re-manufacturing activities through a product-service solution. In particular, the main aspects connected to the existing and new business actors within the organizational model will be presented distinguishing the roles, the skills, the relationships, and the market.

The research methodology was shared among each of the three investigated business environment, and this provided for the preliminary understanding of market players and supply chain mechanisms oriented to the identification of the involved actors, potentially covering a key role within the proposed organizational model. Key actors were selected mainly based on two factors: their relative positioning from the market, hence their ability to comprehend, capture and anticipate clients demand

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and secondly their centrality in the supply chain network. Hence, in the context of tertiary architectures the players identified as pivot in an organizational model based on a product-service proposition were the general contractors for office and retail spaces and the outfitters of exhibition fitting solutions.

The producers, representing the upstream supply chain side, depending on the specific investigated sector, are separated actors from the "pivot" actor (e.g. office) or integrated in the "pivot" actor (e.g. exhibition). The difference between these cases is reflected in the multiple roles and responsibilities exerted by the actors within the organizational models properly adjusted for each business environment.

In the organizational model based on all-inclusive services, re-manufacturers are considered external partners of existing business actors. In the phases of search and selection of stakeholders from the fields, the presence of re-manufacturing capabilities and activities played a relevant criterion, however as this proposed organizational setting provides for, this was not a pre-requisite since re-manufacturers were considered as potentially external players from the existing ones. For instance, in the office reality, re-manufacturers were not identified as existing stakeholders, leaving space to the investigation of potential of new business roles entry for these purposes.

The organizational model includes different roles for the involved actors. The pivot actor, distinguishing general contractors for office and retail spaces and the outfitter in the exhibition business, is considered to be the main enabler of the circular organizational scheme, since it interacts with the customer, to capture the needs and define a proper solution that combines the economic and environmental sustainability. The role of establishing a solid and effective relationship with the customer is crucial in this setting, since the organizational model implies an agreement held by the provider and the customer that is based on the sale of a product integrated with the provision of specific services. This mechanism requires the building of a customer loyalty strategy, in order to allow that the client is retained and plays a key role in the activation of reverse loops of the products. Indeed, the organizational setting implies a close-loop flow of materials, hence a relevant role of the existing customer within the supply chain network. The customer is asked to be an active player in the support of procurement of post-consumer object and he is also bound to the business agreement with the provider to receive a re-manufactured solution.

The boundaries of roles covered by the producers, key providers and external re-manufacturers in the application of the presented organiza-

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tional model are not strictly defined, yet they depend on the specific supply chain context. Indeed, the vertical integration of key providers is a significant variable that affects the types of activities run by each player in the value chain. In the exhibition fittings environment, existing outfitters are often prepared and equipped in terms of machinery, expertise and skills for processing products, hence the role of re-processing the object for the extension of its lifecycle could be shared with external technical operators. Differently, general contractors operating in the office fit-out activities do not have technical skills and resources to perform certain processing activities, hence the roles between them and a potential external re-manufacturer are clearly defined. The same logic applies to the producers roles: the exhibition sector demonstrates that outfitters work closely with architects that are often part of the internal staff for the solution design: in this context producers of components are pulled by a pivot actor that has design and technical capabilities.

The concept of roles is necessarily linked to the available and potential skills and resources that each actor may ensure within a multi-stakeholder network. Consequently, within the specific value chain setting the roles of each actor were assigned and re-defined during the research, based on the understanding of existing know-how and capabilities. The presented organizational model, beyond the necessary skills that has in common with the other two presented models, particularly focuses the attention mainly on three aspects that are the know-how of design for re-manufacturing, the ability to build a product-service solution with the customer, and the cross-sectoral knowledge for the operation management of the closed-loop product flow. In general, these skills emerging as necessary and significant in the viability of this value chain model reflect the importance of multiple sides: the design phase, the marketing management, and the logistics management.

The product design oriented to facilitate re-processing activities resulted crucial in the definition of a circular product-service solution, lowering the physical, technical, and functional barriers for extending the lifecycle of post-consumer goods. This phase plays a crucial role also considering the closed-loop relationship built between the provider and the customer that implies a customized solution, hence a designed solution for the specific purpose and customer need.

Secondly, the nature of a closed network implies that the provider builds a sufficiently solid customer relationship, hence demonstrating proper marketing capabilities for building the premises of a long-term agreement that combines the sale and the provision of re-processing services. Third, the sustainability of a closed-loop supply chain depends on

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the resources and skills that can ensure the reverse logistics management at operational level. Indeed, the role of a collector, responsible for the reverse procurement, transportation, storage e re-allocation of post-consumer products, is considered crucial for the activation of circular supply chains. Consistently, also in this application the presence of these resources and capabilities emerges as key enablers of the circular mechanism.

Studying the interactions among the multiple stakeholders, the presented organizational model leverages on two main significant relationships: a market-oriented relationship, as anticipated in the introduction of actor roles, and a supply-chain relationship.

The customer relationship results pivotal for the acceptance of a product-service solution, hence as a business viability enabler, and also for the sustainability of a closed-loop value chain management. This financial relationship is built on a performance-based payment, such as pay-per-period contract between the solution provider and the end-user (e.g. outfitter and corporate client in the exhibition fitting business).

The key relationship within supply chain actors stands between the "pivot" actor or key provider and the external re-manufacturer built with the goal to provide a re-manufactured product in a product-service solution proposed to the market. The definition of business partnership structure is crucial, since the actors share the responsibilities over the integrated solution sold to the customer: the physical product and the performance of specific services.

6.6 Perspectives, leverages and barriers

Consistently with the key insights emerged from the interactions with stakeholders regarding the applicability of an organizational archetype based on all-inclusive services in their fields, this section aims at summarizing main leverages and barriers associated to the supply chain and market environments and drawing brief general conclusions.

6.6.1 Leverages

The key leverages emerging from the structured interaction with the representative stakeholders from office, exhibition and retail sectors of tertiary architectures associated to the organizational model based on all-inclusive services are described, distinguishing leverages characterising supply chain mechanisms, and the ones characterising the market.

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The exhibition fitting sector results having an existing supply chain with key elements that turn into leverages for the proposition of the organizational model. Indeed, two main supply chain factors might represent possible enablers of innovative mechanisms in a circular perspective. First, the current relationships the outfitter establishes with the client are characterised by a multi-period duration, favouring long-lasting business partnerships, increasing customer loyalty and hence virtuous circular practices such as the series of use cycles of a given product and the activation of a reverse supply chain between the customer and the outfitter or the partnered re-manufacturers. Second, the concept of product ownership assumes a significant role in the viability of an organizational model based on all-inclusive services and in the exhibition sector the existing reality gave evidence that often the ownership is retained in the hands of the provider, so that he can exert a high-level control on the product and material flows in a closed-loop supply chain system.

Further leverages have been identified discussing the market dynamics and trends of the investigated business fields.

Specifically, the future trends within these markets might play a role in revealing the potential of circular and innovative business propositions. For instance, the office building sector is experiencing a revision of space layout in light of the pandemic-related situation that pushed organizations to rethink the way of office working. This market dynamic could represent the chance to discuss also the environmental footprint of physical spaces employed by organizations, which consider environmental performances more and more as a priority in their strategies. Also, the cost-driven logic that dominates the existing office building business might be questioned in the future market, favouring environmental performances of projects at the same priority level of economic sustainability.

The rising role played by the environmental footprint in the market behaviours is reflected also in the exhibition fitting industry, in which fair tenders progressively integrate environmentally friendly practices within the requirements of outfitter activities. These elements might represent new market entry barriers, hence new competition drivers that trigger outfitter strategies in exploring circular business propositions.

Re-purposing strategies are seen positive and in an increasing trend as corporate social responsibility practices in the retail sector of tertiary architectures. Projects oriented to generate new destinations for products that have a low residual economic value associated to the existing market are gaining relevance in different large-scale organizations that may be interested in reporting sustainability-related activities attached to their core businesses and that have availability of resources to devote.

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6.6.2 *Barriers*

In a specular way to leverages, the interaction with different actors from the fields allowed to understand and recognize the current environment barriers potentially preventing the applicability of an innovative organizational setting that combines a product-service solution with a partnership with external re-manufacturers. Indeed, the organizational model hardly fits with specific elements mainly associated to the studied markets.

All business realities shared the increasing trend of product customization: market demands more and more highly differentiated goods and with the rising competition organizations are pushed more and more to meet clients requests. This dynamic does not match with a sustainability-oriented philosophy and especially with the proposed market mechanism of a long-term relationship with the customer and the achievement in multiplying the use cycles of a given physical component. Outfitters, general contractors for retail and office spaces experience the need to respond to a market that is oriented to more and more customized requests.

Another main element seen as a limit for the viability of re-manufacturing practices that imply the re-utilization and re-processing of components for the market is represented by the existing regulatory frameworks and the presence of certifications. For instance, safety aspects and environmental aspects play a relevant in the office ecosystem for building and furniture components and the regulations are very stringent in determining that a re-manufactured or re-used object is sufficiently safe to be viable in the market.

In the exhibition fitting industry, certifications for fireproof and structural resistance of products, differ frequently from country to country, representing an obstacle for re-re-manufactured products to be compliant with certain standards. Given the intensive use of wood-based products in this field, the non-compliance with fireproof requirements might represent a relevant barrier for the viability of re-manufactured goods.

Further hindering elements emerged from the experiences of specific sectors. For instance, the market arena of office building solutions is dominated by a cost-driven logic: clients demand for low-cost solutions, and this factor pulls industry players that strive to compete on costs. In the as-is setting there is no room for exploring alternative solutions that result less economically convenient than the current ones.

Differently, in exhibition sector the tight timetable imposed by event organization that does not allow a proper disassembly and recovery of products, hence discouraging the introduction of circular activities that are based also on a accurate disassembly phase of the fitting solution.

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The investigation of experiences from the building sector for retail spaces identified an issue in the volume of material flows coming from maintenance, renewal or demolition processes of tertiary buildings. In many cases, the volume is not sufficiently high to justify new industrial processes, also due to the unstable demand, which is often difficult to predict in terms of quantities and product typology. Nonetheless, even in the case of significant demand volumes it is necessary to demonstrate the economic advantage in adopting a re-manufactured product, since if it results with equal or lower quality but more expensive than the new one, it will be hardly reinstated into the market.

6.6.3 General perspectives

Based on the overview of possible leverages and barriers associated to the application of an all-inclusive-service organizational model for circularity in the building sector of offices, exhibitions and retail spaces, some general concluding observations are summarized.

The studied tertiary architectures in the Italian context result sharing some key needs for their readiness to embrace re-manufacturing practices both at supply chain and at market level.

First of all, a general need, already acknowledged within literature and professional practices, is represented by the design and proposition of solutions, thought as trade-off between product modularity and customization. Indeed, it is widely recognized that modularity and standardization of technical elements facilitate assembling and disassembling processes, product retrieval in the market, as well as maintenance and replacement operations. The providers of exhibition fittings solutions, general contractors for office and retail spaces do recognize the need to propose attractive solutions, designed in a way that circular activities are facilitated.

In this sense, eco-design and design for re-manufacturing emerged to be crucial activities for the activation of a business model oriented to include a set of services for the extension of product life cycle and for the replication of customers use cycles. New professional figures are called to fill the gap of adequate cross-sectoral skills, including know-how on sustainability, circular economy and eco-design, as well as competence on technical and operational aspects linked to the building process along the whole product life cycle.

From a supply chain perspective, the operations management of reverse material cycles emerged to be an uncovered responsibility by existing players, since they do not own sufficient resources, or they are not incen-

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tivized by the market requests in a proper way. For instance, as exhibition tenders have integrated some environmental requirements, outfitters are called to explore circular solutions in their businesses, hence facing and managing reverse logistics for circular practices. Similar incentives coming from the market would trigger these uncovered supply chain activities also in the building sector for retail spaces.

Concerning policy and regulatory aspects, an emerging need of tertiary architecture actors is represented by the support of both procedure and methodological guidelines, needed to understand the real possibilities of product re-manufacturing. Besides, the introduction and harmonization of regulatory frameworks aimed at defining new procedures and new bodies for re-manufactured product certifications would support new businesses based on circular approaches.

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7. *Organizational models for re-manufacturing: alternative/secondary markets for re-manufactured products*

by *Serena Giorgi, Nazly Atta, Anna Dalla Valle, Luca Macrì, Sara Ratti, Salvatore Viscuso*

7.1 Alternative and secondary markets for re-manufactured products: new supply chains for new trading opportunities

The present chapter presents the characteristics of an innovative organizational model aimed at promoting circular dynamics through the setting of a supply chain that identifies alternative/secondary markets as potential destinations for reused, re-manufactured and repurposed products.

Firstly, the chapter shows in detail the proposed organizational model (Par. 7.1), describing the organization and supply chain relationships. Secondly, the perspective of key stakeholders of the analysed tertiary sectors (exhibition, office and retail) is treated (Par. 7.2, 7.3, 7.4), highlighting the peculiarities of each sector in terms of products and players. Then, the key players and the need of new roles within the current value chain are described (Par. 7.5), stressing the crucial role of "third sector" as an enabling player. Finally, the drivers and barriers occurred to activate the proposed organizational model are pointed out, and further needs and improvements are identified (Par. 7.6).

The promising organizational model discussed in this chapter is based on the opening of alternative and secondary markets for the reuse, re-manufacturing, and repurposing of products, through new relationships between operators within the supply chain. Alternative and secondary markets can create new trading opportunities compared to the primary sales market of the products.

In the previous chapters, two organizational models have been proposed considering the life cycle extension of a product that remains within the same sector of origin: the first model aims at facilitating a series of cycles of use of a product through rental agreements (chapter 5); the second model aims at providing a set of services for the extension of the

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useful life of a product owned by an individual customer, through a loyalty strategy (see Chapter 6).

Otherwise, the model, presented in this chapter, is suitable for all products that: i) cannot be reused for the same purpose and/or in the same field of application, ii) derive from short cycles of use, iii) are (partially) in good condition and with a residual value. Examples of products available for this model are products for customized outfitting not directly adaptable to a second use (e.g. due to not standardized size), and products for offices and retails highly related to the brand image. This proposed organizational model may be mainly suitable for retail, exhibition and offices, characterized by frequent re-layout (related to temporary events, rebranding of temporary retail spaces, or ever-changing workspaces). In these cases, the products are strongly characterized by the brand identity, and not easily feasible for other customers in the same area (retail, exhibition and offices with a corporate image).

The new life of products in alternative or secondary markets may relate to the same use or other functions, but applied in a different sector, such as the residential one (alternative market), or in a low-income sector, such as social housing (secondary market). In the case of reuse, the product can be placed on alternative/secondary market as-is, performing the same function (e.g. a door sold as a door with the same aspect and features of the first life). In the case of re-manufacturing, the product can be placed on alternative/secondary market, for the same purpose of the original one, but with a re-styling of image or a resizing of the dimensions (e.g. a door sold as a door with a different appearance and features compared to the original one, for example with new colours, customization, etc.). In the case of repurposing, the product can be placed on alternative/secondary market (also in other sectors) after a change of the original function (e.g. some parts of a door may be disassembled and used as a table top).

The value of the product in the secondary market can be influenced by some conditions such as: the customer awareness and sensitivity to environmental issues; the lower cost of the reused/re-manufactured/repurposed product compared to a similar new product; the peculiarity of a unique and characterized product (in the case of re-manufacturing and repurposing after an artisanal reworking).

The original manufacturer (or the one who takes care of the set-up, in the case of the exhibition sector) could be interested in these new market opportunities to increase his income.

Otherwise, this scenario can become a new business opportunity for independent re-manufacturers who can create relationships with the poten-

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tial "supplier" of waste products to be re-manufactured (in a win-win perspective).

The proposed organizational model considers a multiple life cycle extension of the product, planning the end-of-life management of the reused/re-manufactured/repurposed product. Hence, in the case of re-manufacturing and repurposing, the product (derived from a first end-of-useful-life) is re-designed to be further reused/re-manufactured/repurposed at the end of the second useful-life (e.g. re-designed for disassembly, reworked with removable and replaceable decorative film).

The re-manufacturers are, therefore, interested in maintaining a relationship with the customer over time and take back the product at the end of the second life (for easily converting it into a new product to sell). Customers receive the "deposit" back upon return products. This promotes the generation of a win-win business relationships between the re-manufacturer and the customer.

The overview of the organizational model based on alternative/secondary markets is presented in Fig. 7.1.

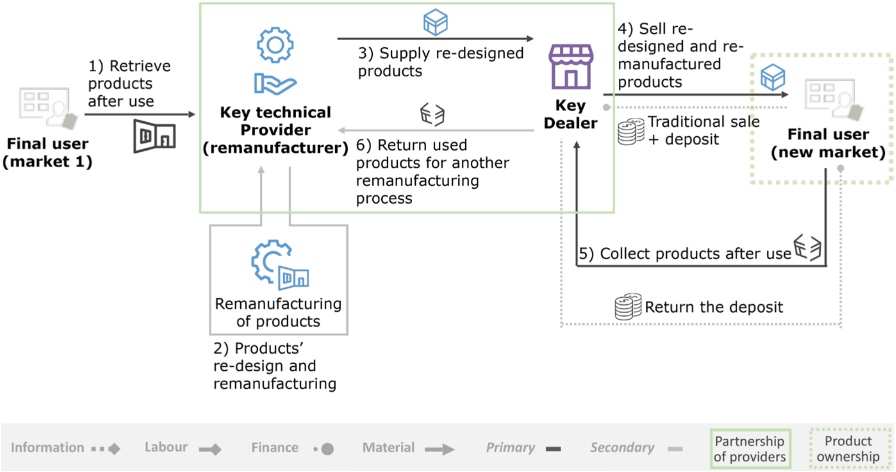

Fig. 7.1 – System map of the organizational model based on alternative/secondary markets for re-manufactured products

The proposed organizational model highlights relevant supply chain relationships established between the independent re-manufacturer and the commercial dealer. The independent re-manufacturer intercepts products

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destined to become waste before their disposal. It has technical capabilities to accomplish the re-manufacturing/repurposing processes related to the products. It autonomously transforms products for alternative/secondary markets. The commercial dealer is supposed to be the intermediary between the independent re-manufacturer and the new costumers. It sells the product and maintains the relationship with the customer (as intermediary) and remains the reference figure of all costumers for returning the products at the end of their useful life (managing the return of the "deposit"). The commercial dealer collects all returned products and brings them back to the independent re-manufacturer (based on a "take back agreement").

In fact, in order to extend the responsibility of the independent re-manufacturer and promote a sustainable circular management of the multiple life cycle, the proposed model considers a "take back agreement" promoted by a "traditional sale plus deposit". The customer, when purchases the product on alternative/secondary market, gives to the dealer a "cash deposit". The costumer will take back his "cash deposit" when he will return to the dealer the product (therefore, the customer is encouraged to return the product to the dealer). The dealer, with a take-back agreement, returns the "second" useful life product to the independent re-manufacturer with the aim of allowing other future processing and further useful life cycle (third life cycle, fourth life cycle, etc.).

As introduced in Chapter 4, the proposed model is based on the key features, summarized as follows:

- original product not designed for re-manufacturing but with facilitating features;
- product procurement based on a surcharge-based mechanism;
- product collection enabled by "collectors" activity;
- independent re-manufacturer;
- product re-designed for re-manufacturing;
- product distribution performed with a dealer intermediation;
- product ownership transferred to the customer;
- different market destination from original product;
- revenue configuration based on deposit-based single payment (with surcharge).

The organizational model was validated in relation to three different sectors (exhibition sector, office and retail) through multiple meetings in the form of "roundtable" engaging different stakeholders representative of each sector. The interaction between the stakeholders allowed to identify

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the network necessary for activating the proposed model. The investigation allowed to define the operators' roles, competences, skills and relationships. Moreover, thanks to the stakeholders' suggestions emerging from the roundtables, potential new markets have been detected.

7.2 Alternative/secondary markets for re-manufactured products in the exhibition sector: the stakeholders perspective

The proposed organizational model considers the possibility to perform circular re-actions on products derived from the exhibition sector, with the aim of placing them on alternative or secondary market, with the same or other possible functions.

The presented model "breaks through" the boundaries of the exhibition sector and assumes it as a source of post-consumer products with high residual value, potentially marketable in a different field. Temporary events like fairs can be important "sources" of secondary materials.

The post-consumer exhibition products may be: products stored in warehouses, with residual technical properties and residual value, that, however, can be no longer sold or rented for exhibition stands due to their high degree of customization (e.g. advertising panels, partitions of customized exhibition stands, carpets); product remnants from exhibition or catering setups, still in good condition, but not usable for further events as not suitable for the events request (e.g. remnants of furniture, remnants of service elements, etc.).

The investigation considers the outfitter (i.e. the operator who produces and provides exhibition products) as a "proactive actor" for re-manufacturing exhibition products, already of his own or coming from other outfitter companies. The organizational model aims at finding new business opportunities in alternative/secondary markets for products destined to landfills, hence for products that represent a disposal cost for outfitters.

To assess the potentiality and criticalities of this model, a group of stakeholders, representing the category of outfitter for temporary events and exhibitions, including the designers and manufacturers of temporary outfittings, were involved in two roundtables.

During the roundtables, the stakeholders were invited to discuss on: the outfitter's ability to accomplish independently the re-manufacture activity; the outfitter interest to open new business towards other sectors (within and outside the construction sector); the feasibility of reverse logistic for placing products at the end of their useful life in other sectors; the level of complexity in establishing a relationship between re-manufacturer and

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designer during the re-design process for the products; the identification of a promising sector to receive re-manufactured/repurposed products (from the exhibition sector); the interest of the exhibition sector to reuse secondary products or to receive re-manufactured/repurposed products from other sectors.

The discussion with stakeholders highlights that the organizational model has a good applicability to the exhibition sector, since the outfitters already have the technical skills, staff and equipment to carry out a potential role of "re-manufacturer".

The outfitter, playing the role of re-manufacturer, does not need additional spaces or additional machineries or additional experiences to activate re-manufacturing processes: in fact, outfitters, generally, are already able to carry out works of resizing, painting, rework, carpentry, etc.

The outfitters, involved in the roundtables, showed a greater interest in re-manufacturing products already of their own, in order to open new business opportunities. Differently, they showed some doubts about re-manufacturing products derived from other companies (in the role of "independent re-manufacturer"). In fact, outfitters do not want to take responsibility for re-manufacturing and selling products derived from other companies, because they do not know the past events of the products, their previous uses and maintenance.

Some re-manufacturing best practices have been already tested by some pioneers of outfitting. In fact, some outfitters, with the support of other skills (in particular designers and assemblers), invent creative solutions to rework products for possible reuse in the same sector (for other fairs, events). This practice is profitable for outfitters because it allows to extend the economic value of the products and to avoid landfill costs as much as possible.

As suggested by the proposed organizational model, outfitters could go over the exhibition sectors, exploring other sectors and secondary markets, establishing steady partnerships with dealers. The outfitters, involved in the roundtables, showed interest in networking with dealers and willingness to take back their re-manufactured products after the "second useful life", in order to accomplish further circular re-actions.

The proposed organizational model highlights the importance of "re-design for re-manufacturing", in order to allow multiple life cycles. The consolidated cooperation between outfitters and the figure of the designer represents an advantage in applying the organizational model to the exhibition sector: sometimes, designers are directly involved in the outfitting companies. Co-creation activities (especially during the executive design) between outfitters and designers are fundamental to allow multiple reuse/

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re-manufacturing processes. This relationship and exchange of information can improve the optimization of the processes of assembling/disassembling, maintenance, transport, and possible reuse/re-manufacturing. The design phase can also re-invent the application of each part of products for alternative sectors (e.g. from PVC sheeting to bags; from Plexiglas panels to tablemats for restaurants). For example, the Covid-19 emergency also required new products. These unexpected requests were satisfied through a redesign and re-manufacturing of some products already owned by the outfitter. Nevertheless, currently the "design for re-manufacturing" does not take place in advance (during the original products design), but it occurs only at the end of product useful life. Hence, there are no best practices in which outfitters put on the market a product already designed to be re-manufactured into something else.

During the roundtable, other issues were discussed: firstly, which could be a promising sector able to receive reworked products (from the exhibition sector); secondly, if the exhibition sector itself can accept the use of reused/re-manufactured/repurposed products, derived from other sectors.

Regarding the first issue, stakeholders detected retail, hotels and residential sectors as promising alternative markets.

Concerning the second issue, stakeholders declared an interest for reused/re-manufactured/repurposed products coming from other sectors. In fact, the exhibition sector is interested in the choice of circular practices for a green image, pursuing the sustainability of their exhibition stands.

Stakeholders suggested the introduction of a sort of "label" to show to the wide public the commitment of the company in the context of circular economy. In their opinion, this "label" can represent a boost for the reuse of secondary materials or re-manufactured and repurposed products.

7.3 Alternative/secondary markets for re-manufactured products in the office sector: the stakeholders perspective

The application of the proposed organizational model in the field of office sector, regards the possibility to perform circular re-actions on post-consumer products derived from office sector, with the aim of placing them on alternative or secondary markets, with the same or other functions.

The post-consumer products derived from office sector may be: false ceilings, floor finishing, internal wall systems, doors, partitioning, furniture, coming from spaces renovation activities. In the occasion of renovation activities, products with residual value and technical performance quality are generally disposed to landfill. In fact, renovation of offices,

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often, are not related to the degradation of the products, but to the request of restyling of corporate image or of re-layout of spaces.

Different stakeholders of the office-building value chain were grouped in a roundtable, in order to assess the potential applicability of the organizational models to the office sector. The roundtable involved three players with different operational roles within the office sector: the manufacturer side, the industry association and general contractor side. The selection of different players responds to the need to collect information from an enlarged set of stakeholders, enriching the spectrum of perspectives on potential implementation of re-manufacturing opportunities.

During the roundtable, the stakeholders were invited to discuss on: the identification of a key-operator, already existing in the current value chain, capable to autonomously carry out re-manufacturing activities; the producers availability to allocate their end-of-life products towards other sectors (within and outside the construction sector); the feasibility of a reverse logistic for collecting end-of-useful-life products; the identification of promising sectors able to receive reused/re-manufactured/repurposed products (from the office sector); the interest of office sector itself to reuse secondary products or to receive re-manufactured/repurposed products from other sectors.

The stakeholders highlight the lack, in the current value chain within the office sector, of a key figure already able to cover the role of independent re-manufacturer. Moreover, the stakeholders pointed out the difficulty to establish a new value chain aimed at activating a revers logistic for collecting end-of-life products. In fact, currently the relationship of operators in the office sector is fragmented and the cooperation between a contractor and a re-manufacturer does not exist.

However, the stakeholders involved in the roundtable showed interest for the activation of circular strategies, opening a discussion about the potentiality of the proposed organizational model.

To activate the organizational model proposed, the stakeholders underlined the crucial role of the facility manager, who manages the layout of office spaces and the maintenance/replacement of products inside the tertiary buildings and know the inventory of product stock. Another important player is the contractor, who have the role of removing fit-out during internal spaces renovations. These key operators have the knowledge of the characteristic of the products derived from the office sector, and of their potentiality to be collected, reworked and destined to alternative/secondary markets.

According to stakeholders, facility managers and/or contractors of office buildings may be linked to an "independent re-manufacturer", who

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could play a new role in the value chain, after the first life of office products. In fact, industrial manufacturers are not able to perform the role of independent re-manufacturer, because they need to work standardized products (industrial production) and constant material flows, with an established supply chain. The end-of-life products derived from office space are different in types, sizes, functions, and conditions/maintenance state (e.g. signs of wear, visible imperfections) depending on the first service life and usage. Furthermore, these products generate non-constant flows, heterogeneous quantity and quality of different types of products, made of different types of materials, coming from different place of urban area.

Hence, the independent re-manufacturer should be a flexible player, with extensive re-manufacture capabilities in terms of design skills, supporting technologies, machineries and human resources (e.g. artisans). Furthermore, he should manage the logistic for collecting end-of-useful-life products, and the space for storing those products, before giving them multiple new life cycles.

For enabling the value chain beyond the first use, the contractor and/or the facility manager should have the task of communicating the availability of end-of-useful-life office products to the independent re-manufacturer. The exchange of information facilitates the opportunities for the collection of "promising for re-manufacturing" products, before they become "waste".

Stakeholders feedbacks highlight the crucial role of the "products re-design" as a key aspect to enable the alternative/secondary market of products. Indeed, industrial manufacturers oppose the sale of their branded products, with the same image (e.g. a designer shelf, a peculiar false ceiling or wall cladding, that are produced exclusively by them), to alternative/secondary market, to avoid competing mechanisms.

Hence, the re-design process is fundamental for the restyling of products, through re-manufacturing or repurposing activities. In addition, the "re-design for re-manufacturing" enables the effective possibility of further products re-manufacturing or repurposing.

Regarding the identification of a promising sector able to receive reused/re-manufactured/repurposed products from the office sector, stakeholders showed interest in a disruptive inter-market approach. Indeed, stakeholders perceive as a great opportunity the identification of alternative/secondary markets in other sectors (different from office sector). In particular, stakeholders consider the residential sector as a possible alternative market, due to the increasing trend of remote working, following the Covid-19 pandemic. Otherwise, stakeholders identify the living/working spaces of low-incoming population, as a possible secondary market for reused/re-manufactured/repurposed products.

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Regarding the potential interest of office sector itself to reuse secondary products or receive re-manufactured/repurposed products from other sectors, the stakeholders expressed hesitation. In fact, office sector is not interest to reuse secondary/re-manufactured/repurposed products coming from other sectors, due to the strict rules on safety in the workplace that require the use of certified and high-performance products. Moreover, the corporate image requires the use of highly customized colours, materials and shapes, often incompatible with the reuse of secondary products.

7.4 Alternative/secondary markets for re-manufactured products in the retail sector: the stakeholders perspective

The application of the proposed organizational model in the field of retail sector, regards the possibility to perform circular re-actions on post-consumer products coming from retail sector, with the aim of placing them on alternative or secondary markets, with the same or other functions.

The post-consumer products from retail sector can include customized products that can no longer be reused for the same purpose, such as: furniture, interior partition, coverings, and finishing products. Furthermore, the finishing products of the interior spaces of luxury shops are constituted by high-quality materials (e.g. valuable fabrics), characterized by exclusive manufacturing process (e.g. panels with 3D textures).

The retail spaces are renewed approximately every two years, and the finishing products are replaced every season (due to the need to renew the image as marketing strategy). The frequent stylistic renewals create a quantity of high-quality material waste, with high residual value and good technical performance, that are typically sent to landfill.

To assess the potentialities and criticalities of the organizational models related to retail sector, roundtables were organised involving a set of stakeholders, including: designers and manufacturer of retail outfitting products; general contractor of franchising stores, belonging to large and smaller companies; general contractor of its own retail stores (who manages the opening and closing of retail stores for major brands); third sector stakeholders as well as structured social cooperatives active in manufacturing and in reverse logistics (of different sectors, from food to clothing, etc.). The involvement in the roundtable of stakeholders with different roles in the supply chain and different features (e.g. organization, size, interests, markets, core business, etc.) aims at developing a network with collaborative synergies with respect to the proposed circular models.

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During the roundtables, the stakeholders were invited to discuss on: the interest of producers/general contractors/social cooperatives to accomplish re-manufacturing activity; the possibility to allocate retails end-of-life products towards other sectors (within and outside the construction sector); the feasibility of reverse logistic for collecting end-of-useful-life products; the identification of a promising sector able to receive re-manufactured/ repurposed products (from the retail sector); the interest of retail sector itself to reuse secondary products or to receive re-manufactured/ repurposed products from other sectors.

Similarly to the office sector, the applicability of the proposed organizational model to the retail sector requires the identification of an operator who covers the role of "independent re-manufacturer", and to establish new supply chain relationships for reverse logistics activation.

The stakeholders discussion highlights the crucial roles of the general contractor for franchising stores and stores affiliated to major brands. In fact, these key operators know the frequency of stores renovation, opening and closing. According to stakeholders, the activation of a reverse logistics is possible by establishing a relationship between these key operators (general contractors and managers) with an "independent re-manufacturer".

The criticality is the inconstant and heterogeneous products flows from retail sector (greater than from the office and exhibitions sectors). The outgoing materials are in small quantity, especially from the small size stores. However, the multiple stores of major brands are outfitted with the same "image", hence using the same products and components: this could be an advantage for collecting similar products. Nevertheless, the multiple stores of major brands are generally distant from each other, consequently the collection of homogeneous materials are difficult and expensive.

According to stakeholders, the feasibility of the proposed organizational model depends on the identification of an actor who can play the role of "independent re-manufacturer". Once again, the independent re-manufacturer should have the flexibility to re-manufacture heterogeneous and not constant quantities of products. Moreover, it is necessary to identify an actor able to manage the products logistics, collecting different products spread throughout the territory.

The retail outfitting producers are unable to play the role of "independent re-manufacturer" since they have an "industrial" production approach, capable of processing only standardized products. Among the stakeholders involved in the round table, the third sector demonstrated interest to play the role of independent re-manufacturer, collector and dealer, capable also of the reverse logistics activation of products derived from tertiary sector.

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Stakeholders of retail sector, involved in the roundtable, showed their interest in delivering end-of-useful-life products for activating circular dynamics. The identified potential alternative or secondary markets for reused/re-manufactured/repurposed products (from retail sector) are: the residential sector and hotel (in particular for furniture or other mobile outfitting), and retails focused on low-cost products (outlet or secondary low-cost shops). However, luxury brands prevent from reusing their shops finishing products to stores in secondary markets, because their products are often highly customized and representative of the company luxury image (both furniture and space plan finishing products). So re-manufacturing and repurposing are the possible scenario, avoiding the reuse of the products as they are.

Regarding the potential interest of retail sector itself to reuse secondary products or receive re-manufactured/repurposed products from other sector, the stakeholders of retail sector expressed a double position. On the one hand, the reused/re-manufactured/repurposed products may interest (as marketing strategy) the retail companies aimed at communicating sustainability message. On the other hand, general contractors and stores brand managers denied the possibility to create a synergistic reuse between stores belonging to the same brand. Moreover, luxury shops are unwilling to use secondary or re-manufactured/repurposed products because they fear that these circular re-actions are not in line with the brand luxury image.

7.5 The involved actors: new roles, skills, relationships, and the inclusion of the "third sector"

The analysis carried out through the interaction and dialogue with the tertiary sectors stakeholders (exhibition, office and retail) allowed: i) to understand the dynamics of the supply chain and the level of interest of the market players; ii) to identify the key players of the current value chain or the need of new key players to activate the proposed organizational model.

The current key players identified are: within the exhibition sector, the outfitters; within the office sector, the general contractors or facility managers of office spaces; within the retail sector the general contractors for franchising stores and stores affiliated to major brands. These actors have particular importance because they manage the temporary use of spaces or the frequent renewal and requalification processes that characterize the tertiary sector and are aware of the input and output flows of products.

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These key players are willing to establish relationships with new players, who can play the role of "independent re-manufacturer" and manage the reverse logistics, to activate circular processes. Only in the case of exhibition sector, the existing outfitters may be willing to play the role of "independent re-manufacturer", because they are often equipped in terms of machinery and technical skills. However, the existing outfitters have expressed their willingness to re-manufacture only the products already belonging to them.

The exhibition and retail sectors are potential areas of demand for reused/re-manufactured/repurposed products, in relation to the marketing driver of the "sustainable image". Furthermore, low-cost secondary markets are another potential area of demand, in particular in the residential sector.

To enable the proposed organizational model in all three sectors, the need to introduce new key players has emerged. The new key players perform the following process: i) the collection, transport and storing of heterogeneous post-consumer products; ii) the products "re-design for re-manufacturing"; iii) the products re-manufacturing and re-proposing; iv) the product reselling.

In this case, third sector emerges as a crucial player to trigger circular processes, related to its ability to carry out all aforementioned four key activities needed to activate the proposed organizational model.

In particular, roundtables results identify the important role of the third sector in the re-manufacturing process for the ability to manage small non-constant quantities of products (such as small group, non-standardized products with different status conditions). Moreover, the third sector is recognized as an important subject for the capabilities to create flexible networks of artisans and to activate second-hand markets for reused, re-manufactured and repurposed products. The third sector, generally, has a synergistic, capillary and structured network of operators, within cooperatives or artisanal network already present in the territory; for this reason, third sector has the capability to activate a re-manufacturing network and define a series of organizational rules and reverse logistics procedures, and costs and salary agreements. This network exploits the shared know-how, tools and contacts to offer re-manufacturing works and related services, guaranteeing circularity on secondary markets.

In addition, the third sector often has relationships with designers who re-design solutions in order to reuse/re-manufacture/repurpose solutions for secondary markets. Moreover, the third sector often has an organization that includes both managerial skills for re-manufacturing processes (Re-manufacturing Manager) and craft skills that enable customized processing of products reuse/re-manufacturing/repurposing.

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Consequently, the third sector can overcome the current barriers due to the fragmentation of the chain, creating and establishing a dynamic value chain of the distribution networks (reverse logistics) and the (online) market for sales.

Fig. 7.2 defines the organizational model including the third sector, to enable the recovery of secondary materials from the tertiary sector and the opening of new markets.

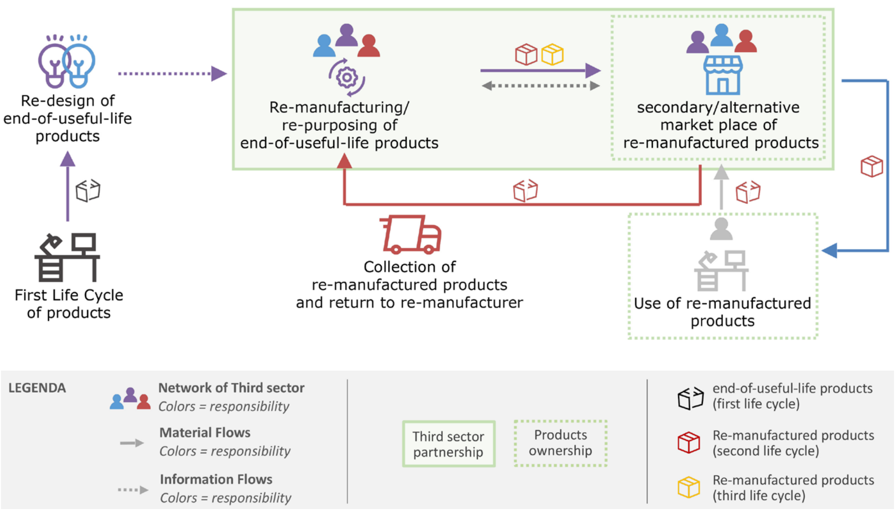

Fig. 7.2 - System map of the organizational model based on alternative/secondary markets for re-manufactured products, introducing the "Third Sector" as enable player

A doubt expressed by the third sector, during its involvement in the roundtables, concerns the assumption of the risk of reworking the products without being sure of the sales potential. Therefore, the organizational model aims at achieving a win-win procedure supported by digital technologies that allow: i) the exchange of information about the available post-consumer products; ii) the advertising of potential re-manufactured products; iii) the identification of "secondary market buyers" in advance (before activating the reverse logistic of collection and the re-manufacturing processes). In this way, the risk that the re-manufactured product will not be sold is limited and the reworking intervention can also be oriented by the preferences that emerged from the customers in the secondary market.

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The main issue of the proposed organizational model based on win-win procedure supported by digital technologies, are:

1. publication on a platform, by the operator who has products/lots to be disposed (coming from the tertiary sector, fittings, retail, temporary shop, hospitality, etc.), of a report containing product information (a picture of the product, the location, the number of pieces, technical data from the manufacturer, dimensions, etc.);
2. analysis by the "independent re-manufacturing" manager and first feasibility assessment, with a possible development of the virtual twin of the product to simulate configurations (in relation to maintenance, transformation, adaptation, re-functionalization, etc.) and estimate of the necessary activities, human resources to be involved, selling price, etc.;
3. proposal of product re-manufacturing alternative solutions through the digital platform with definition of the related price, technical characteristics, sales area, duration of the offer, etc. in order to find in advance a possible customer;
4. expression of interest by possible buyers;
5. upon reaching the minimum threshold of buyers, acceptance of the products to be re-manufactured, activation of the team for eventual products collection, activation of the network of artisans for re-manufacturing activities;
6. at the conclusion of the re-manufacturing activities, delivery of the re-manufactured product to the client;
7. thanks to the "traditional sale plus deposit", at the end of the second life, collection of the re-manufactured products by the independent re-manufacturer of third sector (since the third sector can manage both the re-manufacturing phase and the sales phase, the "take back" logistics process becomes even more efficient and smart).

7.6 Barriers, drivers and future perspectives

The stakeholders involved in the roundtables validated the potential applicability of organizational model to tertiary sector, identifying the actor roles, competences, skills, relationships, and the potential alternative or secondary markets. Furthermore, they allowed the identification of drivers, barriers, and potential perspectives.

Exhibition, office and retail sectors are characterized by different structure and organization of relationship and roles along the value chain;

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instead, the identified drivers and barriers are similar among the three tertiary sectors.

First of all, the stakeholders identified the drivers that boost the activation of the organizational model. In particular, the underlined advantages towards circularity regard the reduction of the disposal costs, and the improvement of "corporate image" by pursuing environmental sustainability objectives. Following, another advantage of reusing/re-manufacturing/repurposing products is related to the high prices of raw materials, that had particularly increased after the Covid-19 pandemic. The circular re-action of construction products can represent an economic boost for construction, which is currently hampered, due to the increase in the prices of raw materials and the difficulty of supplying products. The activation of sustainable circular processes can therefore promote new local organizational opportunities and new job opportunities for operators in the construction value chain, reducing dependence on imported materials. Secondly, the stakeholders discussion was useful to identify the main barriers (described below) concerning in particular: i) highly customized and branded products; ii) uncertainty of second materials flows; iii) and the lack of end-of-life products certifications.

– *Customized and branded products*. The short-life cycle products of tertiary sector (exhibition, office and retail), from the interior finishing to the furniture, are generally highly customized on the image of the company. Specifically, the products customization is one of the main barriers identified. This limits the possibilities to reuse the product in the same sector, but also in secondary markets (because a branded product cannot be reused as-is). Many companies protect the design of the original products through the presence of a design patent or a registered trademark. In this case, the product cannot be re-manufactured assuming an image or shape similar to the original one. Hence, re-manufacturing is hindered by product company policies that often entail as unavoidable end-of-life scenario the product disposal, neglecting possible circular alternatives. Another aspect is the preference of the customers for highly customized solutions (e.g., corporate branding requests to customize office components), either for the products and the occupied space layout. Such factors hinder the possibility of reusing product in the same sector and, at the same time, hinder the reuse of regenerated products within these sectors, because they may not combine with the needs of the customer and the space layout. In order to overcome this barrier, the reworking of components, modifying their image, and the destination to alternative/secondary markets,

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appears to be a possible perspective that could allow the proposed organizational model.

– *Uncertainty of the materials flows.* Another emerging issue is represented by the variable volume of material flows coming from renewal or demolition processes of tertiary buildings. In many cases, the inconstancy and the reduced quantity of secondary products are not sufficient to justify new industrial processes, also due to the unstable demand, difficult to predict in terms of quantities and product typology. In order to overcome this barrier, the creation of networks of artisans, able to manage non-stable flows of different type of products, could be a possible solution.
– *Lack of certification.* Another significant aspect concerns the availability at the end of the service life of the product labels and certifications, that define the characteristics and performances of the product. To this is added the actual characteristics and the residual qualities of end-of-useful-life products, that are typically unknown. Therefore, the impossibility to guarantee the products residual performance. The loss of information about the original characteristics of the product and about its life-cycle involves difficulties to maintain the product value and its market potential. The operators are not willing to take responsibility for placing re-manufactured products on the market starting from products whose characteristics they do not know. The unknown performances of products are measurable and verifiable through a material characterization process, that often makes reuse economically unsustainable. This aspect acquires particular relevance in the proposed organizational model, since for placing secondary products on alternative/secondary markets the product certification is required by legislation and customers. In this regard, the current regulatory framework does not provide support for obtaining adequate certifications for secondary products. Therefore, often, products fall on secondary destination with an alternative function (downgraded), that does not require precise and high performances.

To overcome the listed barriers, possible supporting solutions concern: i) the traceability of products life cycle, ii) the application of a life cycle design approach, iii) the networking creation among stakeholders, iv) the improvement of regulatory framework, v) and the application of life cycle cost and life cycle environmental assessment.

– *Traceability of product life cycle.* A better traceability system allows to know the original characteristic of the product (registering the certi-

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fications), the type of rework/maintenance already undergone, and in what conditions the end-of-useful-life product is. In this context, the digital supporting tools like BIM (Building Information Modelling) and materials passport (see Chapter 13) should be significant enabling tools. Moreover, the monitoring of the products flows leaving the tertiary sectors, useful for feeding a supply chain of repurposed materials destined for the secondary market, is necessary. This is because re-manufacturing companies need to know the quantity and availability of product flows in order to predict the potential target market and identify the real demand for secondary materials, necessary to start up the organizational model. Knowing the availability of end-of-useful-life products and their potential uses in advance, a re-manufacturer may willing to activate a re-manufacturing and market process. This aspect could be supported by online trading platforms.

- *Life cycle design*. The "re-design for re-manufacturing" of products represents a fundamental process for the success of the organizational model. In fact, generally customized end-of-useful-life products need to be modified and re-manufactured in order to find alternative/secondary markets. Only through a "life cycle thinking" design, it is possible to foresee a re-manufacture process that allow further multiple product life cycle. To enable product repurposing and the possibility of future re-manufacturing, it is important to follow life cycle design approach, favoring disassembly technologies (e.g., dry assembly, reversible customizations systems, etc.) and durable materials, allowing the extension of the useful life of the product and its potential for reuse/re-manufacturing/repurpose.
- *Networking across the value chain*. Flexible types of agreements between different companies are necessary to encourage networking across the value chain. Through networking, the independent re-manufacturer can intercept a critical mass of secondary materials, and a substantial purchasing network. Furthermore, a networking among re-manufacturing companies can also be very important to allow the improvement of practices and trigger common investments, for example by activating consortia to purchase certain machinery or tools necessary to increase re-manufacturing/repurposing activities.
- *Regulatory framework*. An identified need concerns the regulatory tools and incentives oriented to promote re-manufacturing activities and "green" requirements within tender procedures. In particular, the involved offer-side and demand-side stakeholders expressed the shared view on the strategic role of the green procurement to raise awareness on circular practices. In addition, it is necessary to develop a regulatory

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framework, aimed at defining new procedures and new roles to certify re-manufactured products (e.g. controlled value chain label). In parallel innovative procedures and methodological guidelines are necessary to understand the real feasibility of product re-manufacturing and to support stakeholders towards circular re-action activities.

– *Life cycle cost and environmental assessment*. The stakeholders highlighted the need to evaluate in advance the reverse logistic costs, before activating products re-manufacturing processes. Predicting costs is important for the entire value chain, in order to guarantee the profit of each player and to sale secondary products on a competitive and attractive market. In parallel, it is necessary to assess in advance the effective sustainability of the circular organizational models. Hence, it is necessary to evaluate the entire product life cycle and consider the possible extension for multiple useful life, considering the reuse of components, re-manufacturing and repurposing with a cradle-to-cradle perspective.

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Part III

Insights

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8. *Design guidelines for product re-manufacturing*

by *Luca Macrì, Carlo Vezzoli*

8.1 Background literature and practices about design guidelines for re-manufacturing

The chapter focuses on the topic of design for re-manufacturing (DfRem), presenting a set of guidelines that can facilitate product re-manufacturing processes toward more circular and sustainable organizational models in specific contexts, with particular attention on the tertiary sector.

The concept of design guidelines to ease re-manufacturing is inherently linked with the evolution of design for re-manufacturing (DfRem) itself and in particular with the end of the eighties, when the relevance of early design stages toward the prevention of barriers during re-manufacturing processes started to be observed and acknowledged (Hatcher *et al*., 2011; Ijomah *et al*., 2007; Keoleian and Menterey, 1993; Manzini and Vezzoli, 1998; Yang *et al*., 2015). Indeed, research interests started to focus on how to intervene during early stages of the product development process in order to satisfy re-manufacturing requirements in advance, i.e. adopting DfRem tools like guidelines (Vezzoli, 2018; Yang *et al*., 2015).

The following lines go through some peculiar approaches adopted along the years for the development of product DfRem guidelines, in order to outline the framework behind the guidelines presented in the next section.

Early contributions in this sense were mainly focused on comparing proposed designs to current re-manufacturing standard processes in order to develop metrics and tools to improve the ease of re-manufacturing (Ijomah *et al*., 2007). This included a DfRem-specific approach together with other aligned and complementary approaches for re-manufacturing, like design for product lifespan extension. It is the case of RemPro matrix

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by Amezquita *et al.* (1995), in which some selected product properties (e.g. ease of identification, ease of access, ease of separation) are crossed with re-manufacturing steps (e.g. inspection, cleaning, disassembly). A slightly different approach was adopted in the RePro 2 tool by (Gehin *et al.*, 2008), in which proposed design are supposed to be compared with 'Re-manufacturable Product Profiles' in order to detect and enhance preferable features to facilitate re-manufacturing.

Other research efforts tried to bring together the literature on DfRem heuristics and some best practices from the industry, in order to develop guidelines that are more and more relevant for re-manufacturing practices. It is the case of Prendeville (Prendeville *et al.*, 2016), who conducted a literature review on existing general DfRem guidelines, identifying four main design areas to facilitate re-manufacturing and successively making a detailed comparison with design features of twelve best practices from different industries. The results highlighted a still very limited application of DfRem guidelines in the industry, mainly because the design potential at the early stages of the product development is overlooked under many points of view (e.g. marketing, innovation, engineering).

More recently, the research focus on specific DfRem contexts has also raised: a study by Shahbazi *et al.* (2021) focused on the potential use of automation technologies to enhance re-manufacturing and how to design products in order to facilitate the process. Through an empirical study based on a case study, the authors put together not only insights from product design evidence, but also about the specific context of automation, in order to facilitate its implementation by specific design guidelines and enhance remanufacturability.

In the outlined framework, active contribution came also from LeNSlab Polimi, a team based in Politecnico di Milano that has been doing research, consultancy and education on Design and System Innovation for Sustainability (DIS) for more than twenty years in multiple international research projects, as part of the Learning Network on Sustainability (LeNS)[1].

Over the years, the group actively contributed to the definition of Life Cycle Design (LCD) guidelines to facilitate re-manufacturing or broadly product lifespan extension – e.g. design guidelines facilitating upgrading and adaptability, maintenance, repair, and disassembly (Vezzoli, 2018). The guidelines – as well as tools containing them – have been mostly outlined

1. An international network of Higher Education Institutions aimed at the development and the diffusion of the Design for Sustainability (DfS) discipline in worldwide curricula with a multipolar, open and copyleft ethos.

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and refined through several company consultancy projects on Life Cycle Design, resulting in outcomes that have been also integrated into companies' product development processes, e.g. handbook of LCD guidelines. This is also due a structured and validated methodology with solid foundations in the consultancy experience with several companies (e.g. NECTA Vending Solutions, Kone (elevator), Bonaveri), that have been successively formalized and improved over the years to elaborate product-specific LCD guidelines to be more effective in company practice than general ones (Vezzoli and Sciama, 2006).

All this considered, the next paragraph introduces a set of design guidelines to facilitate product re-manufacturing, selected as promising for tertiary architectures products in the context of the research Re-NetTa (Re-manufacturing Networks for Tertiary Architectures) (see Chapter 1).

8.2 Toward specific design guidelines for re-manufacturing: a selection in the context of tertiary architecture

In this section, a set of design guidelines for re-manufacturing and broadly for lifespan extension (connected to the former) is presented as a selection from the ones developed and used in LCD company consultancy by the LeNSlab Polimi (Vezzoli, 2018). This is made as far as they could be extended (as they are or with adaptations) to short-time architectural components in the tertiary sector. In this sense, a structured process to move from the selected general Life Cycle Design guidelines toward specific ones – e.g. to elaborate guidelines for the design of a precise typology of building components – is also introduced at the end of the section.

The guidelines selection has been carried out along with activities and learnings from the above-mentioned Re-NetTA project, which allowed to gather different inputs from multiple sources. Among the others, relevant insights came from: a desk research on international best practices in terms of business and organizational models based on design for product lifespan extension (see Chapter 3); interviews to practitioners from different areas in the tertiary architecture sector – exhibitions, office, retail (see Chapter 5,6,7); multiple roundtables with stakeholders and practitioners from the industry (see Chapter 5,6,7). Here below guidelines are introduced and listed.

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8.2.1 *Design guidelines for re-manufacturing*

The first bunch of selected design guidelines gathers the ones specifically aimed at facilitating re-manufacturing processes, which means to design in order to facilitate the re-collection of used products as well as to make them suitable for storage, since they will be reintroduced into a new structured industrial process. In this sense, design interventions related to easy disassembly operations would be appropriated and are presented as the last group of this section. Guidelines are:

- Design and facilitate removal and substitution of easily damageable components;
- Design structural parts that can be easily separated from external/visible ones;
- Provide easier access to components to be re-manufactured;
- Calculate accurate tolerance parameters for easily damageable connections and components;
- Design for excessive use of material for easily deteriorating surfaces.

As anticipated, the set contains also other guidelines for product lifespan extension, since they could be potentially connected with re-manufacturing. It is the case of design guidelines facilitating reuse, upgrading and adaptability, maintenance, repair, and disassembly.

8.2.2 *Design guidelines for reuse*

To design for product reuse means to preserve its conditions and facilitate the transition toward a second end-user, which include all the maintenance and repair operations to assure its integrity. Guidelines are:

- Increase the resistance of easily damageable components;
- Arrange and facilitate access to and removal of retrievable components;
- Design modular and replaceable components;
- Design components according to standards;
- Design reusable auxiliary parts.

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8.2.3 Design guidelines for facilitating upgrading and adaptability

The easy upgrade or adaptation of products is particularly important in terms of Life Cycle Design because allows to extend their lifespan even in case of changing conditions (technological, cultural, geographical etc.). In particular, speaking about eco-efficient upgrade we refer to interventions in which a significant part of products stays unaltered. Differently, designing for adaptation is meant as making products suitable to be continuously used in relation to environments that are changing. Guidelines are:

- Enable and facilitate software upgrading;
- Enable and facilitate hardware upgrading;
- Design modular and dynamically configured products to facilitate their adaptability for changing environments;
- Design multifunctional and dynamically configured products to facilitate their adaptability for the change in individuals' cultural and physical backgrounds;
- Design products that are upgradeable and adaptable on-site;
- Design complementary tools and documentation for product upgrading and adaptation.

8.2.4 Design guidelines to facilitate maintenance

Designing to facilitate precautionary adjustments through maintenance allows to avoid costs and environmental impacts related to product repair or substitution (which cause untimely disposal). Indeed, maintenance operations are often crucial to assure products proper durability (e.g. proper protection, cleaning etc.).

- Simplify access to and disassembly of components to be maintained;
- Avoid narrow slits and holes to facilitate access for cleaning;
- Prearrange and facilitate the substitution of short-lived components;
- Prearrange the usage of easily available equipment;
- Equip products with diagnostic and/or automatic diagnostic systems for maintainable components;
- Design products for easy on-site maintenance;
- Design complementary maintenance tools and documentation;
- Design products that need less maintenance.

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8.2.5 *Design guidelines to facilitate repair*

High value of a product can be recovered through repair operations after a damage. Design to facilitate this process means to reduce as much as possible the complexity and the costs related to the required interventions. Guidelines in this sense are:

- Arrange and facilitate disassembly and reattachment of easily damageable components;
- Design components according to standards;
- Equip products with automatic damage diagnostics system;
- Design products for facilitated on-site reparation;
- Design complementary repair tools, materials and documentation.

As anticipated, here below are described also a selection of the guidelines for Design for Disassembly (DfD), since they are useful to make the separation of either parts or materials easier and more convenient. Indeed, the facilitation of parts separation makes product re-manufacturing, reuse, maintenance, repair, upgrade and adapt easier.

8.2.6 *Design guidelines to facilitate disassembly*

A first set of guidelines to facilitate disassembly is about *minimising and facilitate operations of disassembly and separation*:

- Overall architecture:
  - Prioritise the disassembly of more easily damageable components;
  - Prioritise the disassembly of the parts more subject to technological and/or aesthetic obsolescence;
  - Engage modular structures;
  - Divide the product into easily separable and manipulable subassemblies;
  - Minimise hierarchically dependent connections among components;
  - Minimise different directions in the disassembly route of components (and materials);
  - Increase the linearity of the disassembly route;
  - Engage a sandwich system of disassembly with central joining elements.
- Shape of components and parts (in case of automatic disassembly):
  - Avoid difficult-to-handle components;

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  - Avoid asymmetrical components, unless required;
  - Design leaning surfaces and grabbing features in compliance with standards;
  - Arrange leaning surfaces around the product's centre of gravity;
  - Design for an easy centring on the component base.
- Shape and accessibility of joints:
  - Avoid joining systems that require simultaneous interventions (on more than one joint) for opening;
  - Minimise the overall number of fasteners;
  - Minimise the overall number of different fastener types (that demand different tools);
  - Avoid difficult-to-handle fasteners;
  - Design accessible and recognisable opening for dismantling;
  - Design accessible and controllable dismantling points.
- The second and last set of selected guidelines that facilitate disassembly are related to the *engagement of reversible joining systems*:
  - Employ a two-way snap-fit;
  - Employ joints that are opened without tools;
  - Employ joints that are opened with common tools;
  - Employ joints that are opened with special tools, when opening could be dangerous;
  - Design joints made of materials that become reversible only in determined conditions;
  - Use screws with hexagonal heads;
  - Prefer removable nuts and clips to self-tapping screws;
  - Use self-tapping screws for polymers to avoid using metallic inserts.

As already mentioned, although the presented set of guidelines is a selection of the ones that could be relevant for the tertiary construction sector, the highest effectiveness to enable re-manufacturing practices would be given with more specific guidelines in relation to the product to be designed. To give a more precise idea of the shift from general to specific Life Cycle Design guidelines, please refer to the following example:

General LCD guideline: Design multifunctional and dynamically configured products to facilitate their adaptability for changing cultural and physical individual backgrounds.

Product-specific LCD guideline: Design reconfigurable office walls that can adapt to changes in relation requirements, such as with adjustable corners or length extensions, e.g. by using rotating edge hinges.

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Even though the focus of the chapter is not to outline a methodological framework, it is useful to introduce an abstracted example of the process behind guidelines specification, to enhance further research and practice in the specific context of short-term components for tertiary architectures. As anticipated, the process has solid foundations in consultancy experiences that have been successively formalized and improved over the years (Vezzoli and Sciama, 2006).

Going step by step, for a proper specification of Life Cycle Design guidelines a preliminary assessment of the environmental impact (either qualitative or quantitative) of the product life cycle should be conducted, as well as a consequent prioritisation of LCD strategies to reduce the overall impact. This framework represents the knowledge basis for a successive collaborative workshop, usually involving expert stakeholders in relation to the specific product or sector. After being updated about the assessment result and the prioritisation of LCD strategies, the core activity of the workshop is a structured process that is adopted for each guideline taken into analysis, allowing participants to apply a variety of specifying actions: integrate a guideline in relation to any precise product or typology; add a new guideline related to any precise product or typology; add note/remainder related to any precise product or typology; erase a guideline. As a result of the workshop, a draft of specific guidelines is achieved, followed by a further stage of review and refinement to integrate final improvements.

In order to bring further the connection between the presented guidelines and the practice of re-manufacturing in the tertiary architecture sector, the next session goes in depth with a series of examples, able to exemplify and clarify the meaning of some relevant guidelines.

8.3 Guidelines and examples to facilitate Design for Re-manufacturing in the tertiary architecture sector

8.3.1 Gispen furniture

A first example (Gispen, 2022; LeNS International, 2022) to better understand guidelines in practice is represented by some product collections designed by of Gispen, a dutch brand producing furniture and outfitting products for different kinds of environments (e.g. education, healthcare, office). Looking at the company's chair collection, it is reported that the design is based on a 75% of standard components that are universal for other product groups, such as different chairs, bar stools or tables. For

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example, the backrest of a chair can also become the backrest of a bar stool. In other words, the modularity of components and their ease to be replaced helps to extend product's lifespan and could be valuable also for re-manufacturing, since it facilitates the replacement of parts for required rework operations. The backrest can be replaced or swapped on site by one person within ten minutes, without causing any damage, due to one single screw connection. Moreover, material blends are avoided, and the steel frame is separable from the wood and foam parts, as well as from the cover made of fabric. Gispen goes also beyond furniture, adopting the same approach even to higher scale solutions like conference room fittings, which are again designed to be modular and can be constantly re-arranged.

The main DfRem guideline applied in the example is the *design of modular and replaceable components,* which is actually a complementary guideline that could be valuable for many different processes to extend the product lifespan, e.g. reuse, upgrade, adaptation and in some cases even maintenance and repair. This is coherent with feedbacks received from the industry, since modularity turned out to be one of the most applied concepts in the industry and well as a desirable design approach for interviewed stakeholders and practitioners within the Re-NetTA project. It is implicit that the example presented could be also connected to other guidelines among the ones presented, e.g. *design modular and dynamically configured products to facilitate their adaptability for changing environments; design components according to standards etc.*

8.3.2 Brummen Town Hall

The second selected case (RAU Architects, 2013) to exemplify some presented guidelines is the Brummen Town Hall designed by RAU Architects and Turntoo. Due to concerns over frequently shifting municipality borders, the municipality of Brummen commissioned a building for a service life of 20 years. Thus, the design approach applied by providers was to make it as a 'raw material depot' based on the possibility of retrieving all the building products after disassembly. In this sense, for example, the use of concrete has been minimized in favor of prefab timber components and different types of reversable joints allow to collect and reuse 90% of the building. Moreover, each component's data has been identified and registered, in order to allow producers to plan its destination after disassembly and arrange the logistics accordingly.

In this case, the main design guideline referred to the example is from Design for Disassembly, and in particular it focuses on *minimising and*

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facilitate operations of disassembly and separation. Indeed, as anticipated, the dismantling process is crucial to enable proper re-manufactuiring, since it deeply affects logistic processes and costs. As it was observed from the direct engagement of stakeholders, this is particularly important for outfitters, who play a specific role at the disassembly stage of the value chain, and it clarify how much their involvement in the design stage would be relevant to activate re-manufacturing. Secondary guidelines applied in the example are for sure *design of modular and replaceable components; engagement of reversible joining systems (in general).*

8.3.3 Desso-Tarkett Carpet tiles

The third example (Tarkett, 2015) comes from the company Desso Commercial Carpets by Tarkett, which is a global carpet and carpet tiles company that works for commercial customers from different sectors. Among their solutions, they provide the Carpet Leasing Service, which is based on turning carpet tiles into a service: Desso keeps the ownership of products and provide installation, cleaning, maintenance and eventually removal. Moreover, after the standard 7-years contract, a new carpet is provided by Desso and the old one is recycled and reintegrated into a new life cycle.

The key design choice that allows Desso to extend the overall flooring lifetime is a design oriented toward maintenance and repair, based on the use of tiles. Differently from rolls, tiles are designed to be modular and easily removable, since each tile is sticked through tape and can be punctually removed. This allow specific intervention in case of damages, avoiding a complete renovation of the flooring. Moreover, since Desso doesn't sell the tiles, the company provide services like maintenance and substitution, that contribute to extend the lifetime of products.

In this last example, the main design guideline represented is a combination of two: *arrange and facilitate disassembly and reattachment of easily damageable components; arrange and facilitate disassembly and reattachment of easily damageable components*. Indeed, although eased disassembly is a crucial feature of the product, it can be identified as peculiar for its implication in terms of maintenance and repair, which have been presented as complementary to re-manufacturing.

As noted also from stakeholders' feedbacks, the example shows that the design of an eco-efficient product could allow also a shift in the offer model, where economic interest is aligned with the pursuit of environmental benefits. This latter topic is treated in detail within Chapter 14, where Sustainable Product-Service Systems are introduced.

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9. *Design for Re-manufacturing (DfRem) of short chains from design-to-construction: the case of textile-based tertiary architecture*

by *Carol Monticelli, Alessandra Zanelli*

9.1 The peculiarities of Textile-based Tertiary Architecture (TTA)

This chapter focuses on the peculiarities of the typical design-to-construction process of textile building systems, that today have been mainly used in tertiary architecture.

The so-called textile architecture or membrane architecture is a niche of construction where durable materials are mostly applied for temporary uses.

The time-span of textile architecture may widely vary wether the textile artefacts are designed for interiors or for outdoor installations.

On one hand, textile-based architectural products shall include ceilings, movable partitions, curtains and even more innovative self-standing detachable and modular walling systems. Their application in tertiary architecture sees very short cycle of installation and renewal. Typically, the first service life of textile products in interior architecture is ranging from one to five years.

The latter open-air application shows even wider time-span, from few days (ephemeral uses), or few months (seasonal purposes) up to 10 years (long temporary functions). The main uses are ephemeral mobile pavilions, seasonal sport halls, as well as tensile membrane structures for public events and coverings for exhibitions or fairs.

The Design for Re-manufacturing (DfRem) approach is always intrinsically inherent to the textile-based building artefacts. Independently by the functionality, textile architecture foresees dry and reversible installation methods, that are the basic approach for any further transformability of building artefacts.

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Despite of the shortage of their use, the durability of membrane products (fabrics and foils) is ranging from 25 to 30 years. Considering the typical long-lasting, petrol-based, composite nature of current architectural membranes, it's worth to promote their reuse, renewal and re-manufacture in further installations, after their first temporary service.

Short-time architectural functionality and long-time durability of materials are added values for the re-manufacturing of tertiary architecture. Textile-based products have a widespread use in tertiary architecture, thanks to their lightweight, easy handling in the installation phase and a general design-to disassembly potential. Nevertheless, their DfRem attitude and their real re-manufacturing practice need to become more effective and wide-spread, after the first service life.

9.2 Fundamentals of Design for Re-manufacturing (DfRem) in TTA

The designers of the so-called tent-architecture (Drew, 2008) have always adopted a design approach aimed at disassembling, with the final goal of easily replacing components during the service life, as well as their repurposing in further installations and artefacts (Otto, 2004; Knippers, and Speck, 2012; Fabricius, 2016). In other words, since ancient time, designers specialised in tent-like constructions have been following the fundamental rules of the Design for Re-manufacturing (DfRem) approach:

a) the minimisation of the number of parts to be installed and their easy replacement by means of reversible, visible fixing systems;
b) the minimisation of the interface surfaces and the types of materials used, usually summarised as: primary structure (wood, steel, rarely aluminium), membrane in a single sheet and single material, tensioning kit (aluminium profiles, steel cables, ropes);
c) the optimisation of the membrane to be pre-assembled in the industrial manufacturing phase, aimed at minimising fabric waste and simplifying the sewing and welding operations (cutting pattern and fitting phase);
d) the preparation of a rigorous plan for packing and unfolding the textile membrane aimed at reducing the days of installation at height but above all to avoid the installation of fixed cranes on site;
e) the coincidence of operations and responsibilities relating to industrial manufacturing, installation and often also of the general contractor of the entire work;

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f) the delivery of the work-report to the end user, consisting of a series of recommendations for the use of the textile structure, the declaration of the duration of the construction system, its maintenance, the repair of the parts at the foot of the work, and the its final uninstall (EN 13782:2015).

9.3 Fundamentals of Design for Reducing (DfRed) in TTA

In the niche of the best temporary textile-based constructions, even before the Design for Re-manufacturing approach, a combined use of the imperatives of Reducing and Re-thinking is effectively adopted. This occurs during the "form-finding" process, in the early-stage design phase, when designers work on an iterative process of both refinement and reduction of each structural element, on one hand, and of the whole structural and architectural shape, on the other hand. The general Design Reducing (DfRed) strategy deals with the design principle of "doing more with less", for thus achieving the lightest weight of the whole systems, through a refinement of the structural concept.

The lightness paradigm in textile architecture is inevitably meaningful in a double level: highest efficiency of the shape (tensile membrane) on one side, and highest efficiency of the matter (pre-stressed membranes, fabrics or foils) on the other one. Appropriate combination of both aspects is the best feasible outcome of an innovative design process. Furthermore, the reversible perspective of the construction process might have a greater influence to the environmental contest (Beukers and Van Hinte, 2005; Drew, 2008).

Why nowadays can DfRed principles be seen as an advantage in general terms for any type of construction, not just textile-based ones? Four good reasons to extend the DfRed and lightweight principles today to a wider range of mass-building systems follow:

1. An optimised DfRed building system might be transportable: a lightweight system allows a simplified and faster installation process.
2. An optimised DfRed building system might be transformable along its service life; it meets the ever-changing needs as it is the output of an "error friendly" design thinking (Manzini, 2012).
3. A constructive system with less embedded materials might be more efficient in terms of hand-ability and usability; this principle is well known by nomadic users of tent-architecture.
4. A DfRed lightweight system might be designed with the natural sense of limit (Knippers and Speck, 2012): it is a constructive system for

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which the designer will be forced to develop more creative strategies, and to figure out a solution "of necessity"; it is one of the greatest understanding by the study of natural artefacts.

The attitude of continuously reducing the weight of the textile architecture has been a long process of refinement of the construction systems' efficiency, that it would be desirable to concern today also the architecture in general, i.e. not only tensile structures, not only temporary constructions, but also other more durable or massive ones. The optimisation of the building components' weight is not enough considered by architectural designers, while it is an essential requirement of other kind of lightweight construction, i.e. aero-spatial, nautical and automotive sectors. Looking for a lighter – optimised DfRed – architecture means to enlarge the research into flexible and advanced materials (Cost Action CA17107, 2019), reducing the thickness of components, optimising the sections of the construction. If in the past materials suggested their own most appropriate use, today designers mould and create materials to cater to the project's requirements, no longer with any limits. Thus, the main aspects to be assessed during this optimised DfRed phase become more and more:

a) the embodied energy of components and the whole building system;
b) the reusability /recyclability of each material embedded in the whole construction;
c) the expected lifespan of building, which is closely linked with the way of managing connection details for installation, maintenance and final dismantle.

The above-mentioned topics can be conceived as strategies for the membrane structures' eco-efficient design (Cost Action TU1303, 2017; Monticelli and Zanelli, 2016 and 2020). Nevertheless, most of those design guidelines might be hopefully transferred to other building technologies widely applied today, as well as to more sustainable technological approaches of renewing the built environment.

9.4 Focus on durability and environmental informations of textile-based building products applicable in TTA

Nowadays, the main peculiarities of TTA, as the optimised lightweight system and the flexibility of fabrics, need a further development, in the light of the updated sustainability issues.

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The design criteria of material and energy saving are still mandatory but not enough, while consumers, stakeholders, customers and designers are more and more demanding information about the environmental implications of construction activities.

Environmental information about technical textiles and transparent laminated foils for tensile membrane structures is still very limited.

The transferring new materials, especially plastics (Motro, 2013) in architecture has been meant the extension of the durability of textile-based products as well. Nowadays, a membrane product shall have an expected life time of 15-30 years. A polymeric coated/woven fabric like pvc-coated/polyester fabric has typically a durability of 15 years, while ptfe-coated/glass woven fabric shall achieve a durability of 25 year; eventually flour-polymeric membranes as e-ptfe tenara fabric or etfe foils shall extend the life time of a textile building product up to 30 years.

Foams, films, sheeting, coatings, chemical additives: very few studies are available to deeply knowing the impact to produce them, to replace them after their life cycle and the impact to recycling them (Hegger, *et al.*, 2005; Knippers *et al.*, 2011). The responsibility of producers of human-made yarns and polymeric membranes in this field is crucial. The ecological information at the product level allows the producer's deep understanding on how to reduce energy consumption, material consumption, waste production, and last but not least economic cost (Monticelli and Zanelli, 2016; Zanelli *et al.*, 2020). Unfortunately, a comprehensive description of environmental performance of each material can't be managed by a designer, throughout the routine of work practice. The typical results of a life cycle assessment can be interpreted only by specialists. A simplistic way of compressing them into a readable score, or an ecolabel, which essentially says "good" or "bad" product, is not applicable at neither the simplest, one-day-use, architectural object, due to the complexity of the environmental issued that a choice of a single building product implies over the entire design-production-construction-service-dismantle process.

It is thus clear that the environmental data on the building products has to be considered as technical information, as a performance profile, leading the designers' decision. Furthermore, the environmental data used for assessing the building's life cycle has to be consistent, without gaps, and then possibly audited by an independent third party.

In the field of TTA, a starting point for collecting environmental data is to supporting a program of development of environmental product declaration (EPD), defining data quality requirements into a Product Category Rules (PCR) documents for textile-based membranes (Monticelli

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et al., 2021). Currently, regarding membranes there are no PCR, with the exception of the Waterproofing membranes. Since 2019, the TensiNet Working Group Sustainability and Comfort has been working with 24 members (membranes' producers, manufactures, builders, as well as designers, testing labs and academic experts) to deepen how the association may support, at the European Level, the definition of the Architectural membrane PCRs, considering that two main families of products (textiles and foils) exist on the global market. The interest is focus on harmonising the PCRs for this specific sector and defining common rules such as the LCA system boundaries to be considered, the end of life scenarios, the functional unit as a basic rule to allow the comparison of the EPD data at the end of the process.

The main issues of debate by the producers of raw materials in the textile construction sector – technical fabrics on the one hand, polymers and fluoropolymers on the other – concern the raising of the performance level of building systems, in the face of the increased demand for systems of longer duration even if temporary. This demand certainly makes it even more important to find levers for the future re-manufacturing of materials of increased commercial value and long life.

In recent decades, membrane manufacturers have improved the performance of basic polymers, synthetic fibers and composite membranes. The warranty of architectural membranes is constantly increasing: from an average of 10 years to 15 years for the most basic and cost-effective membranes; form an average of 20 year to 30 years for the most advanced, performative and expensive products. Thus, membranes play a new role in the field of structural materials. The harmonisation of design standards is a further step in the direction of being able to consider membranes as the lightest building material. If the mechanical performance is no longer in doubt, now the attention of the developers is on the transition to more sustainable and less impactful industrial processing methods and procedures on the environment. Almost all of the technical textiles used in the textile architecture sector today are of chemical synthesis and petroleum origin. It therefore becomes urgent to evaluate alternative strategies to create new polymers, of biological origin and, at the same time, to evaluate the possibility of recovering waste internal to the supply chain and/or even external to it, in a circular economy approach (Zanelli *et al.*, 2020).

The TensiNet association has seen in recent years an intense activity of the WG Sustainability and Comfort working group which wants to lay the foundations for a more sustainable development of the entire production sector, sharing evaluation methods based on the LCA approach of membrane building components and working on the progressive efficiency

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and reduction of the environmental impacts of textile building systems along the entire life cycle, from industrial production to their disposal. In terms of understanding the environmental impact produced by the range of textile materials currently in use in textile architecture – recent studies (Monticelli *et al.*, 2021) show how the minimum quantities involved per unit of surface area (per sm) see the field of textile constructions winning over other building technologies, certainly at least in terms of carbon footprint, while more in-depth studies are underway on the comparison of the impacts along the entire life cycle of the textile building.

9.5 Re-actions in TTA field

This part of the chapter includes re-actions' experiences concerning the current Textile-based Tertiary Architecture. From these experiences, ideas are gathered for transferable eco-design principles and re-manufacturing approaches that seem appropriate and applicable to wider ranges building products.

9.5.1 Reuse of membranes, towards their Re-manufacturing

When structural membranes are used for a shorter time than the certified durability of the material (as indicated in the manufacturer's technical sheet), undamaged membrane materials, after a simple cleaning process, can be re-used. The possibility of whether or not to reuse the materials is closely linked to the material properties and other variables, e.g. cutting patterns, storage conditions of the material when not in use and assembly/disassembly methods. For example, some materials such as glass-fibre-reinforced-polymers or extruded foils are sensitive to folding and therefore may not be suitable for repeated use (Mazzola, 2020).

Sometimes the reuse may find some difficulty due to the specificity of each project (e.g. size and required performance) and to the necessary verification of the actual conditions and performances of the recovered materials (e.g. aesthetic, mechanical resistance, water-proofing). When temporary membrane-based buildings cannot be entirely re-used, membranes can be reused – and thus at least partially re-manufactured- as building components in the form of portions cut from the original panels, or for other purposes. This option is reliable and feasible in the special sector of textile membrane structures as the fabric materials – whether of not of first of second hand – needs to be specifically tested for its mechan-

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ical performances, before its application as a building product. This is why this textile-based buildings are not fully covered by the common rules of harmonized standards of the building products covered by the communitarian regulation n. 305 (EU Regulation, 2011), while technical committees ad the European level (CEN/TC 250/WG 5 and CEN/TC 248) are working hardly to finalise common rules for the whole process of design – production – testing – packaging – installation and dismantle of a new generation of structural membranes and textiles-based buildings (Mollaert *et al.*, 2016).

9.5.2 Recycling current textile-based composites, towards re-thinking and re-processing future textile membranes

In the last ten years, the recyclability is a quite advanced achievement in the market of membrane products used in textile architecture. Beside the most commons composite membranes (pvc coated/polyester and ptfe coated/glass) there are new mono-component membranes, i.e. fluoro-polymeric foils (ETFE, THV, ECTFE) that are produced by means of extrusion processes that allow the production of highly performing foils characterised and, the recyclability of 95% of both production's by-products and post-dismantling wasted products (Campioli and Zanelli, 2009).

A virtuous example of recyclability of composite architectural membranes has been recorded, since 2000, by Solvay, a company that developed and patented a process called "Texyloop" (Motro, 2013), a selective recycling system for PES/PVC coated fabric that separate PVC fibers and polyester resin through the selective chemical dissolving of the coating. Through the application of this process, the French company Sérge Ferrari has been recycled several post-dismantle pvc-coated/polyester fabrics at the Vinyloop industrial plant in Ferrara, Italy, from 2008 to 2018 (Fournier, 2013). Starting from 2020, a new business model has been lauched by Polyloop, Smart Factory 4.0 start-up. The new compony is going to supply to the end-manufacturers of the textile architecture field a medium-size rig for re-cycling their own by-products and the dismantled membranes straightly into their warehouse, as those companies are responsible for the installation the repairing and any further maintenaince actions of every textile-based construction they have buit (Faysse, 2020).

The further steps on the way of eco-efficiency might be, on one hand, the re-thinking of production processes towards new families of mono-component coated-fabrics, where both woven yarns and protection coating

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are made of the same recyclable raw components, and, on the other hand, the introduction of novel bio-based textile products and the enhancement of their performances along the time.

9.5.3 Reusing temporary textile-based architectures, towards movable systems

There are many emblematic cases of itinerant or seasonal textile pavilions that have been well designed by archistars to be easily disassembled, washed and maintained and then properly stored for months, to be reused and installed in the new season or in a new location. This is the case of the Tea House by architect Kengo Kuma, but also of the stage for the Oslo Jazz Festival by architects Snoetta. At the end of their temporary life cycle of less than 5 years, none of these artifacts have actually been reused.

One wonders if it is really reasonable to tear apart an architectural artifact and propose building components for sale through online building materials platforms, in the name of a sustainable re-manufacturing action. Would we do the same with the components of Richard Buckminster Fuller's fly's Eye Dome or with Renzo Piano's IBM pavilion?

Undoubtedly, the reuse of the System is to be promoted more than the reuse of single parts.

9.5.4 Re-manufacturing textiles within circular economy: first trials of closing the loops between apparel and architecture sectors

Finally, a higher level strategic approach can aim to reduce the impacts of the textile-clothing industrial chain by introducing in the field of temporary textile architecture a range of materials with certainly more limited and less durable performances, but adequate for the short cycle of use., for example for ephemeral installations of days or up to 3 months.

There are two cases that go in this direction.

9.5.5 Re-m 01: from sport-ware to tertiary architecture. The Re-manufacturing of Speedo swimsuits for a textile-based Pavilion, London Architecture Festival

After having produced the LZR Raced line, Speedo, the manufacturer of swimsuits, he has seen them rejected because they are considered technological doping. Speedo decides to sell 600 unusable swimsuits

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to Chelsea for free Collage of Art & Design. The project was directed by Cyril Shing, professor of Interior Spatial Design, together with the students, which were challenged to explore how to transform the swimsuits into an architectural pavilion for the London Festival of Architecture.

9.5.6 Re-m 02: from fashion wastes to shading system. The re-manufacturing of Humana post-consumers T-shirts for a shading system, T-Shade project, Leonardo Campus, Politecnico di Milano, 2020

An ultra-lightweight shading system made of 500 post-consumer fabrics, such as reusable t-shirts, with the support of HUMANA people to people onlus, was installed at Polimi Campus, the 30th June 2021. It was a demonstrative temporary artefact to show how reversible connections may facility the installation of reused fabrics. The mechanical behaviours of the post-consumer T-shirts was preliminary testes and the output of the testing investigation oriented the form-finding process and the design optimization of the new T-shade membrane.

All over the world, lifestyles are increasingly bringing out the need for flexibility, speed and dematerialization and these changes, though in a slower way, also involve the construction sector. Membrane tensile structures as ultra-light constructions (Sobek, 2016; Zanelli *et al.*, 2022), in recent decades are playing a key role whenever the first objective is the compression of time from the conception of the project to the inauguration of the work (international expo, temporary events) but also when the speed of installation and the manageability of the system are added values. Despite the stimulating continuous technological advancement, it is indeed important that the sector of light structures does not forget the precious lesson of the past.

The ancient uses of fabrics in different cultures have been oriented and guided by the concepts of saving and efficiency of materials, which today can be read as inspiring concepts of intrinsic environmental sustainability for the textile architecture of tomorrow. Indeed, a lightweight system should always continue to be designed with a natural sense of limit; to say so, a lightweight membrane construction system will have to continue to be designed as a "necessity" construction kit where nothing is superfluous, and each is an essential part of an integrated system in the environment.

Almost seventy years after the start of the membrane tensile construction industry, a significant result of the joint work of all the professionals

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that revolve around the design, industrial production and construction and maintenance of membrane structures, has certainly been the creation of a technical table for the drafting of a specific Eurocode on the design of membrane structures. In 2016, under the supervision of the JRC of the European Commission, the first SaP Report concerning the guidelines for the structural design of membrane tensile systems was published (Mollaert *et al.*, eds, 2016) While the works of CEN/TC250 are in the final phase Structural Eurocodes related to membrane structures. Furthermore, since 2019 Europe through the EN 17117 standard has also normalized the procedures for verifying the quality of coated textile materials, introducing the need to standardize the procedures for performing biaxial mechanical tests on all textile and polymeric products that can be used in construction at membrane. Through these important standardized design tools it will be increasingly possible to operate with an approach of material minimization and intelligent structural conception, sought together by architects and engineers, as the first key step for future dismantling and effective recoverability of the parts of the building system.

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10. *The role of digital technologies for the activation of re-manufacturing actions in the tertiary sector*

by *Salvatore Viscuso, Alessandra Zanelli*

10.1 Design for re-manufacturing retrieved products

The digitalization of the construction industry enables effective communication and collaboration among stakeholders. This facilitates access to shared information, controlled coordination, and monitoring of construction processes (Grilo and Jardim-Goncalves, 2010), which, in turn, encourages the involvement of all stakeholders right from the concept phase of the building through the entire lifecycle (Eastman *et al.*, 2011). Moreover, it allows the actors to collaborate effectively through horizontal integration among the various disciplines (Ciribini, 2016).

Another functionality is the ability to simulate building performances such as cost estimation, energy consumption, lighting analysis, etc., with the aim of driving the possible design options through data analysis (Deutsch, 2015). The behavioral simulation of a physical object in a digital twin – quite recent in the field of architecture but applied for decades in advanced manufacturing sectors such as the aerospace industry and mechatronics – is based on the use of simulation tools that are developed for processing, analyzing and evaluating large amounts of data; the goal is to make them available in real-time during the decision-making in construction and operations (Eastman *et al.*, 2011).

Despite the environmental/economic impacts that concern the management of building stocks during repairing, substitutions, or at the end of their life, none of the existing commercial digital tools and software can predict any complete simulation of the waste management options and the related carbon footprint scores. This gap calls for rethinking the current functionalities offered by digital tools, to capture and address any potential reactions (reusing, re-manufacturing, regener-

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ating, repurposing, etc.) for the products that are dismantled during the strip out of buildings (Sanchez *et al.*, 2020).

Focusing on the tertiary sector (offices, retails, exhibitions), the processes linked to the renewal of spaces involve short cycles of use of the building fit-out (finishes, walls, furniture), thus making significant waste streams. Within this context, it is especially interesting to investigate how digital technologies can support the transition to a Circular Economy of the tertiary building through the digital simulation of the short cycles of disassembly and re-manufacturing stages. The Chapter is organized through an operative framework that has been proposed by WRAP (Waste and Resource Action Plan) since 2000, for defining the design strategies that can reduce the construction waste intended for landfills: (i) **designing the recovery and reuse of the elements** that can be retrieved from the original products at the end of their life (described in this paragraph); (ii) **designing the de-constructability and flexibility of systems**, with the aim of planning an easy disassembly and the consequential renovation of raw materials (see Paragraph 10.2); (iii) **designing the material optimization** that focuses on the efficient use of resources (see Paragraph 10.3), for producing less waste as possible in the processes (also through a symbiosis with other businesses) without compromising the initial concept or performance (WRAP, 2007 et 2021).

In the first strategy, it's necessary to distinguish first the fit-out standard called "CAT A Delivery" (prescribed by the British Council for Offices in 2011), which involves the construction of false ceilings, raised floors, air conditioning systems, lighting systems, fire prevention systems, and toilets, from the construction works for which the tenant is directly responsible (CAT B Delivery): partitions, finishes, electrical systems, wiring, audiovisual systems, furnishings, and branding. This model allows companies to customize the spaces to their liking for the entire duration of the lease, with the obligation to restore the initial delivery conditions once the premises have been vacated. The capital investment in charge of tenants is thereby important, but it can be amortized over the life cycle of the office itself. This aspect affects the propensity for change. Besides, at present, the post-pandemic uncertainty about office occupancy strategies is pushing demand more and more towards work flexibility. So, what to do to optimize the tertiary fit-out, reduce costs, be more sustainable and avoid – at the end of the rental agreement – throwing away a lot of construction products?

Following the tendency of other industrial sectors, like automotive and electronics, the interest in the regeneration and reuse of construction products is becoming increasingly relevant in the last years, notwith-

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standing the low quantities of recyclable material that at present it is possible to recover from the selective demolition of the tertiary fit-outs. Diverse research projects, initiatives, and macro-regional networks have been launched recently to support the reuse and re-manufacturing of recoverable building products (Durmisevic *et al.*, 2017; Schützenhofer, 2020). Rotor Deconstruction and New Horizon can be considered – respectively in Belgium and the Netherlands – as 'urban miners' for the recovery and reuse of building products: they dismantle, repair/regenerate, and reintroduce on the market construction materials that still present latent potential usability. Using digital platforms and databases (opalis.be, oneplanetnetwork.org), they also promote new value chains based on systematic collaboration between small and medium manufacturing enterprises and general contractors operating in that macro-regional district (Devlieger, 2019).

The "Mundo-A" office building in Antwerp, which since 2018 hosts no-profit organizations operating in the third sector, represents a valid case history of a successful re-manufacturing network that involves stakeholders and contractors that works in the tertiary sector (Fig. 10.1). The designers (B-architecten) and the owner (an ethical and social investment fund)

Fig. 10.1 - In Mundo-A Office Building in Antwerp (B-Architecten, 2018), the designers have provided a digitally computed tessellation to solve the different height of partitions between the old buildings and the new location (Source: www. b-architecten.be)

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shared the goal to limit the building's environmental impact as much as possible, beyond the simple efficiency of the energy operating performances. With this aim, the project incorporates partition systems (opaque and transparent) and doors recovered from the deconstruction of other buildings in Brussels and Zaventem, including the Baudouin Palace (headquarter of the Flemish government from 1992 to 2018). The architects used the parametric tools to obtain multiple creative solutions for the reassembling of re-manufactured boards, glazing, and doors, with the objective to resize the novel partitions on the multiple-story heights of the new building (Pintos, 2021).

To give an idea of how these best practices are quickly spreading in the European countries, in the "Kopfbau Halle 118 Winterhur" project (inaugurated in 2021 in Winterthur, Switzerland) the transformation and the extension of an industrial building offered the occasion to reuse structural, facade and interior elements recovered from a local supply area (Fig. 10.2). Through the digital modeling of the recovered material, the architects prefigured the off-site and on-site assembly of diverse components and semi-finished products together with new raw materials with a high level of adaptability, in order to work out the different sizes and proportions of products. E.g., in the prefabricated wooden elements of the façade extension, the gaps around the reused windows (that are smaller than the hosting voids) are filled with straw insulation and locally extracted clay. In this way, the different sizes of windows did not represent a problem anymore: straw and clay were molded into the residual space without creating waste (no cutting losses) during the off-site re-manufacturing works. Inside, the walls are covered with reclaimed wood panels from the construction industry for temporary event structures and are fitted with reclaimed doors. The result is the 60% of greenhouse gas emissions and 500 tons of raw materials saved compared to a conventional tertiary renovation (Pintos, 2021).

The projects described above are now presenting several challenges to be systematically replicated on a larger scale of deployment. In the tertiary sector, the greatest obstacle to the diffusion of the re-manufacturing and reuse of second-hand products is represented by three main barriers (Hart *et al.*, 2019): (i) the cost of reverse-logistic processes and the impossibility of promptly restocking the market and the production chains, generating uncertainties in provisions; (ii) the regulatory gap, that still does not take into account a harmonization process for second-life products and does not contemplate virtuous alternative processes to the consolidated recycling chains (and composites are frequently not recyclable because of treatments or contamination of base elements and raw materials); (iii) last but

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Fig. 10.2 - The Kopfbau Halle 118 Office Building, in Winterthur, Switzerland (Arch. baubüro in situ, 2021), is almost completely built with reused components, including its loadbearing system; during the design stage, the architects used the BIM model to record the disassembled products and to compare the LCA impacts of multiple design alternatives (Source: www.insitu.ch)

not least, the workability of the recovered materials due to their deterioration and/or contamination. This slows down a wider diffusion of practices and potential networks, that could activate consolidated macro-regional re-manufacturing chains. Even if – in the European context – some individual B2B initiative (led by a few local demolition enterprises) has been starting to be configured as a digital marketplace with constant furniture of second-hand products for re-manufacturing or repurposing applications (www.cycle-up.fr, opalis.eu, etc.).

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To overcome the first barrier, New Horizon has recently launched an 'urban mining' scan service for existing properties, aimed at quantifying and qualifying the potential for reuse of their materials and components within a digital database (Boje *et al.*, 2020). With the same objective, the Interreg North-West Europe Project "Digital Deconstruction" (2019-23) is developing advanced digital solutions supporting the reuse and high-quality recycling of building materials (Durmisevic *et al.*, 2021). The project develops the following different outputs, such as the development of: (i) an innovative digital decision support system at TRL 7, integrating various digital tools (3D scanning, Building Information Modelling add-ons, a digital materials and buildings database, RFID, and blockchain technology), that enables a replicable and scalable deconstruction and waste management strategy in a sustainably and economically manner; (ii) a network of Regional Innovation Hubs (RIH) that support the optimization, validation and widespread of innovative digital tools for urban mining; (iii) pilot sites to test and assess digital tools for urban mining in an operational environment (Fig. 10.3).

These ongoing projects focus on markets of States (The Netherlands, Belgium, Luxembourg, and France) that set in the last decades ICT and digitization in the industry as one of their priorities. In fact, it is demonstrating how digital services are crucial to take suitable decisions with the real (variable) market and industrial needs, ensuring a wider knowledge base of digitally assisted deconstruction processes and paving the way for higher volumes and a constant flow of recovered products.

If the research sector is working on the development of digital tools able to define more sustainable and economical deconstruction and reuse strategies, the second barrier – the legislative gap – is currently under the observation of lawmakers and technicians, that are proposing a review of the Construction Product Regulation (CPR) 305/2011. Among the various proposals, one of the most relevant goals is to simplify the delivery of non-harmonized assessments for certifying the elements that will be dismantled from the buildings in the following years.

The review process of the regulation is also aimed to incentivize a new generation of construction elements that are easier to disassemble, repair, and re-manufacture. The inability of the current CPR framework to deliver on broader policy priorities (and the underperformances in terms of digital transition and resource-efficient strategies) are producing a set of novel product requirements for builders and manufacturers. The next paragraph investigates the main design conditions, that permit an easy recovery of the elements and their reuse at the end of life, avoiding the generation of parts that are not re-manufacturable or reusable (third barrier).

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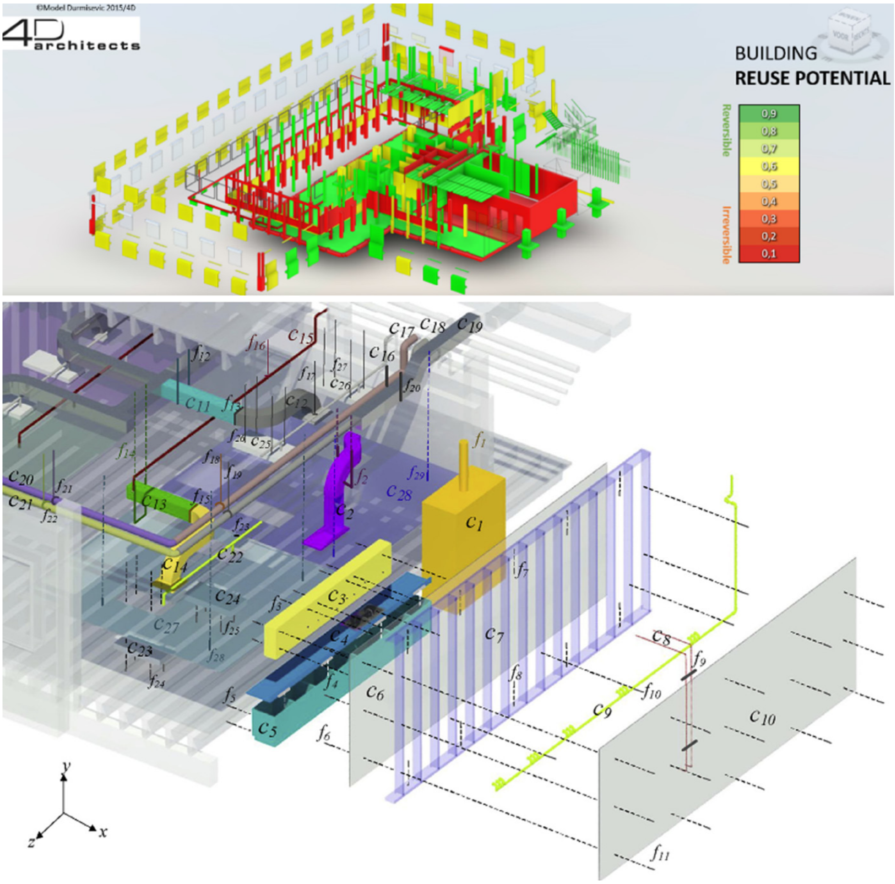

Fig. 10.3 – Breakdown of assembly models – obtained from the digital scan of existing buildings – for analyzing the re-manufacturing and reuse potential of recoverable components (Source: Durmisevic et al., 2021; Sanchez et al., 2020)

10.2 Design for disassembly of novel products

Some research conducted by the EPA (the United States Environmental Protection Agency) shows that deconstruction could be cost-competitive with demolition, only if there were enough recoverable materials, with medium-high market value, capable to compensate the supply uncertainty and the higher labor costs (Weber *et al.*, 2009). It means that the reversible design becomes an indispensable strategy for activating reuse and re-manufacturing chains only if it guarantees that the product retains its value once it reaches its end of life, and therefore it is possible to regenerate it or rework it.

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The recent publication of the Standard BS ISO20887:2020 (Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles, requirements, and guidance) intends to provide a framework for the different stakeholders and technicians involved in the construction process, to promote the possible design actions for dismantling architectural and mechanical building systems and components at the end of life. Designing for disassembly, therefore, requires the drafting of detailed disassembly plans, including instructions for disassembling the elements, as well as a (digital) filing of components, building materials, and methods of reuse, recycling, or recovery. Therefore, separating the different technological systems (thus making the disassembly or simple replacement of the individual components less impacting for the building as a whole) reduces the obsolescence of the building and makes it adaptable to other functions or uses.

While modularity and standardization facilitate the re-manufacturing and reuse of products, process reversibility plays an important role in the product customization process. For this reason, product customization should be postponed as far as possible to the later stages of the production chain. The value preservation or the easy retrieval of dismantled products may activate new circular processes able to be competitive with the new-product benchmarks.

These criteria become crucial if we reflect on the frequent renovations of contemporary tertiary spaces, or the crescent needs of temporary offices, also considering that these markets are strongly oriented to use bespoke/branded finishes. The geometric definition of basic elements, operated within a reversible layering/nesting design of BIM objects, can decisively affect the possible re-manufacturing or the direct reuse of the products. A valid example is the temporary extension of the Brummen Town Hall (Fig. 10.4), in the Netherlands, designed for a life span of 20 years, in which the designers (RAU Architects and Turnoo) conceived the structural frame in glulam by assembling columns and beams parametrically "constrained" by the manufacturer in their dimensions, depending on the re-manufacturing opportunities (Densley Tingley *et al.*, 2018).

In addition, the customization through elastic or plastic deformation of the materials permits them to restore (often directly on site) their initial configurations, thus favoring transport, multiple re-manufacturing options, and, consequently, more competitiveness in the market. E.g., to design the soft roof of the "Sanno" temporary office in Okazaki (Japan), Velocity Studio exclusively used thin wooden boards, that design a curved surface shaped by gravity and pretension load bearing, thus giving the idea of a slightly concave and convivial envelope (Fig. 10.5). The flat beams in laminated wood, bent directly on site, can be reshaped to their original profile after the disassembly and used again in different configurations (Zaxarov, 2020).

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Fig. 10.4 - Temporary City Hall in Brummen, The Netherlands, designed in 2013 by RAU Architects with reversible technologies that turn it into a raw material depot for future buildings' applications (Source: www.rau.eu)

Fig. 10.5 - Sanno Temporary Office (Arch. Studio Velocity), inaugurated in 2020 in Okazaki (Japan) and characterized by the digitally computed elastic deformation of glulam beams that will be reshaped to their original outline after the disassembly (Source: www.studiovelocity.jp)

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To prefigure a dynamic reconfiguration of products recovered after the disassembly, starting from the early design stage, it is necessary to separate the different functions of the building using autonomous subsystems for each function, which can be assembled independently from the other parts of the structure (Durmisevic, 2006). For example, drywall partitions are designed following the functional breakdown into sub-functions, such as closure, finishing, insulation, water protection, mechanical resistance, etc. Subsequently, the sub-functions are allocated into autonomous elements with different lifespans, joined together employing simplified connections and interfaces. By breaking down the drywall into several independent components, the system becomes more flexible because it can be easily modified or reconfigured according to new needs of brightness, insulation, position of the openings, cladding.

During the digital modeling of the technological project, the main characteristics that enable possible re-actions can therefore be summarized in the following simple principles (Vandenbroucke, 2016; Durmisevic, 2018), which can be translated into "rules" within the codes for modeling and nesting the parametric geometries, such as: (i) the object decomposition until the material levels, which correspond to independent functions; (ii) geometrical checking of the object dimensions and connection interfaces, considering the potential re-action at the end of life; (iii) grouping different time-based sub-sets in relation to the obsolescence; (iv) definition of parallel rather than sequential assembly/disassembly processes.

In contrast, static configurations do not present any potential for functional and technical decomposition. Traditionally, construction elements are closely related to each other, without any consideration for the different functions and life cycles they may have. The main causes of this integration between the components are mainly due to: (i) material levels that do not correspond to independent functions and/or do not permit the re-manufacturing because of the geometrical compromission of the elements; (ii) assembly/disassembly hierarchies unrelated to the component service life and the estimated time to obsolescence; (iii) application of sequential assembly processes.

Once the digital model of a construction project has been defined, the geometric and information data of the materials constitute a complete digital database (Building Passport), which can be implemented over time as a digital support to the Facility Management. This will make it possible to reconstruct the previous life of the elements, and thus be able to evaluate their possible nesting in the digital model of a future project (Jensen, Sommer, 2019). However, most of the current (few) Building and Material Passports are still simple databases; to achieve buildings that

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can potentially be used as effective material banks, any decision-making process on them should be digitized, such as the backup of maintenance and substitutions, or any changes in ownership and function. This will make it possible to examine the conditions of the disassembled components and their raw materials/base elements, thus analyzing their residual performance directly through the direct investigation of the digital twin (Schützenhofer, 2020).

For that reason, the role of the architect/programmer/data manager is going to become more and more crucial, because he is skilled to bring about the computational design of new construction (and deconstruction) technologies as support for new circular models. The following paragraph investigates how the computational design can also optimize the balance of the materials used into the construction products and the reduction/reuse of their byproducts, with the objective to unify the notion of Designing 'out' Waste (DoW) with the potential opportunities given by the Designing 'in' Waste (Thomas, 2015).

10.3 Design the material optimization of products

In the field of industrial design, the term "adaptation" denotes the ability to respond competitively to the needs of the market, while "adaptability" or "fitness" means the propensity to maintain and expand the evolutionary plasticity of a product, or the possibility of evolving in a great variety of environments (Pietroni, 2006). Following this last peculiarity, in architectural design, the digital interaction between technological design and mass production now allows the creation of adaptable and performing construction systems, proposing itself as a tool for on-demand digital manufacturing processes (Cangelli, 2018). These drivers originate generative computer engineering logics that control the material-based geometric constraints and optimize the fabrication outputs. «At ZHA CODE [Zaha Hadid Architects Computation and Design Group] we are developing a lot of our own custom tools to model the constraints of fabrication processes», says Patrik Schumacher, director of Zaha Hadid Architects (Schumacher, 2017, p. 107).

The integrated digital simulation allows to perfectly describe the construction systems, not only all their parameters in terms of physical and mechanical behavior but also the manufacturing process and the production waste. Adjustments can then be made until all parameters are optimally aligned with each other, e.g., for bringing the virtual simulation closer to physical reality and allowing a substantial decrement in

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safety factors that must be applied, or for obtaining a zero-waste pattern to fabricate the basic elements with cutting or subtracting technologies. The design, therefore, focuses on the efficient use of resources to use fewer materials and/or produce less waste in the processes, without compromising the initial concept or performance. The results are tailor-made construction systems that are consequently lighter and more sustainable (Lienhard, 2015).

Expanding the analysis to other industrial sectors that have already taken advantage of the adoption of a tailored design approach, diverse fashion textile SMEs (small to medium enterprises) and startups are currently adding value to textile waste: by applying their practical skills, knowledge, and expertise, several companies rework production remnants and postconsumer textiles, with the aim to achieve zero-waste chains (Taylor and Townsend, 2014; Woods and Ballie, 2015). The digital tools compute the best cutting pattern that makes uniform the offcuts dimensions for reusing them (in the same industrial chain or in another one that uses the identical raw material), while the nonuniform fabrics are reprocessed for designing and fabricating high-performative products for tertiary buildings, in which the multiple material composition and dimensions are not critical, such as: (i) surface area for evaporation and filtration (metal building anti-condensation flocked panels, machinery parts with reduced condensation, and oil spill management, etc.); (ii) sound absorption and vibration isolation (flocked wall coverings and coatings for music studios, car ventilation units, computer and printer housings, acoustical absorption in metal buildings, industrial ceiling treatments, etc.); (iii) cushioning and shock isolation (flocked packaging materials for sensitive instruments and jewelry products and scratch-proofing of surfaces, etc.).

The ability to digitally customize products in the last fabrication stage can encourage the development of new macro-regional networks or consortia between cross-sectorial SMEs, to which access to digital technologies – able to guarantee productivity even for small volumes – is easier than in large industries. On the other hand, many of these SMEs still deliver substantially standardized products, or with a limited number of variants. The reason is that few of them have internally the skills needed to fully exploit the possibilities of numerically controlled work centers (Caneparo, 2012). The digital interoperability between designers and manufacturers could support the lack of computational skills within SMEs: the designer can directly manage the final customization of the construction products to the specific needs of the project, also experimenting with techniques and re-manufacturing materials recovered from other industrial chains.

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11. Advanced digital information management tools for smart re-manufacturing

by *Nazly Atta, Cinzia Talamo*

11.1 Exploiting ICTs towards smart re-manufacturing in the building sector

Overcoming down-cycling practices, Re-NetTA project developed three service-based circular models (see Chapter 4) for closing the product loop, performing re-manufacturing for extending product lifespan and guaranteeing multiple use-cycles, thus maintaining the embedded resources and limiting environmental impacts. The in-depth analyses of the three proposed models performed through the dialogue with key stakeholders of the building sector (see Chapters 5, 6 and 7) highlight some barriers that currently hinder the widespread adoption of re-manufacturing practices within the building sector. These barriers are mainly organizational, information, regulatory, technical, economic and cultural. With respect to these barriers, the first two can now be handle more effectively by means of the Information and Communication Technologies (ICTs) (Atta, 2022), especially Internet of Things (IoT). The adoption of ICTs has the potential to support the three proposed circular models (see Chapter 4) by enhancing organizational and cognitive processes. In particular, they offer innovative capabilities of real-time monitoring, remote communication and scenario modelling, opening up to new information management solutions for re-manufacturing. Hence, ICTs and IoT can contribute to reduce the uncertainty that characterizes re-manufacturing processes in the building sector by means of advanced data collection and processing, thus replying to some gaps of current practices:

– lack of tools for the continuous monitoring of the levels of use and degradation of building elements and products during their use-cycles in order to outline residual performances and to assess in terms of

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technical, economic and time feasibility the possible re-manufacturing actions (Butzer *et al.*, 2016; Zhou *et al.*, 2018; Wang *et al.*, 2020) to be implemented according to the three proposed organizational models;
– lack of communication systems to implement collaborative and cooperative re-manufacturing processes (Butzer *et al.*, 2016; Wang *et al.*, 2020) by connecting the involved stakeholders (e.g. manufacturers, maintenance operators, clients, dealers, re-manufacturers, etc.), thus allowing the sharing of data (e.g. customer demand of re-manufactured products, availability of products to be re-manufactured, localization of products, logistic data, spare parts requests, etc.);
– lack of standardized time- and cost-effective information management procedures, shared between the stakeholders acting in the different phases of the closed-loop (e.g. production, procurement, construction, use and management, maintenance, re-manufacturing, etc.) in order to avoid data losses (especially when passing from the production to the use phase and from one cycle to the subsequent one within rent-based models) (Wang *et al.*, 2020).

Based on these premises, the present chapter proposes an overview of ICTs that have the potential to overcome the above-mentioned lacks, supporting the implementation of circular re-manufacturing models within the building sector. In particular, the next paragraphs investigate the potential of:

– *Smart data*. Sensors and tags for advanced collection and management of product lifecycle data and informed re-manufacturing decision-making (Par. 11.2);
– *Smart services*. Internet of Things (IoT) and data analytics for real-time product monitoring and tailor-made operations within re-manufacturing models (Par. 11.3);
– *Smart links*. Information platforms for strengthening stakeholder connections and creating new digital marketplaces (Par. 11.4).

11.2 Smart data: advanced collection and management of product lifecycle data and informed re-manufacturing decision-making

Encouraging circularity within the construction sector, Internet of Things (IoT) – with its sensing devices (e.g. smart tags, sensors, actuators, RFID, wearable and mobile devices, etc.) and wireless network

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technologies (e.g. Wi-Fi, NFC, Bluetooth, etc.) – now allows physical products to gain virtual identities and real-time communication capabilities, becoming the so-called "smart products" (Wang *et al.*, 2020) (Tab. 11.1). IoT capabilities offer the possibility to develop "feedback-rich systems" (Alcayaga and Hansen, 2017) during the product lifespan, with benefits for product monitoring in terms of assessment and estimation of performance, behaviours and costs. These systems are based on "smart data", meant as a novel category of data characterized by a high transfer velocity and high detection frequency that contribute to an accurate and time-effective information sharing and management (Kamble *et al.*, 2018). In particular, the novel ICT-based abilities (Tab. 11.1) allow smart products to collect and process smart data, to communicate with other devices over the internet and even to automatically activate predefined actions according to specific purposes.

In the field of re-manufacturing, with the development of detection technologies and the extensive adoption of sensors, smart data refers to a large amount of data (Big Data) produced during the manufacturing, maintenance and re-manufacturing phases, concerning several technical and business aspects including: performed interventions, costs, ownership, expected life, spare parts availability, rent, etc. (Zhang *et al.*, 2016; Ding *et al.*, 2018). Hence, smart data management refers to the process of data normalization, integration, processing, analysis and interpretation (Ding *et al.*, 2018; Kerin and Pham, 2020). In feedback-rich systems, smart data and Artificial Intelligence (AI) solutions (Tab. 11.1) are usually packaged with other technologies for re-manufacturing, including data-carrying devices and identification labels (smart tags, QRcodes, RFID, etc.) (Kerin and Pham, 2020). Indeed, by equipping products with a unique ID, it is possible to gather data during the product use phase, allowing a real-time traceability. Furthermore, empowered by sensing and communication capabilities, smart products can monitor and report their own status and use conditions (Atta, 2022). They can also communicate over the internet with other smart devices and with people by means of data visualization tools through digital dynamic interfaces (Tab. 11.1). These new capabilities are opening new scenarios of information gathering and analysis, following the products even after the they leave the production site and the logistic facility (Alcayaga *et al.*, 2019; Blömeke *et al.*, 2020). This can facilitate, at the operational level, the tracking and monitoring of component quality, performance, quantity, location, etc. and at the same time it can support strategic decisions, such as for instance, the determination of the best re-manufacturing path to reduce costs and environmental impacts, or

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the proper site or facility where re-manufacturing the products optimizing resource efficiency and profits (Kerin and Pham, 2020; Wang *et al.*, 2020), etc. In this perspective, the adoption of IoT technologies and the increased capabilities and value of smart products support the development of innovative circular models (Alcayaga and Hansen, 2017). Moreover, they can contribute to streamline processes and overcome the main inefficiencies related to the collection and management of product-related data that currently hinders the spread of re-manufacturing practices within the construction sectors.

Tab. 11.1 - Advanced IoT-based information management functionalities for re-manufacturing processes

IoT capability	**IoT-based functionalities and activities**
Data gathering	Sensors gather product (e.g. health status, energy usage) and product-related data (external influencing factors, e.g. ambient temperature). Smart products are sensor-embedded (e.g. ID tag, RFID, GPS, etc.). They collect, save and share data from their life cycle phases, thus implying the need for data acquisition software.
Remote monitoring	Data and information are remotely collected in real-time (continuous data streams). Data concern different aspects of the product, including technical parameters, location, availability, use profile, performance, health status, degradation condition, etc. By means of data visualization software, these data are displayed and/or queried on online smart interfaces (web, mobile or wearable).
Dynamic data storage	Dynamic storage in cloud-based databases, following the product lifetime, of static and dynamic data in different format (e.g. audio, video, picture, alpha-numerical string, text message, etc.) coming from multiple sources (e.g. web and mobile application, remote monitoring systems, communication tools, etc.). In particular, product-related dynamic data (e.g. failure rates, remaining useful life and usage, prediction of maintenance requests and part replacement, etc.) come from remote monitoring systems and analytics tools.
Data processing	By means of business intelligence tools, data processing (Big Data management, integration, clustering, correlation, analytics, etc.) exploits the data collected during the product lifetime and stored in the dynamic databases. The aim of data processing is to provide accurate, reliable and timely information (availability of insights about the use phase of products, e.g. behavioural analysis, fault diagnosis, etc.) to decision-makers facilitating the decisional processes.

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Tab. 11.1 - continued

IoT capability	IoT-based functionalities and activities
Modelling and simulation	The modelling and simulation functionality is realized by means of a digital twin, namely a three-dimensional representation of the product that mirrors the status and behaviour of its physical twin. Through a set of sensors and actuators able to connect the physical and the related digital copy, the digital twin is continuously updated by feedback data coming from the real twin. In this way the digital model acquires the potential to describe the behaviours, profiles of use, degradations, failures, anomalies, etc. that occur in the real twin, also constituting a valuable base for performing predictive analyses, (e.g. behavioural forecasts, simulations of the order of the dis/assembly steps, estimations of technical feasibility of the re-manufacturing works, including time and costs assessment, etc.).
Advanced visualization	The tools of advanced visualization include both Virtual Reality (VR) and Augmented Reality (AR), namely technologies for providing to humans additional visual information with respect to the reality that they are already able to perceive. These tools are able, for instance, to support processes in logistics or maintenance, to train the operators to perform dis/assembly activities visualizing the procedural and operational steps, to picture the possible results of repurposing activities (e.g. aesthetic quality of the product), etc.

In this regard, one of the main recent technology, that is widely recognised as re-manufacturing facilitator for its data aggregation and visualization capabilities (Kishita *et al.*, 2018 Diez-Olivan *et al.*, 2019; Kerin and Pham, 2020; Lu *et al.*, 2020) is represented by the so-called Digital Twin (Tab. 11.1). The term refers to a three-dimensional digital copy of the real physical asset (Chen and Huang, 2020). It represents a virtual model of the real product mirroring the actual structure, dimensions, geometry, physical characteristics as well as functional attributes (Wang *et al.*, 2020). The adoption of such a tool, enabling the one-to-one correspondence between digital and physical, unlock new opportunities to simulate maintenance and re-manufacturing interventions, also estimating the related time, costs and impacts, reducing in this way the uncertainty on re-manufacturing feasibility and sustainability (Wang *et al.*, 2020). The digital twin can also be digitally connected to smart sensors and devices and, in addition, it can be integrated with artificial intelligence (AI), smart monitoring systems, big data analytics and machine learning in order to (Atta, 2022):

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- replicate the specific behaviour of the real product and automatically updating the digital model (3D representation and related data) when changes in the physical world occurs (Zhao *et al.*, 2022), by exploiting the bi-directional dynamic information flows and data exchange established between the physical and the digital twins;
- detect in real-time the health conditions of the assets and analyze their maintenance conditions, by exploiting sensor-based continuous monitoring and diagnosis systems;
- plan predictive maintenance interventions to be carried out to extend the lifespan of products according to a data-driven approach pursued through data analytics and machine learning functionalities;
- perform scenario simulations for modelling the complexities of re-manufacturing operations (e.g. priorities in sequences of dis/assembly, spare part substitutions, entity of damage repair activities, etc.), while estimating time, costs, needed skills, environmental impacts, etc. (Goodall *et al.*, 2019; Kerin and Pham, 2020).

In addition to supporting the delivery of service-based re-manufacturing models, the adoption of a digital twin has also the potential to integrate current building product design practices with novel strategies of Design for Disassembly and Design for Re-manufacturing (*Design-for-D/R*). These circularity-oriented approaches are already adopted with several environmental and economic benefits in different industrial sectors (Battaïa *et al.*, 2018), such as aerospace, automotive, electronics, machinery, etc.). *Design-for-D/R* criteria and specifications (Tab. 11.2) have the key aim of ensuring the deconstruct-ability of built assemblies in order to facilitate re-manufacturing, repair and reuse of products and/or their components (Rios and Grau, 2020). The presence of a virtual 3D model to perform trials to assess the product design according to *Design-for-D/R* specifications represents a strategic tool towards an informed decision-making, reducing the uncertainty on re-manufacturing activities by performing accurate behavioural/performance forecasts and time/costs/impact estimations (Denis *et al.*, 2018; Wang *et al.*, 2020). By anticipating the economic and technical feasibility assessments in the design stage – therefore at low costs compared to those that should be incurred during the use phase of the product – it is possible to achieve two main advantages: on the one hand, it is possible to estimate which components are best suited to be reworked and then consequently designed in such a way that they will be easily re-manufactured in the future (Denis *et al.*, 2018). On the other hand, it is also possible to identify already in the design phase which will be the best re-manufacturing options and the related most suitable interventions to be performed after the use-cycles (Okorie *et al.*, 2018; Liu *et al.*, 2019).

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Tab. 11.2 - Examples of DfD/R criteria and specifications for building products to re-manufacture

DfR/D Criterion/Specification	**Description**
Accessibility and ergonomics	The element is accessible so that the maintenance operator can reach the element and unfasten all its connections.
Move-ability and transportability	The volume and mass of the element are suitable for machinery transportability (e.g. by wheel, train, etc.). In addition, the weight of the element is suitable to be moved by human operators.
Modularization/ standardization of product dimensions	The element has standard dimensions and it is made up by standardize modular components so that the related spare parts are easily available on the market.
Interchangeability of spare parts	The element can be broken down into standard interchangeable parts.
Availability of cores and spare parts	Core parts of the element (product) to be disassembled for re-manufacturing must be available.
Upgradability	The element has the potential to be upgraded overtime.
Technology availability	Availability of the basic technology to perform the re-manufacturing activity. In addition the technology is expected to remain stable over more than one life cycle.
Economic affordability	The cost of obtaining and reprocessing the element (or its parts) is low in comparison to the remaining added value.
Reversibility of connections	The different elements (products) and the connected parts of each element can be separated without damaging the elements, their components and connections.
Ability to be disassembled	The assembly is easy to be dismantled, requiring simple actions and a limited time to unfasten its connection, as well as limited work-force and common tools (thus limited costs).
Sequential dependency of disassembly steps	The sequential dependency of dismantling actions must ensure an easy disassembly (absence of interdependencies between elements and between the parts of an element). Ease to identify which other connection and/ or element need to be unfasten prior to the disassembly of the component to rework or substitute.
Market availability	Presence of a (primary or secondary) market segment and a market demand for the element (product) re-manufactured/to be re-manufactured.

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11.3 Smart services: ICTs for innovative product life-extension strategies within re-manufacturing models

The novel capabilities introduced in the previous paragraph open to new approaches to strategic and operational decision-making within circular models and, especially, service-based models (Lindkvist *et al.*, 2019), allowing to increase in resource efficiency while reducing the overall product life cycle costs (Bressanelli *et al.*, 2021).

In particular, ICTs have the potential to improve current product life-cycle extension practices (Alcayaga *et al.*, 2019), introducing advanced strategies for circular models within the construction sector, namely (Tab. 11.3): ICT-based Use, ICT-based Maintenance, ICT-based Reuse, ICT-based Re-manufacturing. Tab. 11.3 describes these strategies, focusing on the related enabling technologies and their contribution in the achievement of an effective management of products, data and information to guarantee value creation within circular models.

Tab. 11.3 - ICT-based strategies and enabling technologies for circular models within the construction sector

ICT-based Strategy	Execution frequency	Enabling technologies	Role of technologies towards a smart management	Improvements towards circular models
ICT-based Use	Constant during product use-cycles	– Sensors – Actuators – IoT – RFID – BMS – Data visualization tools	– Gathering and analyses of product location, availability and status (condition, operation, usage and environment information) – Product remote and/or autonomous control – Analytics tools for processing data on product usage levels	– Remote monitoring to collect use-related data improving product efficiency and safety – Product database to record overtime data at product/ component level – Analytics tools for estimating product residual lifespan
ICT-based Maintenance	Regularly during product use-cycles	– Real-time monitoring systems – BMS – Dynamic databases – Visualization tools and dashboards – Big Data management	– Technological capabilities from Smart Use – Preventive maintenance, including predictive and condition-based solutions based on big data analysis and prognostics algorithms	– Higher servitization level, diversification of the service offer and availability of new ICT-based services – New IoT-based preventive maintenance strategies, allowing to reduce

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Tab. 11.3 - continued

ICT-based Strategy	**Execution frequency**	**Enabling technologies**	**Role of technologies towards a smart management**	**Improvements towards circular models**
		– Data analytics and business intelligence tools – Sensing and Responding tools	– Real-time monitoring systems and databases on product maintenance history (records of faults) to draft accurate and dynamic the maintenance plan – Exploitation of data analytics and business intelligence tools and (in some cases) actuating capabilities	maintenance costs, downtime, unnecessary interventions, product replacements and waste production – Maintenance is performed adaptively according to product behaviours, thus reaching increased product availability, quality and performance while reducing expenditures – Product lifespan extension
ICT-based Reuse	After a use-cycle	– BMS – Data visualization tools – Dynamic databases – Data analytics tools	– Technological capabilities from Smart Use – Updated databases on product location, status and maintenance history (records of faults) gathered during previous use-cycles of the product – Data analytics tool to estimate residual performance of products	– Accurate evaluation of the reusability potential of smart products through the advanced detection/ estimation of product residual performance – Better informed decision-making for reuse – Increased efficiency of reuse processes, e.g. reduction of materials losses and logistic costs due to easy-accessible, reliable and updated product data (location, technical features, usage level, etc.)
ICT-based Re-manufacturing	After multiple use-cycles	– BMS – Data visualization tools – Dynamic databases	– Technological capabilities from Smart Use – Updated databases on product location, status and	– Advanced detection/ estimation of product residual performance – Informed decisions about product

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Tab. 11.3 - continued

ICT-based Strategy	Execution frequency	Enabling technologies	Role of technologies towards a smart management	Improvements towards circular models
		– Data analytics tools	maintenance history (records of faults) gathered during multiple use-cycles, including additional information on product design, technical features, disassembly and reassembly sequences, etc. – Data analytics tool to estimate residual performance of products	re-manufacturing based on reliable product lifetime data – Improved output quality, and possibility to simulate/estimate re-manufactured product performance – Reduction of re-manufacturing time, costs and waste (sorting, disassembly, reworking) – Availability of useful information for improving the design process of new products (Design for Re-manufacturing/ Disassembly strategies)

Source: Adapted from Atta, 2022

Specifically, these capabilities and the related improvements (Tab. 11.3) can be exploited within the three circular organizational models proposed by Re-NetTA project, namely:

– *OM1 "Rent contract as a support for re-manufacturing"*. This model is based on leasing and renting contracts, i.e. the same product is sequentially used by different customers. This kind of model involves new use-oriented payment systems including pay-per-use and pay-per-period.
– *OM2 "All-inclusive solution to support re-manufacturing"*. This model involves the selling of the product as a service plus a set of "quality services" (e.g. periodic quality testing, condition monitoring, preventive maintenance, sub-component upgrading, etc.) during the product use-cycles. The additional set of offered services enables to guarantee the availability and reliability of high quality construction products. This model implies pay-per-performance payment systems.

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– *OM3 “Alternative/secondary markets for re-manufactured products”*. This model is based firstly on the recovery of post-use products for reuse or repurposing, performed by an independent re-manufacturer and secondly on the distribution of re-manufactured products (on different markets or segments with respect to the original one), performed by a dealer. The payment system is deposit-based (product-oriented) in order to incentivize the customer to return the products after use, guaranteeing circularity.

Hence, Tab. 11.4 shows the suitability of the ICT-based strategies with respect to the three different proposed organizational models, highlighting for each case: the stakeholder/s performing the strategy, the ownership of the product, as well as the related payment system.

Tab. 11.4 - ICT-based strategies for Re-NetTA circular organizational models

Strategy	**Organizational Models**	**Strategy performer**	**Product ownership**	**Payment system**
ICT-based Use	OM1	Customer with Original Equipment Manufacturer	Retained by the Leaser/ Renter	Traditional single payment/pay-per-use or pay-per-period formulas
	OM2	Customer with Contracted Re-manufacturer	Retained by the Contracted Re-manufacturer (service provider)	Pay-per-performance (or pay-per-service) formulas
	OM3	Independent Re-manufacturer	Transferred to the Customer	Deposit-based single payment (with surcharge)
ICT-based Maintenance	OM1	Original Equipment Manufacturer	Retained by the Leaser/ Renter	Traditional single payment/pay-per-use or pay-per-period formulas
	OM2	Contracted Re-manufacturer	Retained by the Contracted Re-manufacturer (service provider)	Pay-per-performance (or pay-per-service) formulas
ICT-based Reuse	OM1	Original Equipment Manufacturer	Retained by the Leaser/ Renter	Traditional single payment/pay-per-use or pay-per-period formulas
	OM2	Contracted Re-manufacturer	Retained by the Contracted Re-manufacturer	Pay-per-performance (or pay-per-service) formulas

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Tab. 11.4 - continued

Strategy	**Organiza-tional Models**	**Strategy performer**	**Product ownership**	**Payment system**
ICT-based Re-manufacturing	OM1	Original Equipment Manufacturer	Retained by the Leaser/ Renter	Traditional single payment/pay-per-use or pay-per-period formulas
	OM2	Contracted Re-manufacturer	Retained by the Contracted Re-manufacturer	Pay-per-performance (-per-service) formulas
	OM3	Dealer with Independent re-manufacturer	Transferred to the Customer	Deposit-based single payment (with surcharge)

11.4 Smart links: digital platforms to shorten and strengthen connections between product manufacturers, users and re-manufacturers

Information platforms are commonly seen as promising vehicles for circular strategies development, spreading and innovation. Multi-stakeholders information platforms are expected to contribute to the long-term engagement among stakeholders (Alcayaga *et al.*, 2019) in order to establish collaborations useful for addressing still open issues and for overcoming the main barriers to the spread of virtuous re-manufacturing processes within the construction sectors. Information platforms exploit the advanced capabilities of data processing offered by ICTs and IoT for the activation and management of stakeholder networks, where the various actors cooperate, sharing and exchanging information (Ness *et al.*, 2019).

In particular, the Information Platforms scenario is currently characterized by two main trends that highlight a different use of the novel capabilities and potentialities of data management and processing offered today on the market by the several ICT providers. Indeed, it is possible to distinguish two main purposes of exploitation of information platforms:

1. creation and management of stakeholder network where the various actors can share and exchange knowledge and best practices, also having the possibilities of enlarging the extent of their business relationships (Innovation Platforms);

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2. creation and management of virtual marketplaces where the demand can match the offer, reshaping the traditional way of selling products by designing brokerage websites of e-commerce for the purchase and sale of goods and/or services (Marketplace Platforms).

The first category of information platforms (Innovation Platforms) supports the collaboration among stakeholders, enhancing their capacity to innovate. Indeed, the platform benefits from the interaction between a variety of stakeholders with different backgrounds and business segments and with access to different sources of knowledge that, if properly gathered and shared, has the potential to strengthen their collective actions (Hermans *et al.*, 2017). In particular, through information platforms, stakeholders become dynamic nodes that interact and share information, co-creating value within a sustainable digital ecosystem (Moro Visconti, 2019). Within the inclusive environment of the information platform, participants can exchange knowledge, experiences and their best practices (APSRG, 2014). The platform acts as an arena that bridges and holds together relevant actors to implement together problem solving strategies. At the European level, it is possible to identify several information platforms for stakeholder networking aimed at boosting innovation of circular economy strategies, including UNEP Circularity Platform (*buildingcircularity.org*) and ECESP "European Circular Economy Stakeholder Platform" (*circulareconomy.europa.eu/platform*). These information platforms act as dynamic virtual environments where stakeholders can exchange experiences and interact, submitting contents such as best practices, publications, events, networks, etc. They also involve already-structured networks, such as (among others) the ERN "European Re-manufacturing Network" (*re-manufacturing.eu*) that has been established under the Horizon 2020 Framework by the European Commission to encourage the development and uptake of re-manufacturing practices throughout Europe. At the national level, the creation of an initiative mirroring the European one was initiated by ENEA with the establishment of ICESP "Italian Circular Economy Stakeholder Platform" (*icesp.it*). ICESP represents an outstanding platform that aims at the dissemination of knowledge about circular economy, the promotion of dialogue and possible synergies between the Italian actors of different circular initiatives, the mapping of Italian good practices, also facilitating inter-sectoral collaborations.

The second category of information platforms is represented by the Marketplace Platforms or Transaction Platforms (digital matchmakers). This kind of platform is aimed to facilitate the online buying and selling by creating an e-commerce for B2B or B2C transactions. Therefore,

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Marketplace Platforms can be considered technology-enabled marketplaces that facilitate business connections between stakeholders. Hence, this typology of platform becomes "a new virtual stakeholder" (Moro Visconti, 2020; Atta, 2022) that links the traditional actors of the building process, including: product manufacturers, construction companies, dealers, facility managers, service providers, users, etc. With regard to Re-NetTA circular models, this kind of platforms seems to be particularly advantageous in the case of product renting and leasing (OM1) and in the case of product repurposing (OM3), promoting stakeholders' interactions by acting as product displayer, customer-finder and/or transactional intermediary.

At present, several marketplace platforms for the buying and selling of reused and re-manufactured (or to be re-manufactured) building components, construction materials and products (Tab. 11.5) are active on the national, European and international market, such as Enviromate (*enviromate.co.uk*), Opalis (*opalis.eu*), PlanetReuse (*planetreuse.com*), Reusewood (*reusewood.org*) and Salvex (*salvex.com*) (Atta, 2022), representing virtuous experimentations within construction fields. Tab. 11.5 presents the possible configurations (Atta, 2022) of virtual marketplace platforms emerged from the case study analyses.

Tab. 11.5 - Features of Marketplace Platforms for construction products

Marketplace Platform feature	**Description of possible configurations**
Mono-product or multiple products	Some platforms sell and buy products produced from a single raw material (e.g. Reusewood). Other platforms sell and buy a wide variety and range of products without focusing on a single raw material (e.g. Opalis, Salvex, PlanetReuse, etc.).
State of use of products (used, new, reworked or to be reworked, etc.)	Some platforms sell only used product to be "use as is" or to be re-manufactured (e.g. Opalis, Salvex and PlanetReuse). Other platforms also sell new products (e.g. Resusewood).
Presence/absence of mediator (Platform broker)	Some platforms play a significant role in the relationships between buyer and sellers (e.g. Salvex), defining: the roles for participation to the platform; the sustainability and feasibility of further use of the product proposed by the buyer; contract terms and conditions; payment modalities. While in other cases (e.g. Opalis, Reusewood, PlanetReuse), platforms only act as a virtual place that facilitates the match between demand and offer, without regulating the relationship between the contracting parties.

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Tab. 11.5 - continued

Marketplace Platform feature	Description of possible configurations
Geographic scale of the market	Some platforms act worldwide (e.g. Salvex), while others focus only on few neighboring countries (as in the case of Opalis that acts in Belgium, The Netherlands and France). Other platforms focus on regions (as in the case of Reusewood and PlanetReuse that act in North America). Laslty, there is the case of platforms acting in a single country (as in the case of Enviromate that operates throughout the UK).
Types of contract	Some platforms deal with sales contract to purchase products (e.g. Salvex, Enviromate) or services (e.g. Reusewood), some others deal with renting contracts for the renting of products.
Accepted stakeholders (B2B, B2C, C2C)	Some platforms accept only companies for a B2B contracts (e.g. Reusewood, Salvex). Otherwise, some companies accept also single buyers/sellers for B2C or C2C relationships (e.g. Opalis, Enviromate, PlanetReuse).

Concluding, digital technologies represent a valuable support for sustainable practices based on reuse and re-manufacturing, boosting the application of circular business models to the construction sector through advanced information management processes. Providing an overview of the main digital technologies for re-manufacturing (i.e. sensing technologies, IoT and smart data, digital twin, information platform), the chapter highlighted possible use-scenarios for overcoming organizational and information barriers towards the achievement of the expected economic and environmental benefits.

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12. *The environmental assessment of re-manufacturing*

by *Anna Dalla Valle, Andrea Campioli*

12.1 The shift from single to multiple life cycles

Resource scarcity, energy costs and supply chain management increasingly highlight the need to overcome the linearity of "take-make-waste" models in favour of circular practices. Accordingly, many circular strategies are pursued and applied for activating reverse logistic and Closed-Loop Supply Chain (CLSC). CLSC is meant as "the design, control and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time" (Guide and Van Wassenhove, 2009). In this perspective, recycling and re-manufacturing are in the spotlight (Govindan and Soleimani, 2017; Kazemi *et al.*, 2019), becoming significant market player at the core of the sustainability debate. The crucial difference is that while recycling is the action or process of converting waste into reusable material, re-manufacturing is the action or process of maintaining the value of a product to at least its original performance (Gunasekara *et al.*, 2018). Therefore, re-manufacturing turns out to be an upstream solution at the forefront of Circular Economy (CE), by preventing waste and full exploiting available resources (Paterson *et al.*, 2017).

Although promising, it is worth stressing that the implementation of re-manufacturing does not automatically lead to more sustainable products and buildings (Buyle *et al.*, 2019). Re-manufacturing has to be carefully assessed from both an environmental and economic point of view (Ghisellini *et al.*, 2016), accounting the specific process (e.g. disassembly, cleaning, reprocessing, assembly) but also the connected activities of the organizational model (e.g. transport, recovery and supply chain). For environmental purposes, Life Cycle Assessment (LCA) is well-recognized as the most eligible method to evaluate the environmental impacts of

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a product system over its life cycle. However, LCA is conceived as a linear environmental impact assessment approach that misfits the circular economy idea of multiple product life cycles (Eberhardt *et al.*, 2019a). Indeed, traditional LCA studies focus on the impact of a single life cycle, as appropriate, of materials/products/systems/buildings (Hauschild *et al.*, 2018). By contrast, pursuing CE for instance trough re-manufacturing, construction products potentially have different and multiple use cycles (van Stijn and Gruis, 2020; Suhariyanto *et al.*, 2017). Hence, a rethinking of LCA is required in order to support CE decision-making (Eberhardt *et al.*, 2020; van Stijn *et al.*, 2021), especially within the construction industry where re-manufacturing is mostly unexplored or still at the preliminary stage. The methodological challenge is to shift from "one life cycle" approach towards "multiple life cycle" approach to encourage continuous loops of products and materials.

In particular, the main critical and controversial LCA issues concern the definition, on one hand, of the service life and, on the other, of the allocation procedures. Indeed, the potential for multiple life cycle is limited by the products reversibility and the number of use cycles strictly depends by the associated service life. The trouble is that the service life calculation is affected by high uncertainty (Goulouti *et al.*, 2020) due to a variety of factors, including: the design level, the material and workmanship quality, the technological changes, the residual and resale values, the external and internal operational environment, the functional and aesthetic appeal (Cooper, 2004). As a result, LCA applications generally consider standardized values, for instance to assess the replacement phase of building products, neglecting the dynamic nature of the embedded material and elements. Nevertheless, since service life is pivotal to determine the number of use cycle in view of CE, it calls for more substantial insights to slow and close loops optimally. Emphasis is placed on the need to understand the interplay of the different types of service life (van Stijn *et al.*, 2021), matching technical, functional and economic lifespan. The technical lifespan is defined as the maximum period during which the product can physically perform (Cooper, 1994). The economic lifespan is the period in which benefits outweigh costs (Geraedts *et al.*, 2010). The functional lifespan is influenced by regulations and changing user needs, including the function or appearance of the building product (Geraedts *et al.*, 2010; Méquignon and Ait Haddou, 2014). By jointly analysing the different lifespans, the leading service life of the building product system can be identified, determining the related obsolescence and use rate (van Stijn *et al.*, 2021).

Beyond that, the distinction in LCA standards between closed-loop product systems and open-loop product systems raises the question of

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allocating the environmental benefits and burdens of reuse or recycling between multiple product systems. Closed-loop systems means that materials are reused/recycled in the same product to replace virgin materials, whereas in open-loop systems materials are reused/recycled into different product system. For facing multiple cycles (also called multifunctionality), ISO 14044 presents a hierarchical procedure. As a priority, allocation should be avoided (scenario a) by dividing the processes into sub-processes and cutting off the secondary cycles (a.1). Otherwise, system expansion has to be applied (a.2), including multiple cycles into the system boundary. If system expansion is not possible, allocation should be performed (scenario b) in the following order using: (b.1) underlying physical relationship (e.g. mass); (b.2) other relationships (e.g. economic value); (b.3) number of subsequent uses of the material. Hence, the European building LCA standards, namely EN 15804 and EN 15978, entail a combination of approaches, by using the "cut-off" allocation for production, use and end-of-life impacts (module A-C), extending the system boundaries to reuse, recycling and recovery potential but reporting separately the connected benefits and burdens (module D). Indeed, to date, there is no a single and widely accepted modelling approach for the environmental crediting of reuse/recycling (Allacker *et al.*, 2014). Three are the main commonly recognized approaches: 0:100, 100:0 and 50:50 (Baumann and Tillman, 2004), which attribute the impacts respectively to the second cycle, to the first cycle or equally to the first and second cycles.

To shift the environmental assessment from single life cycle to multiple life cycle, many open issues have to be solved, requiring simplification and standardization to enable consistent evaluations and easily put LCA into practice as a decision-making supporting tool towards circularity.

12.2 Materials flows analysis towards re-manufacturing

To encourage CE into the industrial practices, re-manufacturing is increasingly promoted and performed as a means of both maintaining the value of products and minimizing the waste of resources. Indeed, it allows to return used products (first cycle) to a level of performance equal to the original ones in order to achieve further applications (multiple cycles). The most virtuous re-manufacturing processes even upgrade product performances to condition beyond the original state, adjusting initial design flaws, improving traceability and/or adding functional and aesthetic improvements. In this way, impact reductions, cost savings and increased resource efficiency are only the main benefits of stakeholders associ-

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ated to re-manufacturing activities (Nasr *et al.*, 2017). The primary aim is to extend the service life of products, optimizing energy and material stream and thus preserving resource value. Dealing with durable assets, the lifespan extension opens up new opportunities for the accomplishment of additional life cycles by way of re-manufacturing products multiple times. This imply, as a necessary precondition for the establishment of re-manufacturing organizational models, the recovery of products to be re-manufactured. The crucial issue is that products involved into reverse logistic have to be suitable in terms of durability and characteristics to the follow-up investment of time, energy and materials, proving advantageous both economically and environmentally compared to virgin production (Krystofik *et al.*, 2018). However, assessment of the reliability and sustainability of supply chain presents uncertainty, since environmental impacts and economic performance are influenced by a wide range of variables.

In this context, a deep understanding of the material flows behind re-manufacturing plays a key role for different purposes. Firstly, to run the most varied sustainability assessments, including LCA quantification of the environmental impacts. Secondly, to provide interested parties a clear and fully comprehensive overview of the resources at stake in order to encourage re-manufacturing practices. In any event, with the aim to cycle building products at their highest utility and value, a paradigm shift is required in the way of looking at building product systems. Recalling the concept of "shearing layers" coined by Duffy and later further elaborated (Brand, 1994), they have to be intended as composite of materials and products, each marked by its own lifespan (van Stijn *et al.*, 2021). Hence, if joined by reversible technologies, the different layers could be changed independently, implementing as appropriate re-manufacturing depending on their residual performance. For extending the service life of the whole system, products and materials have to be exchanged and processed at different rate (Bocken *et al.*, 2016; Jansen *et al.*, 2020). Anyhow, it is worth stressing that the subsequent cycles are never completely closed-loops, demanding the consumption of new input resources and thus the supply chain of new materials (whether virgin or not). To sustain multiple re-manufacturing cycles, resource networks and processes are needed for enabling materials from products otherwise designated as waste to be utilized in a valuable manner (Guide *et al.*, 2003).

Targeting to reduce the complex re-manufacturing organizational model to the simple visualization of the underlying resource flows, Sankey diagram offers remarkably support. Indeed, focusing on materials and energy in many applications, it serves to map out process, aiding the understanding of losses and inefficiencies and giving a sense of scale

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across a system (Lupton and Allwood, 2017). The distinctive features are: (i) the diagram represents physical flows, related to a given functional unit or period of time; (ii) the magnitude of flows is shown by the stream widths, which are proportional to an extensive property of the flow, such as mass or energy (Schmidt, 2008). Currently, Sankey diagrams are intended to both Life Cycle Assessment (LCA) and Material Flow Analysis (MFA). Nevertheless, the pursuit of circularity and especially multiple cycles (CE) in conjunction with increasingly complex and detailed models call for changes in the flows display. A proposal revising such diagrams could be to correlate the dominant flow direction left to right with the time line, so that arrow heads on flows are not needed. Consistently, the main flow could be marked with vertical lines to specify the different process steps (e.g. production, construction, use, end-of-life) and emphasising the preserved resources by creating circular flows (e.g. in case of multiple use cycles). Indeed, as usually happens, it is horizontally divided into the constituting parts/materials sized according to their quantity. At some stage, new input resources are expected and thus added to the main flow for performing the specific processes, as well as some resources could be turns into output of the product systems.

To the issue of re-manufacturing, Sankey diagram results therefore pivotal for data visualization, by identifying inefficiencies and potential for savings when dealing with resources and mapping value flows in systems at different potential scales, as appropriate: at product, operational level or along supply chains.

12.3 Environmental profiles of re-manufacturing practice

As advertised, the well-structured and internationally recognized Life Cycle Assessment (LCA) is currently facing new challenges for quantifying the environmental impacts of re-manufacturing and, in general, of CE within the built environment (Eberhardt *et al.*, 2020; van Stijn *et al.*, 2021). These relate, for example, to the attribution of impacts in case of material sharing between more than one product system, to the account of substituted and new imputed materials, to the uncertainty derived from the assumption of service life and the estimation of long study period. Because of the lack of agreed LCA rules to support multiple cycles, the currently available LCA studies follow heterogeneous methodological approach, making difficult to compare results. Moreover, narrowing the application field to construction sector, they deal with different product systems, comparing alternative technological solutions at the different scales: from

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product to construction systems up to the entire building. In particular, objects of study are: office furniture subjected to multiple re-manufacturing cycles (Krystofik *et al.*, 2018); insulation products sourced by linear versus circular supply chains (Nasir *et al.*, 2017); common building elements, such as concrete column, window and roof felt, set out by linear versus circular design for reuse and recycling (Eberhardt *et al.*, 2019a); design variants of circular kitchen and business-as-usual kitchen (van Stijn *et al.*, 2021); internal wall assembly alternatives, including conventional and demountable/reusable solutions (Buyle *et al.*, 2019); office building with concrete structure designed for disassembly for subsequent reuse (Eberhardt *at al.*, 2019b). Generally speaking, circular product systems designed to accomplish multiple use cycles present higher initial impact compared to traditional solutions but low life cycle impacts over the long-term.

Besides the use of materials with different degree of innovation, technological connections are the chief distinction between product systems intended for linear models (traditional practice) and circular models (re-manufacturing practice). While traditional connections are characterized by wet technologies (e.g. adhesive, mortar), posing highly constraints for potential reuse; the connections conceived for circular processes are based on dry technologies (e.g. screw, interlocking sections). Indeed, being reversible, they ensure the easily disassembly of elements and materials, without compromising their integrity and essential functions. As a result, in line with "shearing layers" perspective (Brand, 1994), elements and materials may be exchanged and subjected to re-manufacturing at different rate according to their lifespan and performances, in order to extend the service life of the whole system. Potential benefits of introducing demountable and reusable construction solutions to meet multiple cycles are point out by many literature studies, however the question of how properly modelling their process circularity in LCA is still open.

Recognizing the need for a comprehensive sustainability assessment to drawn responsible choices, a preliminary assessment of the environmental profile of traditional versus potential re-manufacturing practice is following disclosed, on the base of the different underlying technological connections. Note that re-manufacturing practice is considered as potential since envisioned starting from construction products currently available on the market and suitable for the implementation of re-manufacturing organizational model, but not yet jointly established in practice. In particular, the attention is turned to the reversibility of fixing solutions for wall finishing as crucial factor for activating multiple cycles and thus extending life of product systems frequently changed especially within tertiary architectures.

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The focus is on magnetic Glass Panels Systems (GPS), now marketed with two fixing connection alternatives (Squiggle Glass Limited, 2017): glued to the wall ("glued-to-wall") or attached with hooks supplied by the company ("hook-on"). With a view to circular economy, the fundamental difference is that hook-on solution enables to effortlessly remove panels from the supporting brackets and to move them to new locations using basic hand or power tools. In this way, depending on the adopted connection type, GPS turn out to be representative with glued-to-wall panels of traditional linear model and with hook-on panels of potential circular re-manufacturing model, since designed to be re-usable and re-locatable if properly configured. Once installed, both serve as finishing layer of interior walls, providing great flexibility, in covering whole or partial surfaces and fit spaces of any dimensions, and great visual impact, since available in a wide range of colours and fully customizable by printing images or logos behind the glass. Moreover, GPS are substitutable to drop-down screens and traditional writing boards, allowing users to project and write at the same time, easily cleaning with magnetic eraser. Due to their functionality and versatility, they are nowadays used in a variety of application context (Squiggle Glass Limited, 2017), including business (e.g. open plan and individual offices, breakout and reception areas, meeting and conference rooms), commercial (e.g. retail shops, dining), healthcare (e.g. waiting rooms, children and patient wards), education (e.g. teaching rooms, staff offices), service (e.g. information hall, rest areas) architectures. Nevertheless, note that the proposed re-manufacturing practice shows great promise for tertiary sector, distinguished by frequent renewal of the fit-out and thus by the use for short cycle of product systems that are usually removed still with high residual performance.

The present LCA study thus assesses and compares the environmental profile of glued-to-wall GPS traditional practice (linear model) versus hook-on GPS inclined to re-manufacturing practice (circular model). They are modelled according to three alternative scenarios that, given the variability of the functional lifespan of construction product systems especially within tertiary buildings, are not representative in terms of time of study period but rather in terms of possible use cycles. Scenario A evaluates the life cycle of GPS considering one single use, whereas scenario B and scenario C account two use cycles, by adding to the first standard use a second use cycle intended for the estimation of potential life extension and resource optimization. Specifically, scenario B looks on the second use as an application inside the same building by the same owner ("reuse inside"). By contrast, scenario C envisions the second use as an application outside the original building, transferring the products to a new building and owner

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(“reuse outside”). The functional unit is 1 m^2 of Glass Panels Systems (GPS) with related fixing connections, including as system boundary: the raw material extraction, transport and production (A1-A3); the transport from manufacturing plant to building site (A4); the construction-installation process (A5); the use (B), properly as single/multiple applications, inside or outside; the de-construction for recovery (C1); the transport from building site to treatment facility (C2); the treatment processes of materials and elements (C3); the disposal at end-of-life (C4) and credits for potential reuse, energy recovery and recycling of materials and elements in subsequent product systems (D). To avoid burden shifting, the LCA-based environmental profile is performed on the complete range of impact categories aimed at providing a holistic and comprehensive overview of the practices under study.

Concerning the life cycle inventory (LCI) of the background system, emphasis is placed on the collection of specific Environmental Product Declarations (EPD), released by the same program operator (International EPD System). In the few cases of non-availability, the environmental data are sourced from recognized databases (Ecoinvent, Okobaudat). Consistent with traditional or re-manufacturing practices, the LCI of the foreground system is set out starting from the technical information found in the EPDs. Moreover, a dialogue has been established notably with GPS manufacturers, in order to fully understand product materials and the degree of reversibility in relation to the type of connections. Based on this, assumptions are made for assessing the entire life cycle scenarios (Tab. 12.1), including single or multiple use, for both traditional practice (glued-to-wall GPS) and re-manufacturing practice (hook-on GPS).

GPS products are composed of steel and flat glass sheets jointly glued and with frameless construction that allows to offer a seamless presentation area and to fit any flat vertical surface (Squiggle Glass Limited, 2017). During manufacturing, steel sheets are coated with a polyester-based powder coat and the glass toughened then back-painted using a polyurethane paint, within specialist facilities prior to final assembly of the panels at GPS production plant. The mass of the declared unit (1m^2 of panel system) is about 21kg for glue-to-wall GPS (37% steel) and 22kg for hook-on GPS (39% steel). Finished panels are prepared for delivery by arranging protective corners, that are removed after installation and returned to production plant for reuse. In line with EPD assumptions, GPS products are delivered directly to the construction site, considering negligible any intermediate stop to central warehouse and taking into account an average transport distance. In case of glue-to-wall solution, the installation activities include adhesives as additional materials and plastic packaging as waste materials on the building site. Instead, hook-on

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Tab. 12.1 - LCA inventory for glue-to-wall practice (traditional model) and hook-on practice (re-manufacturing circular model)

Phase	Description	Object	GLUE-TO-WALL PANEL	HOOK-ON PANEL	UM
A1-A3	Raw material supply, transport and manufacturing	Glass Panel System (GPS)	21	22	kg/m^2
A4	Transport from manufacturer to building	Distance	70	70	km
A5	Construction/installation processes	Adhesive	0,1	-	kg/m^2
		Steel connections	-	0,3	kg/m^2
		Electricity	-	0,075	kWh
		Plastic waste	0,05	-	kg/m^2
1st use	Single use with no maintenance	-	-	-	-
2st use inside	De-construction	Electricity	n/a	0,075	kWh
	Re-installation within the office	Electricity		0,075	kWh
2st use outside	De-construction	Electricity	n/a	0,075	kWh
	Transport from office to retail (including printed film)	Distance		70	km
	Re-installation into retail	Electricity		0,075	kWh
	Application of	Printed film		0,28	kg/m^2
C1	De-construction processes	GPS	21	22	kg/m^2
C2	Transport from building to treatment facilities	Distance	70	70	km
C3	Treatment processes	Glass panel	13,2	13,8	kg/m^2
		Steel components	7,8	8,2	kg/m^2
C4	Waste disposal	Adhesive	0,1	-	kg/m^2
D	Recycling benefits	Glass panel	13,2	13,8	kg/m^2
		Steel components	7,8	8,2	kg/m^2

Source: authors elaboration from Squiggle Glass Limited, 2017

solution call for the combination of galvanised brackets and steel screws, totally avoiding waste generation. Along the operational phase, both GPS products require no special maintenance beyond cleaning, which is carried out with a purpose-made magnetic eraser. At end-of-life, being composed primarily of glass and steel elements, panels are 95% recyclable. After the easily performed separation of different material sheets, the remaining 5% of glue is removed, trough appropriate treatments prior to recycling. Thereafter both glass and steel, follow the standard recycling scheme in compliance with the European waste directive.

The modelling of alternative scenarios is carried out in relation to the specific fixing connection, considering circular practices viable only for hook-on GPS and unattainable when GPS are fixed with glued-

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to-wall solution. This is why scenario B and C of glued-to-wall GPS is modelled by doubling the environmental impacts of the traditional life cycle (scenario A), assuming that GPS are produced, installed and disposed for allowing the first use as for accomplishing the second use. Conversely, all hook-on GPS are suitable for re-manufacturing practices, being designed to be reusable and re-locatable, if properly configured. In this case, for performing the re-layout of spaces and the personalization of specific areas, panels are easily disassembled from the supporting brackets and the brackets moved to the new location using basic hand or power tools. Scenario B (reuse inside) takes thus into consideration an additional consumption of electricity used by the equipment tools before for the de-construction and after for the reinstallation of hook-on GPS in another location of the original building. Note that since steel connections are intended for reuse, no additional materials are expected during the second use cycle. Instead, scenario C (reuse outside) of hook-on GPS accounts besides the energy usage for disassembly/assembly, the follow-up transport from the original building to the new building (e.g. from office to retail) and the new input materials of printing layer (3M, 2019). Indeed, since at present panel colour cannot be changed once the product system is manufactured, it is expected the application of self-adhesive film to meet branding purpose both for indoor and outdoor graphics and signs.

Tab. 12.2 discloses the LCA-based environmental profiles of glued-to-wall GPS and hook-on GPS, each according to scenario A (single use), scenario B (reuse inside) and scenario C (reuse outside) and considering the complete set of impact categories. By interpreting the environmental impacts of scenario A, literature results are hereby confirmed, namely the higher initial impact of circular product systems compared to traditional solutions. In fact, glued-to-wall GPS shows the best environmental performance when one single use is taken into account over the product life cycle. Here (scenario A), hook-on GPS leads to higher emissions, rising of about +5% all indicators (percentage share based on the average of values). The benefits of reversible fixing solution appear evident in case of multiple use cycle, being capable of achieving considerable emission reductions thanks to the implementation of reuse and re-manufacturing practices for maximum effectiveness and optimization of available resources. In particular, in the event of GPS second use inside the building (scenario B), hook-on solution allows to decrease up to –35% the overall emissions (average value) compared to glued-to-wall solution. Emission saving are limited to around –30% (average value) when the second use of GPS occurs outside the original building (scenario C), because of the additional impacts caused by the further transport of product system and

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Tab. 12.2 - LCA results for glue-to-wall practice (traditional model) and hook-on practice (re-manufacturing circular model) according to the different scenarios

			Scenario A		Scenario B		Scenario C		Benefits beyond the system	
			Total A-C w/ 1st use		Total A-C w/ 1st use and 2nd use inside		Total A-C w/ 1st use and 2nd use outside		Total D	
			GLUE-TO-WALL PANEL	HOOK-ON PANEL	GLUE-TO-WALL PANEL	HOOK-ON PANEL	GLUE-TO-WALL PANEL	HOOK-ON PANEL	GLUE-TO-WALL PANEL	HOOK-ON PANEL
ENVIRONMENTAL IMPACT	Global warming potential (GWP)	[kg CO2-Eq]	5,56E+01	5,74E+01	1,11E+02	5,74E+01	1,11E+02	6,63E+01	-1,36E+01	-1,43E+01
	Depletion potential of the stratospheric ozone layer (ODP)	[kg CFC11-Eq]	6,48E-06	6,65E-06	1,30E-05	6,65E-06	1,30E-05	7,19E-06	6,44E-08	6,79E-08
	Acidification potential of land and water (AP)	[kg SO2-Eq]	2,95E-01	3,05E-01	5,89E-01	3,05E-01	5,89E-01	3,31E-01	-3,40E-02	-3,58E-02
	Eutrophication potential (EP)	[kg PO_4^{3-}- Eq]	4,40E-02	4,65E-02	8,80E-02	4,65E-02	8,80E-02	5,21E-02	-3,14E-03	-3,29E-03
	Formation potential of tropospheric ozone photo- chemical oxidants (POCP)	[kg Ethene Eq]	3,14E-01	3,15E-01	6,29E-01	3,15E-01	6,29E-01	3,20E-01	-3,75E-03	-3,97E-03
	Abiotic depletion potential for not fossil resources (ADPE)	[kg Sb Eq]	3,83E-04	6,31E-04	7,66E-04	6,31E-04	7,66E-04	6,59E-04	-3,99E-05	-4,20E-05
	Abiotic depletion potential for fossil resources (ADPF)	[MJ]	9,26E+02	9,48E+02	1,85E+03	9,48E+02	1,85E+03	1,08E+03	-1,40E+02	-1,47E+02
RESOURCE USE	Use of renewable primary energy excluding renewable primary energy resources used as raw materials (PERE)	[MJ]	4,98E+01	5,24E+01	9,96E+01	5,24E+01	9,96E+01	6,66E+01	5,42E+00	5,73E+00
	Use of renewable primary energy resources used as raw materials (PERM)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Total use of renewable primary energy resources (PERT)	[MJ]	4,98E+01	5,24E+01	9,96E+01	5,24E+01	9,96E+01	6,66E+01	5,42E+00	5,73E+00
	Use of not renewable primary energy excluding not renewable primary energy resources used as raw materials (PENRE)	[MJ]	9,72E+02	9,99E+02	1,94E+03	9,99E+02	1,94E+03	1,14E+03	-1,38E+02	-1,45E+02
	Use of not renewable primary energy resources used as raw materials (PENRM)	[MJ]	4,56E+01	4,15E+01	9,11E+01	4,15E+01	9,11E+01	4,15E+01	0,00E+00	0,00E+00
	Total use of not renewable primary energy resources (PENRT)	[MJ]	1,02E+03	1,04E+03	2,04E+03	1,04E+03	2,04E+03	1,18E+03	-1,38E+02	-1,45E+02
	Use of secondary material (SM)	[kg]	4,11E+00	4,46E+00	8,22E+00	4,46E+00	8,22E+00	4,46E+00	0,00E+00	0,00E+00
	Use of renewable secondary ruels (RSF)	[MJ]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1.29E-21	-1.35E-21
	Use of non renewable secondary fuels (NRSF)	[MJ]	2,32E-02	2,18E-02	4,63E-02	2,18E-02	4,63E-02	3,27E-02	-1,52E-20	-1,59E-20
	Use of net fresh water (FW)	[m^3]	6,74E-01	6,98E-01	1,35E+00	6,98E-01	1,35E+00	7,42E-01	1,11E-02	1,18E-02
OUTPUT FLOWS AND WASTE	Hazardous waste disposed (HWD)	[kg]	3,31E+00	3,62E+00	6,62E+00	3,62E+00	6,62E+00	3,64E+00	-7,58E-06	-7,99E-06
	Not hazardous waste disposed (NHWD)	[kg]	9,02E+01	9,71E+01	1,80E+02	9,71E+01	1,80E+02	1,01E+02	9,66E-01	1,02E+00
	Radioactive waste disposed (RWD)	[kg]	4,37E-03	4,49E-03	8,73E-03	4,49E-03	8,73E-03	6,99E-03	-8,41E-04	-8,78E-04
	Components for reuse (CRU)	[kg]	0,00E+00	0,00E+00	0,00E+00	6,31E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Materials for recycling (MFR)	[kg]	5,39E+00	5,56E+00	1,08E+01	5,56E+00	1,08E+01	5,56E+00	0,00E+00	0,00E+00
	Materials for energy recovery (MER)	[kg]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Exported Electrical energy (EE)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
	Exported Thermal energy (ET)	[MJ]	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Source: authors elaboration

the application of the new printing layer. In compliance with building LCA standards, all scenarios entail significant benefits beyond the system boundaries (module D), since mainly composed by recyclable materials not to be disposed. Indeed, after the treatment processing assessed in module C3, both glass panel and steel elements are intended for recycling, causing negative impacts by avoiding in the following cycle the consumption of new raw and virgin materials. Note that here hook-on GPS are more advantageous since slightly heavier (22 kg) than glued-to-wall GPS (21 kg), increasing the benefits up to +4% compared to the traditional solution.

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LCA results prove therefore how circular product systems designed to accomplish multiple use cycles (hook-on GPS) present higher initial impact compared to non-reversible solutions (glued-to-wall GPS), but low life cycle impacts over the long-term. However, it is worth stressing that this is a preliminary assessment of the environmental profile of the different technological products systems and related potential practice. It does not claim to be exhaustive, but rather to support eco-innovative approaches for designing, producing and operating in order to maintain resource value and extend product life cycle. In view of the potential benefits, the aim is to raise awareness among construction operators of the whole supply chain and stimulate the offer of circular products and processes. The present study provides therefore insights into the environmental impacts of re-manufacturing practice, while allowing to point out the technological hotspots to be further developed (reversibility of all elements by avoiding the use of glues) and the relations to be build up to implement multiple cycles. Here, the challenge is the developing of business synergies (e.g. between GPS and printing layer manufacturers) and the consequent activation of re-manufacturing network to put it into practice.

To conclude, it is of interest to note how in some instance the practice of re-manufacturing can turns into "adaptive re-manufacturing," a neologism to describe the use of product core to create similar but non-identical product (Krystofik *et al.*, 2018). This is the case of scenario C (reuse outside) in which the updating and customization of products enable to meet present market needs and to achieve life cycle extension beyond what is attainable with standard re-manufacturing. Indeed, the application of new printing layer allows the company to adapt the product offerings to the evolving market demands without requiring fundamental changes in the resource supply chain. The original product system (wall finishing) operates in the same function, only changing in terms of appearance (branded print), showing great potential for retail application context, such as to fulfil the fast and quick change of shop windows. For securing closed loop cycle, the potential of re-manufacturing as well as adaptive re-manufacturing attains the maximum when end-user cyclically becomes the supplier and the customer for the re-manufacturer (Krystofik *et al.*, 2018). In this perspective, the circularity of product flow into re-manufacturing practice can generate both long-term environmental and economic benefits. The crucial issue to succeed in a circular economy is that benefits of extending product life through multi-cycle must outweigh the impacts of re-manufacturing processes and practice. To this extend, LCA can validate the potential environmental savings associated to design and business choices that foster a circular economy towards re-manufacturing.

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13. Traceability system to support sustainable reuse and re-manufacturing process

by *Serena Giorgi, Monica Lavagna*

13.1 Product life cycle information to enable reverse logistic

The manufacturing of most building products is a globalized process, often involving a complex supply chain, from raw material to final product. Usually, the producers are not aware of the material ingredients and sourcing of raw materials of certain parts of the product they manufacture. Thus, they remain uninformed about the entire supply chain and the several characteristics of the product (e.g. recycled content). After the production, from the use to the end-of-life phase, the products change ownerships, generally, without any monitoring on their use, maintenance, performance degradation. Currently, building products follow a linear approach and, at the end of their useful life, they are usually disposed in landfills, or, at best, they are downcycled (Giorgi *et al.*, 2017), as they are considered without any residual economic and performance value.

Before being sold, the building products are equipped with mandatory or voluntary certifications (e.g. the conformity marking CE is mandatory in the European Union; the EPD – Environmental Product Declaration – is a voluntary certification), technical information sheets, declared performance levels, and a shared and clear economic value. This information is important for the manufacturer in selling the product to the customer.

Subsequently, however, after the installation and the assembly on site, the building products suffer a "loss of identity", as the wealth of information is frequently not stored and preserved. This loss of knowledge occurs regardless of the time of use and the quality conditions of products. This practice determines that building products, at the end of their use, are "devoid" of any characteristic that makes them attractive to other potential future users.

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Due to the complexity and fragmentation of the entire life cycle, that involves several phases carried out by different stakeholders, it is very difficult to know all product information during the entire life cycle (from material extraction to the disassembly after use and the end of life). The lack of knowledge of the product characteristics, often, hinder the potential extension of its useful life through the activation of a "reverse logistic". Revers logistic means the return management, after the sale and use of products, through a circular operation such as re-manufacturing, reusing, refurbishing, recycling, in order to recapture value at the end of product's useful lifecycle (Agrawal *et al.*, 2016; Macongue and Chinomona, 2022). Revers logistic moves the products back to the initial producer or to a new operator in the original value chain, or to another chain. To activate this circular dynamic, it is necessary to identify the value of product, recognized either by the original producer or by other markets. Consequently, it is necessary to know the (original) characteristics of the product, but also all the interventions that occurred during use and which may have compromised or maintained its characteristics and performances.

Keeping track of information along the life cycle is, therefore, a way to "maintain the value" of the product over time. This is particularly true in cases where the cycles of use are short, due to the temporary nature of the function in the building, so the product has not undergone degradation and effectively "preserves" its performances. Producers, re-manufacturers or potential reusers do not want to take the responsibility to reuse or re-sell products of which they do not know the characteristics, the supply chain and the life cycle operations (Chapter 5-6-7; Giorgi *et al.*, 2022).

The possibility to trace information relating to each specific material is fundamental to improve quality control and maintenance of value over time, increasing confidence in second-life products by users and re-workers. However, there are currently limitations in traceability and communication through the supply-chain.

13.2 Supporting tools for product traceability within a life cycle and circular perspectives

In this context, technology is a carrier to achieve the implementation of digital and intelligent transformation for supply chain transparency and material traceability, helping the activation of circular economy. Principally, BIM (Building Information Modelling) is identified as an enabling technology with great potential for the circular economy as it is possible to accumulate and keep information on the life cycle of products

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into a building (Eadie *et al.*, 2013). Through that digital technology, it is possible to trace the geometric and mechanical characteristics, the location, the age, and the expected service life of the products, to allow possible evaluation on potential products' reuse in a new project (Minunno *et al.*, 2018).

With the introduction of BIM technology, the key-players – such as architects, engineers, main contractors, subcontractors, facility managers – can use the same model for the design, the construction and the management. The initial characteristic of products stocked in a building, information about elements and the entire building system, can be stored in the BIM model. This information can be useful for the future management throughout the building life cycles and can be updated with information during the use, e.g., for each maintenance activity or requalification change.

BIM, as sharing information tool along the life cycle, becomes even more useful in the case of temporary uses of buildings and circular management of products (reuse, re-manufacturing, repurposing) through the life cycle by a network of operators.

To enable circular pathways and reverse logistics of products, multiple tools, often interoperable with BIM and conceived as web-based digital platform, are being developed and debated in the literature (Abruzzini and Abrishami, 2021; Atta *et al.*, 2021; Bertin *et al.*, 2020; Charef and Emmitt, 2021). For example, Material Passport is a tool that are most promoted and discussed by policies and stakeholders.

Material Passport (MP) can be developed as a web-based passport for registered buildings and construction objects. The aim is to create a common digital platform of knowledge about quantity and location of materials stocked in the built environment. The concept of preserving the (economic) value of materials is one of the main objectives of the MP. Through the MP, it is therefore possible to know the type of material and the quantity present in a specific building, the characteristics and the origin. Consequently, this information makes it possible to know the quantity of materials that become available after the first cycle of use, for possible reuse, re-manufacturing, repurposing or recycling.

An example of a MP already developed is Madaster (Rau and Oberhuber, 2019) set by Madaster Foundation with the scope to encourage intelligent design, facilitate the reuse of materials and eliminate waste. The platform Madaster (which collects all Madaster MPs) has a public interest, but the primary users are buildings asset owners, facility managers and design teams. The Madaster MP is interactive with BIM or excel source files, imported by users. Inside MP, all information about the building and materials are inventoried and documented. General information about the building are collected, e.g., location, size of the building, cadastral infor-

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mation, (if any) environmental labels present (e.g. BREEAM excellent), energy consumption. The Madaster MP provides the quantity of materials stocked inside the building, divided into "six part of building", based on their expected duration (based on the "six layers" of Stewart Brand): site, structure, skin, services, space plan, stuff. In addition, the Madaster MP shows the net financial value of each material. It is interesting for investors/owners to understand the value of materials inventory at the end of their life cycle. The economic evaluation provides a forecast of demolition costs and the transport costs of the end-of-life material, in comparison with the value of the same raw material. The comparison of cost and value provides the awareness of the economic advantage (or disadvantage) of the potential reuse of material. Currently, MP shows, in particular, that metals and glass products (which are also materials often used for interior office spaces) maintain a positive value over time, representing a possible gain for investors. Madaster evaluates also, for each building equipped with MP, a "circularity indicator" (CI), between 0 and 100%.

To support the traceability activities, there are also other kind of tools. For example, the RFID (Radio Frequency Identification) technology would allow products to be "chipped" not only allowing to keep memory directly on the product characteristics, but also to potentially map the routes (transport), e.g. favouring reverse logistic collection. This technology allows to attribute a unique electronic identity to the product: authenticating it, tracing its life cycle, following it in its production, distribution and use phases, collecting and crossing data (Big Data) along this path generated by multiple actors involved, in a dynamic and conscious process of co-creating value through information (see Chapter 11).

The information contained in the memory of the chip can be modified and updated over time, in order to keep track of transformations or ownership passages to which the product is subjected during its life cycle: with the RFID tag, the information follows the product, from the beginning to its disposal, becoming a narrative label.

In this case, traceability can enable a logistical optimization for collecting heterogeneous products on dissassembling sites, intervening in a targeted manner and selecting only the material or products of interest. Moreover, in the case of reverse logistic, the logistic management of returning products can be optimized, mapping their real time distribution on the territory.

These tools are particularly important in the context of temporary uses, where the traceability of information related to the life cycle is simpler, considering that the activities along the whole life cycle can be monitored. The use of tools able to keep and share information can be the neces-

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sary support to overcome the barriers related to the lack of awareness of products performances and the difficulty of detecting flows of available materials, which emerged from the interaction with stakeholders during roundtables for the applicability of proposed circular organizational models (see Chapter 5, 6, 7).

Therefore, the collection of information, through the use of digital technologies, can constitute an important knowledge on use, assembly-disassembly, transport, etc. This information can help to create a product life cycle "management" chain and support the manufacturer to extend control over the entire life cycle, monitoring actions outside the productive plant, optimizing processes and activities toward reuse/re-manufacturing. This management can be carried out by the producer of origin or shared between several operators across the network. In this case, the exchange and updating of information constitute an indispensable link to enable circular actions.

13.3 Necessary improvements of life cycle traceability information towards sustainability

New circular strategies could apparently bring environmental benefits in a single phase of the life cycle, however, by shifting environmental impacts to other phases. For example, to solve the problem of construction and demolition waste, often, circular strategies lead to the promotion of recycling, considering the environmental benefit of avoiding landfill disposal, but without considering the environmental implication of the recycling process activities (transport, reprocessing, etc.). Hence, the traceability and collection of environmental information along the whole life cycle of circular products is important also to evaluate the sustainability of circular re-actions and circular organizational models. However, information on product life cycle sustainability is not yet systematically collected, not even in MPs (like Madaster).

The building products at the end of building life cycle have "embedded" environmental burdens (related to its production, assembling, maintenance and so on), that constituted an important element in the balance of the product. Consequently, the product "information profile" have to be related not only to its residual economic value or its residual performance, but also to the environmental burdens that it already generated during its life.

Early disposal of products (as occurred in case of temporary use or tertiary architecture) creates an increase in the environmental burdens,

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related to every production of short-life products. By contrast, multiple life cycle of products, through reuse/re-manufacturing, can "avoid the environmental impacts", related to the manufacture of new products and the disposal of end of life products. In fact, the reuse/re-manufacturing of a product determines the opportunity to avoid new impacts for the creation of a new product, constituting an important environmental benefit.

The Material Passport or traceability tools have an important role in keeping track of the environmental information on the product, allowing to know the impacts incorporated along its life cycle, but also to know important aspects that can affect the modelling of impacts (e.g. in relation to the material composition, to the presence of scarce material resources, to the recyclability potential, to the ability of storing carbon, to the disassembly conditions).

From a life cycle point of view, it is necessary to trace all information regarding:

– the raw materials/recycled materials and their source (including transports);
– the production of the product, as well as the product composition, the environmental profile of production phase, if possible obtained from the EPD (Environmental Product Declaration) of the product itself;
– the distribution of products (logistics) to the building site;
– the technologies of assembly, during the building construction phase, and the condition to disassembly and reuse;
– the management of the product, inventorying the maintenance works and partial replacement occurred throughout the use phase;
– the service life and durability, verifying the real cause of disposal, whether due to obsolescence or really due to performance degradation;
– the end-of-life management (e.g. reverse logistic), mapping the typical end of life scenarios for the specific product and related transports;
– the reuse/re-manufacturing/repurposing activities, eventually occurred, and number of cycles of use (in a circular perspective).

If this information were constantly tracked for all products, there would be a process of enrichment of the information related to the phases of the life cycle that are currently poorly documented (in particular the use phase).

The activation of the traceability of life cycle information creates a double advantage. On the one hand, it returns a knowledge value that helps to preserve information over time, allowing the activation of circular dynamics (reuse/re-manufacturing/repurposing) aimed at sustainability. On

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the other hand, the collection of information along the life cycle constitutes a knowledge value. For example, during the use phase the collection of information would help to know the real durability of the elements (beyond the producers' declarations, which identify indicative scenarios of durability or even "eternal" durability), understanding the real reasons of the end of life and residual performances after temporary use. Hence, this knowledge value would help the planning of improvement scenarios towards sustainable construction and management practices of circular buildings and reuse/re-manufacturing practices of products.

13.4 Potentiality of traceability tools and the role of operators across building process

The use of digital technologies for the traceability of life cycle information not only affects the knowledge processes, but also affects the design and management of the operational processes. It also affects decision-making processes, considering the role of life cycle information to support decision towards an effective circularity and environmental sustainability.

From an operational point of view, traceability tools involve various operators who cooperate horizontally along the life cycle of the building, in particular:

- designers, who have the task of tracing the information during the design phase;
- suppliers, who know the source of product materials and their characteristics;
- manufacturers, who know the characteristics and performance of final products;
- builders, who carry out the assembly phase and know also the technique for disassembly;
- facility managers or users who have to keep the track of use, maintenance, modification or replacement cycles that the product and building undergo during the service life;
- end-of-life managers, who manage the condition for a reverse logistic, towards reuse, re-manufacturing and recycling routes;
- re-manufacturers, who transform and process products to extend their useful life cycle.

However, due to the multiple stakeholders involved, the continuous updating of the inventory over time, and therefore the maintenance

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of correct life cycle information, is not easy. For this reason, recently, the integration of BIM and Blockchain technology (as complementary platforms) is a hot topic discussed in literature. Indeed, blockchain can safely store privacy-sensitive data and aid to exchange effective and truthful information (Turk and Klinc, 2017; Liu *et al.*, 2019), enabling the involvement of users who are core players for building/products management. Blockchain is a new application mode of computer technology, which allows its participants to transfer assets over the internet without centralized third parties (Liu *et al.*, 2019). It is a distributed data structure, that is replicated and shared among the members of a network, where the IoT combination is considered powerful to cause significant transformations in different sectors to enable new organizational models (Christidis, 2016).

The collaborations established between the actors of the value chain allow the collection of information over time, defining the history of the products. In this way, the information goes beyond the memory of the individual operator, and it is kept along the life of the product, through the various cycles of use. The sharing of information along the life cycle and over time (especially in the case of short life cycles and reuse/re-manufacturing/repurposing) allows a continuous updating of knowledge and the possibility for the various operators belonging to the reverse logistics to become aware of the actions carried out along the chain. For example, to enable reuse/re-manufacturing/repurposing process, blockchain technology allow to communicate prescriptions (e.g., modularity, connections, decided during the design phase) or indications for assembly/use/maintenance/disassembly to the other operators in the chain, in a process of continuous improvement.

In this context, digital technology becomes an enabling means to support circular networks in which stakeholders can operate in a context where information sharing and communication facilitate the entire supply chain, along the entire life cycle of products. Moreover, traceability tools are particularly important to extend the useful life cycle of products through reuse/re-manufacturing/repurposing strategies in the direction of environmental sustainability, supporting the control and the assessment of life cycle input and output flows.

In parallel, it is still necessary to improve the integration of different kind of information and activate specific training for supply chain operators to allow systemic data collection.

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14. Value chain insights and opportunities to foster re-manufacturing: adopting a Sustainable Product-Service System approach within tertiary architectures

by *Marika Arena, Sara Ratti, Luca Macrì, Carlo Vezzoli*

14.1 Collaborative organizational models for circularity: a Product-Service System approach

In a circular perspective the imperative is to establish a certain level of decoupling between the economic output and the environmental impact that is attached to the production and consumption of the good or service. A circular vision necessarily questions the dynamics ruling the current production and consumption systems, considered in the mainstream economic model as linear flows of inputs and outputs and by nature not compatible with a circular-oriented approach.

In this regard, the Sustainable Product Service System (S.PSS) has been studied since the end of XXI century as promising organizational and offer models coupling environmental and economic benefits. Specifically, S.PSS is defined as follows (Vezzoli *et al.*, 2021):

«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/user 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 with the provider/s, so that the same provider/s continuously seek/s environmentally and/or socio-ethically beneficial new solutions, with economic benefits».

In relation to the definition of S.PSS, three main model characteristics may be outlined:

– **From product sale to "unit of satisfaction" provision**. S.PSS shifts the business focus from selling (only) products to offering so-called

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"unit of satisfaction", i.e., a combination of goods and services jointly capable of meeting the satisfaction of the final user.

- **Innovation integrating the stakeholder interaction level**. S.PSS addresses at first the innovation at a stakeholder interaction level, then it moves to a technological one. In this regard, multiple innovative stakeholder configurations can apply (i.e., a product offer combined with all-inclusive product life cycle services to customer; offer as enabling platform for customers; final result offer to customers).
- **From ownership to accessibility**. S.PSS shifts the value perceived by he customer from individual ownership to access to goods and services.

S.PSS characteristics are aligned with one of the approaches promoted by the European Union within the Circular Economy Action Plan (2020) based on "incentivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle"(European Commission, 2020).

Three main S.PSS approaches to system innovation have been studied, adapted and listed as favourable for eco-efficiency, including lifespan extension and in particular re-manufacturing and reuse (Hockerts & Weaver, 2002; Tukker, 2004; UNEP, 2002; Vezzoli *et al.*, 2014).

a) Product-oriented S.PSS.
b) Use-oriented S.PSS.
c) Result-oriented S.PSS.

14.1.1 A Product-oriented S.PSS (type I): adding value to the product life cycle

In summary, a Product-oriented S.PSS innovation adding value to the product life cycle is defined as (Vezzoli *et al.*, 2021):

> a company/organization (alliance of companies/organizations) that provides all-inclusive life cycle services – maintenance, repair, upgrading, substitution, re-manufacturing and product take-back to guarantee the life cycle performance of the product/semi-finished product (sold to the customer/user).

A typical service contract would include all-inclusive maintenance, repair, upgrading, substitution, re-manufacturing and product take-back services over a specified period of time. The customer/user responsibility

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is reduced to the use and/or disposal of the product/semifinished product (owned by the customer), since she/he pays all-inclusively for the product with its life cycle services, and the innovative interaction between the company/organization and the customer/user drives the company/organization's economic interest in continuously seeking environmentally beneficial new solutions, i.e. the economic interest becomes something other than only selling a larger amount of products.

14.1.2 Use-oriented S.PSS: offering enabling platforms for customers (type II)

In summary, a use-oriented S.PSS innovation offering an enabling platform to customers is defined as (Vezzoli *et al.*, 2021):

> a company/organization (alliance of companies/organizations) that provides access to products, tools and opportunities enabling the customer to get their "satisfaction". The customer/user does not own the product/s but operates them to obtain a specific "satisfaction" (and pays only for the use of the product/s).

Depending on the contract agreement, the customer/user could have the right to hold the product/s for a given period of time (several continuous uses) or only for one use. Commercial structures for providing such services include leasing, pooling or sharing of certain goods for a specific use. The customer/user consequently does not own the products but operates on them to obtain a specific final satisfaction (the client pays for the use of the product). Again, in this case, the innovative interaction between the company/organization and the customer/user drives the company/organization to continuously seek environmentally beneficial new solutions together with economic benefits, e.g., to design highly efficient, long-lasting, reusable and recyclable products.

14.1.3 Result-oriented S.PSS: offering final results to customers (type III)

In summary, a result-oriented S.PSS innovation offering final results to customers is defined as (Vezzoli *et al.*, 2021):

> a company/organization (alliance of companies/organizations) that offers a customized mix of services, instead of products, in order to provide a specific

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final result to the customer. The customer/user does not own the products and does not operate on them to obtain the final satisfaction (the customer pays the company/organization to provide the agreed results).

The customer/user benefits by being freed from the problems and costs involved in the acquisition, use and maintenance of equipment and products. The innovative interaction between the company and the customer/user drives the company's economic and competitive interest to continuously seek environmentally beneficial new solutions, e.g., highly efficient, long-lasting, reusable, easy-to-re-manufacture and recyclable products.

14.2 The implementation of Product-Service Systems in re-manufacturing contexts: challenges and opportunities for product durability

S.PSS might overcome the criticalities emerging from the application of a linear and traditional sale organizational model to a circular business proposition. Indeed, in a traditional product supply and demand chain, economic benefits mainly derive from the sales volume (directly related to the amount of goods sold). According to this view, product durability is a characteristic that potentially threatens the sales volume, hence the economic revenues, by reducing the number of sold units. Hence manufacturers might not encourage the extension of product lifespan, being not incentivized from an economic point of view.

Differently, an S.PSS implies that the origin of economic revenues of a product or service provider shifts from the sole sale of good to an offer of products and services, paid per unit of user's satisfaction. By offering services oriented to extend the product lifespan (i.e., maintenance, repair, upgrade, substitution, re-manufacturing), the longer durability of product or its components, the higher probability of avoidance or postponement of provider's disposal costs or costs attached to the production and selling of new product (economic benefits). In this setting, producer/providers are driven by economic interests to offer products and services oriented to fulfil customers' needs, rather than the product sale. This implies the motivation to lengthen product lifespan duration, hence minimizing environmental impact of businesses and favouring circular business propositions, such as re-manufacturing.

In relation to the specific context of re-manufacturing, the main opportunities connected to a Product-Service System can be summarized as: environmental optimization of product lifecycle through product and

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material lifespan extension and manufacturers' ownership. These will be briefly discussed.

As anticipated in the previous paragraph, the promotion of product lifespan extension is a key aspect of S.PSS that fits with the primary objective of a circular business proposition, such as re-manufacturing-based ones. In particular, as far as the S.PSS provider is offering the product, retaining the ownership and being paid per unit of satisfaction, or providing an all-inclusive product-service offer (i.e., maintenance, repair and upgrade and substitution), the longer the product/s or its components durability (environmental benefits), and the more the provider avoids or postpones the disposal costs plus the costs of pre-production, production and distribution of a new product substituting the disposed one (economic benefits). Hence the providers are driven by economic interests to design (offer) for lifespan extension of product/s.

In a similar way, the approach to both the design and use of materials and components are driven by the objective to extend their usability and durability as long as possible. Indeed, as far as the product-service provider is selling the product all-inclusive of end-of-life services, she/he will try to recycle or extend the lifespan of materials to avoid or to limit the costs attached to landfill or to the purchase of new primary material, energy or compost.

Consistently, the S.PSS focal aspect on accessibility in substitution of user's product ownership advances potential synergies with a re-manufacturing approach, both from the manufacturer's and user's side. Indeed, by retaining the ownership and/or the responsibility for life cycle services/costs of the products or its parts, the manufacturers have an intrinsic interest in designing products for longer lifecycles, to enable re-manufacturing opportunities after the use phases. Moreover, by only exploiting the functions of the products, not having the ownership on the physical goods, the user's acceptance for a re-manufactured good is enhanced, hence increasing potential demand for these types of products.

Despite the numerous potential synergies between Product-Service Systems and re-manufacturing, some criticalities are recognized largely in practice, leaving the implementation of re-manufacturing-based S.PPS limited to some experiences. Main challenges and barriers associated to Product-Service Systems and re-manufacturing are connected to the market acceptance, the management and forecast of cost and revenue flows and the approach to organizational changes (Copani and Benham, 2020).

One of the major barriers encountered by re-manufactured products is related to market attractiveness. Indeed, the evaluation of possible outdated performance and aesthetics might make customers more uncer-

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tain in front of re-manufactured alternatives. This aspect proves the reality that re-manufactured products are currently sold in business-to-business sectors, in the contexts of spare part substitution or secondary market segments: in these contexts, function is preferred than aesthetics and other cultural aspects and the market attractiveness is mainly driven by cost convenience and performance.

Product-Service Systems and re-manufacturing imply also to rethink the economic stream flows, such as costs and revenues. Indeed, the introduction of the product return, in a post-consumer phase, implies an additional aspect given the augmented unpredictability related to both the timing and to the conditions of the returned good, hence increasing overall information asymmetries. Also, a Product-Service System, grounded on the provision of a service along a specific period of time, requires a revisited and adjusted demand forecasting system in order to determine the optimal pre-determined price. In general, the complexity of the sales forecasting is amplified and more sophisticated capability to capture evolving market needs is significant in the revenue and cost management system.

Moreover, the complex nature of financial stream management required in a re-manufacturing-based Product-Service System imposes the arrangement for significant changes at organizational level. For instance, the competences and resources needed to assess the financial value of the returned goods, given the multiple uncertainty factors in the system, cover more significant roles in the organization. Hence the different financial management also require the organizational willingness to rethink functions roles and management.

14.3 Product-Service System models in relation to re-manufacturing value chain of tertiary architecture industries

The various categories of tertiary buildings are characterized by short renewal times, accelerated obsolescence of equipment and interior fittings, prevalence of dry assembled and highly performing components. Moreover, tertiary buildings are mostly managed by facility management integrated with service providers that are generally responsible for real estate, representing large volumes of components, requiring repair or disposal in case of building renewal. These intrinsic elements of the tertiary sector within the construction industry represent key premises for the applicability of re-manufacturing, oriented to reduce the current significant environmental impact of the business.

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Considering the various synergic elements between re-manufacturing and Product-Service Systems, Re-NetTa research project aimed at investigating the opportunities of a re-manufacturing-based S.PSS model into the tertiary architecture context, by formulating and discussing potential innovative organizational schemes together with practitioners. In particular, this has been carried out through engagement activities – i.e., semi-structured interviews and roundtable sessions – with companies and stakeholders from different areas of the tertiary architecture sector (exhibition, office, retail). In this section, key insights related to the lesson learnt from this study are summarized, distinguishing the opportunities, the challenges, and the needs.

In relation to enabling elements retrieved in the tertiary architecture context, two major value chain aspects are presented.

One element is connected to the procurement strategy, oriented to activate the provision of the necessary cores for re-manufacturing or re-processing operations. This deals with the establishment of a contractual relationship with the user that ensures the possibility and the conditions to re-collect the product after a use-cycle. Consistently, through the formulation of business models for re-manufacturing for the tertiary construction industry, multiple procurement strategies for activating a reverse supply chain have been presented and discussed.

Specifically leasing-based contracts and service contracts have been selected as proper commercial strategies with customers of tertiary construction sectors, for securing the relationship with customer that is embedded in a service-oriented business model, rather than a single-payment and solely product-oriented one. Surcharge-based (based on a surcharge payment at the return of the sold product) and buy-back mechanisms (based on an offered price to the customer for the return of the sold product) were not identified as suitable strategies in the tertiary architecture applications, mainly due to the relatively low value of the product post-consumption and the service-based orientation of the relationship with the customer.

Specifically, leasing-based systems are recognized to be a reality in some businesses when there is a relevant driver related to fiscal advantages for the customer: this is the case of the leasing of furniture components for corporate offices. As emerged from the interaction with key stakeholders, leasing-based arrangements are also considered potential tools for enabling close-loop business models for selected categories of products within the office environment – which are characterized by a low level of customization and a strong customer focus on the resource function.

A second element retrieved in the value chain of some tertiary architecture contexts that might be in line with a Product-Service System

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offer logic is the shift towards “accessibility” moving away from the sole “product ownership” concepts.

Specifically, the way supply chain actors interact is currently linked to a sale, through which the ownership and the life cycle responsibility over the good is transferred from the provider to the recipient. Differently, the Product-Service System logic challenges this existing interaction structure, by moving beyond the ownership and/or the life cycle responsibility concept and leveraging on the access to a specific experience of product use (through a product, or a service, or a combination of both). In relation to this aspect, some industrial contexts of tertiary architectures emerged to be more ready for a Product-Service System logic than other ones.

For instance, in exhibition fitting sector, some experiences proved that the retention of product ownership in the hands of the provider assumes a significant role in the viability of a circular business offer, since the design and the management of the business proposition are defined for a product lifecycle extension ex-ante: this again fits with inherent features of S.PSS offer models.

The engagement of field actors and experts also led to the understanding of main hindering elements of product-service-oriented models for re-manufacturing.

A major barrier was identified in the increasing level of product customization and branding. If on one hand, these trends might stimulate long-term customer relationships and customer retention strategies, on the other hand they are not often consistent with a product re-manufacturing and reuse approach.

A second issue deals with the flow of materials coming from maintenance, renewal or demolition processes of tertiary buildings. The research led to the understanding of experiences from tertiary architectures, that often demonstrated that the volumes of materials are not sufficiently high to determine the birth of side circular businesses, and the re-organization of existing linear practices. As highlighted among the recognized challenges associated to Product-Service Systems, the demand forecasting covers a relevant role in the design and management of a PSS offer. Therefore, a market characterized by a high demand instability (recorded in terms of types of components and quantity) does not represent a promising arena for the implementation of a product-service-oriented model for re-manufacturing products.

The understanding of hindering factors attached to the tertiary architecture context put the basis for the definition of the key needs for the application of possible circular organizational models based on a Product-Service System logic.

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First, in order to mitigate the customization trend, a relevant need is identified in the formulation of market solutions characterized by a fair balance between modularity and customization. By promoting modularity and standardization of technical elements, post-consumer operations, such as assembling and disassembling, product retrieval, maintenance, repair and replacement, are facilitated. Moreover, more standardized products are more easily to destinate to different markets, opening further opportunities for the product lifecycle extension. This issue shed the light on the enabling role of design phase within the value chain oriented to extend product lifecycle. It is worth to stress that the design of modular and more standardized products should consider the potential threat of a low market attractiveness of those products. Indeed, as explained in 14.2.2, the low market acceptance emerged to be a challenging aspect for the diffusion of re-manufactured products.

Secondly, market players recognize that the shift to a re-manufacturing model requires relevant changes in the structure and dynamics of the existing supply chain, hence a support from the policy and regulatory frameworks is demanded in this regard. Specifically, the operations of a re-manufacturing business model request the availability of various resources (both economic, physical resources and intellectual capital) that are missing or scant in the existing network: hence, the definition and the support for new professional figures with proper cross-sectoral skills, including eco-design and circular practice management linked to the building process along the whole product life cycle.

Further policy tools and incentives are called in relation to the promotion of innovative and circular practices within existing market mechanisms. For example, environmental requirements introduced in the tender definitions are recognized to be a driver for moving existing players toward the experimentation of more sustainable practices.

The investigation of the state-of-art of industrial systems within the office, retail and exhibition arenas led also to the understanding that a set of guidelines of procedure and methodological guidelines are demanded to have a comprehension about possible opportunities for re-manufacturing. Also, more interventions are needed in the aspects of regulations, for the definition of procedures and entities for ad-hoc certifications associated to re-manufactured goods.

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15. Reuse and re-manufacturing in the building sector: current regulatory framework and future needs

by *Nazly Atta, Luciano Zennaro*

15.1 Sale, donation and leasing: regulatory framework for the transfer of goods within re-manufacturing processes

The Chapter aims to provide an overview of the main aspects of novelty introduced by reuse and re-manufacturing practices within the current Italian regulatory framework of the building sector. In particular, the Chapter focuses on three key fields that, from a regulatory point of view, result to be more affected by the introduction of new circular strategies, namely:

– negotiation aspects in the context of sale, donation and leasing (Par. 15.1);
– safety aspects and involved actors (Par. 15.2);
– environmental aspects and waste management (Par. 15.3).

Hence, the present paragraph introduces a study of the three main channels for the marketing and transfer of re-manufactured assets in relation to the proposed Re-NetTA organizational models (see Chapter 4), namely sale, donation and leasing. The objective of the paragraph is to highlight the limits and potentials – from a regulatory point of view – of these practices within the construction sector, hence identifying possible drivers for the effective and efficient implementation of circular practices of reuse and re-manufacturing.

It is important to underline that the research is conducted on a national level, in line with the geographical area of reference of the Re-NetTA project (from the territory of the Lombardy region up to the national level). However, the methodological scheme applied for the analysis of the regulatory context can be replicated in different national contexts (referring to their own legislative references) as well as at the European scale.

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15.1.1 Potentialities and criticalities of the sale of products in circular processes

In the context of the Italian legislation, the deed of sale, on a general level, is mainly governed by two regulatory tools:

– the Civil Code ("*Codice Civile*");
– the Consumer Code ("*Codice del Consumo*") (Legislative Decree *d.lgs.* 206/2005).

The civil laws are dispositive, i.e. they may be waived by the will of the parties. According to Art. 1470 *et seq.* of the Civil Code, «the sale is the contract which has as its object the transfer of ownership of a thing or the transfer of another right to the consideration of a price» and it implies the following obligations for the seller:

– delivery of the "thing" (i.e. physical asset) to the buyer;
– acquisition of the property of the "thing" or the right, if the purchase is not an immediate effect of the contract;
– guaranteeing the buyer the absence of defects of the "thing".

In particular, for what concerns the last point, «the seller is required to ensure that the sold thing is free from defects that make it unsuitable for the use for which it is intended or appreciably decrease its value. The agreement by which the guarantee is excluded or limited has no effect if the seller has concealed in bad faith the defects of the thing to the buyer» (Art. 1490 of the Italian Civil Code). Hence, the legislator leaves this aspect to the will of the parties who, acting in good faith, can define specific agreements to exclude or limit the guarantees. Therefore, in the context of the sale of "not new" products, these agreements could have particular relevance. In fact, the contractors usually know the history of use of the objects to sell and the presence of possible physical deterioration.

On the other hand, the provisions of the Consumer Code are different. They are imperative and therefore cannot be waived between the parties: in fact, any agreement prior to the communication to the seller of the lack of conformity, aimed at excluding or limiting – even indirectly – the rights recognized in the matter of guarantees is null and void. The duration and characteristics of the guarantee are governed by Art. 128 and following. In particular, Art. 132 states that the seller is responsible when the lack of conformity occurs within two years from the delivery

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of the goods, extending the guarantees also to re-manufactured products. Indeed, the provisions also apply to the sale of used consumer goods, taking into account the time of previous use and solely the defects not deriving from the normal use of the thing. More precisely, in the case of used goods, the parties may limit the duration of the liability to a period of time in any case not less than one year.

It is important to stress that the Consumer Code is addressed only to the individuals or "natural persons" (*persone fisiche*) acting for purposes unrelated to any entrepreneurial, commercial, craft or professional activity. Therefore, the Consumer Code does not apply to legal persons (*persone giuridiche*) or other comparable subjects such as self-employed workers, freelancers or the so-called Third Sector (Legislative Decree *d.lgs.* 117/2017). In particular, third sector entities include: voluntary organizations, social promotion associations, social enterprises, social cooperatives, associative networks, mutual aid societies, associations, foundations, etc. set up for the non-profit pursuit of civic, solidarity and social utility purposes.

The following table (Tab. 15.1) describes possible scenarios for the sale of re-manufactured products, focusing on some sale cases between subjects belonging to different categories. In this regard, it is important to highlight the role of the public administration that could favor the use of re-manufactured products within public tenders by regulating, or excluding, certain guarantees.

Tab. 15.1 - Sale of re-manufactured products within the construction sector: laws and scenarios

Sale by private owner	
Sale between individuals (natural persons, "*persone fisiche*")	**Feasible with restrictions** The individual can sell re-manufactured or reused products on an occasional and sporadic basis (not allowed on a periodic and permanent basis).
Sale from a legal person (or other business or professional entity) to an individual	**Feasible with restrictions** Subject to both civil law provisions (derogable) and the provisions of the Consumer Code. These latter provisions cannot be waived and therefore the selling party must guarantee, for the non-new product, a legal guarantee of at least one year.
Sale between legal entities (or other entrepreneurial or professional entities)	**Feasible** Subject to civil law provisions, which – by the will of the parties – can also be waived in the field of guarantee (Article 1490 of the Civil Code).

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Tab. 15.1 - continued

Sale by private owner	
Sale from legal person (or other entrepreneurial or professional entity) to Third Sector	**Feasible** Subject to civil law provisions, which – by the will of the parties – can also be waived in the field of guarantee (Article 1490 of the Civil Code).
Sale from legal person or (or other entrepreneurial or professional entity) to public body	**Feasible with restrictions** Subject to civil law provisions, to the R.D. 2440/1923 (on the general accounting of the State) and the related implementing regulation (R.D. 827/1924), as well as by L. 241/1990 (administrative procedure). It is not subject to the Consumer Code but to the provisions of the announcement, basically with specifications regarding guarantees or certifications.

15.1.2 Potentialities and criticalities of the donation of products in circular processes

The donation is governed, in the first instance, by the Civil Code. The Art. 769 of the Civil Code defines the donation as the contract by which, out of a spirit of liberality, one party enriches the other, disposing of a right in favor of the latter or assuming an obligation towards the same. The donation must be made by public deed, under penalty of nullity, with the exception of donations of movable goods of modest value, as can be the case of products to be re-manufactured. The modest value is also to be evaluated in relation to the economic conditions of the donor. The donation may be burdened by a charge (so-called modal donation) such as the possibility of donating furniture with the express purpose of using them in a circular building process. The "good" must be accepted by the *donee* (i.e. the one who receives the good) and it has no forms of guarantee if exercised in good faith. Art. 797 of the Civil Code affirms, in fact, that the donor must give a guarantee to the *donee* for the "eviction" (withdraw) of the donated good only in the following cases: if he has expressly promised the guarantee; if the eviction (withdraw of the good) depends on the willful misconduct or personal fact of the donor; in the case of a donation that imposes charges on the *donee*, or a remunerative donation. In this last case, the guarantee is due up to the amount of the charges or the amount of services received by the donor. While the following article provides that unless special agreement, the donor's guarantee does not extend to defects in the

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thing, unless the donor has been fraudulent (e.g. presence of non-visible asbestos fibers of which he is aware).

The following two tables describe some scenarios for the donation of reused/re-manufactured products, performing a distinction between public bodies (Tab. 15.2) and private law entities (Tab. 15.3).

Tab. 15.2 - Donation from public bodies of re-manufactured products within the construction sector: laws and scenarios

Donation from public bodies	
Donation from public body to another public body	**Feasible** if it achieves the best and correct management of public assets and the satisfaction of a public interest (see Resolution no. 16/2020/SRCPIE/PAR of the Court of Auditors of Piedmont).
Donation from a public body to the Third Sector	**Feasible** if it falls within the conventions and procedures referred to in: Art. 55 of Legislative Decree 117 of 2017 (Third Sector Code), Law 241/1990 (rules on administrative procedures) and according to the rules governing the social planning of the area. This through: – co-programming (identification of needs and interventions); – co-planning (identification of needs and interventions); – accreditation through comparative procedures reserved for the same (Third sector association). Always subject to the statutory provisions on donation.
Donation from public to private body	**Not feasible** According to art. 3, par. 1, of the R.D. 2440/1923, the acts of alienation of public assets must be included in the "active contracts", which must result in an entry in the financial statements of the entity (see Lombardy Court of Accounts, judgment no. 164 of 7 May 2019).

Tab. 15.3 - Donation from private operators of re-manufactured products within the construction sector: laws and scenarios

Donation by private owner	
Donation from an individual to another private law entity	**Feasible** Subject to civil law provisions: – guarantee for withdrawal; – liability for defects.
Donation from a legal person (or other entrepreneurial or professional person) to another person under private law	**Feasible with restrictions** It must be motivated, such as in cases of "corporate social responsibility", since – from a fiscal point of view – the donation may not be considered congruent with the profit-making purpose of a company.

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Tab. 15.3 - continued

Donation by private owner	
Private donation to the Third Sector	**Feasible** The Ministerial Decree of 28.11.2019 of the Ministry of Labor and Social Policies also regulates the conditions for tax deductions.
Donation from private to public body	**Feasible with restrictions** Subject to the statutory provisions on donation. Subject to the regulations of the single public administration. For example, Article 75 of the Accounting Reg. of the Municipality of Milan provides «without prejudice to the authorizations of the law, the City Council (Municipality) provides for the acceptance or refusal of bequests and donations of goods according to their respective competences; the relative resolution establishes the destinations of these and of any profits deriving from them».

15.1.3 Potentialities and criticalities of the leasing of products in circular processes

The leasing and long-term rental of movable goods in the corporate world are becoming more and more frequent, particularly for goods that require constant maintenance, such as cars and computer or multimedia devices. Leasing is a legal transaction with which an entrepreneurial entity – generally a company of a financial nature or specialized in the provision of loans – offers the use of assets, requesting the payment of a consideration paid in periodic fees.

The leasing and long-term rental can be extended to furniture and building elements, increasing the possibility of reuse and re-manufacturing in the construction sector – as proposed in the organizational models introduced in Chapter 4 (especially OM1 and OM2).

The leasing contracts often also include a maintenance contract. The provision of a maintenance service represents for the owner of the asset an opportunity to record all the interventions performed on the asset itself (maintenance history of the element), being able to inform and guarantee – in case of reuse – the end user on the actual quality of the good. Lastly, it should be stressed that usually leasing is reserved for legal entities and bodies with profit-making purposes, while long-term rental can also address the individual private (natural person, "*persona fisica*").

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15.2 Safety aspects and involved actors: certifications, qualifications and responsibilities

The issue of safety is crucial in the context of reuse and re-manufacturing processes within the construction sector. In particular, in the most common case of employment of reused or re-manufactured elements in the context of a workplace, the issue is addressed by the Legislative Decree *d.lgs.* 81/2008. According to the Legislative Decree *d.lgs.* 81/2008, in workplaces, the assessment of all risks to health and safety in order to reduce exposure for workers is an obligation of the employer. The use of "safe" materials and products, therefore, falls within the general protection measures. Measures that in addition to the employer may involve:

– "designers of places/workplaces and technological systems", who must comply with «the general principles of prevention in the field of health and safety in the workplace when making design and technical choices» and choose «the equipment, components and protective devices that comply with the relevant legislative and regulatory provisions» (Art. 22 of the Legislative Decree *d.lgs.* 81/2008);
– "manufacturers, suppliers and installers", as it is «forbidden to manufacture, sell, rent and license work equipment, personal protective equipment and systems that do not comply with the laws and regulations in force on health and safety at work» (Art. 22 of the Legislative Decree *d.lgs.* 81/2008).

However, except in the cases defined by specific regulations, to date there is no mandatory law that defines for the furniture (such as a table or a chair) or the constructive elements (such as a movable wall or an internal door) which are the criteria for defining them as "safe". It is, therefore, often referred to the "technical data sheets" provided by the manufacturer. For example, the well-known "conformity mark" of the European Community is mandatory only in cases expressly established by the Brussels regulations, which concern the kind of goods that, due to their use or material, could be harmful or dangerous to the health of the consumer or user, such as toys, medical devices, glasses, electrical devices, gas devices, machines, radios and TVs, household appliances, etc. Hence, reused or re-manufactured furniture or non-plant construction elements are not included in the category of assets under the Community scrutiny. It is, therefore, a discretionary assessment that the employer must carry out with the support of skilled professional roles. Among these professionals there are:

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- the "supervisor" (person in charge, "*preposto*"), that is the person who, by reason of professional skills and within the limits of hierarchical and functional powers appropriate to the nature of its assignment, supervises the work activity and guarantees the implementation of the directives received, checking the correct execution by the workers and exercising a functional power of initiative;
- the "head of the prevention and protection service" (RSPP – "*Responsabile del Servizio di Prevenzione e Protezione*") that is the person who owns the skills and professional requirements (pursuant to Art. 32 of the Legislative Decree *d.lgs.* 81/2008) designated by the employer (to whom he responds) to coordinate the risk prevention and protection service.

These professionals, based on the specificity (functions and features) of each individual furniture or building element, evaluate with adequate and certified technical knowledge if the safety requirements are respected or not.

Another figure who can acquire an important role is the "construction supervisor", that is the qualified professional who must verify the correspondence of the work to the project, the observance of the project execution requirements, the quality of the materials used and the installation. The construction supervisor issues, when included in the assignment, a report in which he can certify compliance with these requirements, including the safety of re-manufactured products.

It is important to underline that this discipline does not apply to properties subject to specific regulation: such as – first of all – the business activities subject to fire prevention under the Presidential Decree *d.p.r.* 151/2011, e.g. garages, shops with an area greater than 400 square meters, offices with more than 300 employees or with an area greater than 5,000 square meters, hotels with more than 25 rooms, theaters, cinemas, schools and many types of productive buildings. For all these buildings subject to accident/fire prevention it is not possible to use re-manufactured products where fire reaction (class 0, 1, 2, 3, 4, 5) or fire resistance (REI 30, REI 60, REI 120 etc.) requirement are imposed, for example in escape routes. However, there is still some room for using re-manufactured elements also in these buildings, focusing on not critical spaces. For instance, in an office with more than 300 employees, a re-manufactured door – if not subjected to laboratory tests – cannot be used to separate two passive fire protection compartments or to access escape routes, but it can instead be used for separating the toilets from the anteroom.

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15.3 Environmental aspects and waste management

In the last forty years, European and national policies have been increasingly sensitive to environmental and waste management issues. In this regard, in the long run, the donation and selling of building elements for reuse and re-manufacturing could represent a viable alternative to land-filling. However, currently there is one major still-open issue that needs careful consideration. In fact, the boundary between the interpretation of what is considered waste or scrap and what can be considered material/product to be reused and/or re-manufactured is currently unclear and uncertain.

In the event that the materials/products from construction and demolition activities are disposed of, it is unequivocal that they become a waste (specifically defined by the Legislative Decree *d.lgs.* 152/2006 and by the most recent Legislative Decree *d.lgs* 116/2020) and so subject to the aforementioned legislation.

Furthermore, Art. 183 of the abovementioned decree defines as "waste" any substance or object that the holder discards or has the intention or obligation to discard. However, with the term "discard" there is a risk that a product to be re-manufactured may be equated with waste and therefore subject to specific legislation, hindering reuse and re-manufacturing processes.

This uncertainty, that currently risks to hinder the diffusion of circular reuse and re-manufacturing practices within the construction sector, requires the introduction of an *ad hoc* legislation for this new field and its business operators.

15.4 Future perspectives for the building sector

Going beyond the "waste-resource" approach, reuse and re-manufacturing are able to prevent the creation of waste by anticipating end-of-service-life management actions and setting up suitable product maintaining and transformation processes, in order to reach a "resource-resource" approach. Re-manufacturing practices, albeit still experimental, are today carried out by several operators in the construction sector with satisfactory results and benefits. From a regulatory point of view, reuse and re-manufacturing practices are not yet included in the current Italian law framework of the construction field. In absence of specific regulatory tools, the present Chapter proposed an overview of the applicability of current standards and laws in the context of circular business models,

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highlighting main responsibilities and restrictions. The regulatory barrier seems to hinder the spreading of reuse and re-manufacturing practices for the systematic sale of reworked products among companies but at the same time it leaves room for experimentations and trials in the fields of donations and leasing. The operators of the construction sector recognize the multiple potentialities linked to these circular practices that entice both companies and legislative entities to harmonize the references on the subject of re-manufacturing and to outline together new guidelines for a future systematic adoption of these circular practices in the construction sector.

As a starting point, among the possible viable actions to promote the re-manufacturing market, it is possible to propose:

- the allocation of volumetric bonuses for operators who use re-manufactured products in new construction (pursuant to Art. 3.1 letter e of the Presidential Decree *d.p.r.* 380/2001);
- the attribution of volumetric bonuses in building renovation interventions (pursuant to Art. 3.1 letter d of the Presidential Decree *d.p.r.* 380/2001) – which also include the demolition and reconstruction of buildings (or parts of) – for operators who use re-manufactured products in new buildings and who have activated re-manufacturing actions for existing products within demolition processes;
- tax incentives for operators who use re-manufactured products in new works in the interventions of extraordinary maintenance, conservative restoration and building renovation (pursuant to Art. 3.1 letters a, b, c and d of the Presidential Decree *d.p.r.* 380/2001).

These proposals are consistent with both the volumetric bonuses provided for sustainable construction by various urban planning instruments, such as the urban government plan ("*Piano di Governo del Territorio – PGT*") of the Municipality of Milan, and by some urban regeneration laws, such as the L.R. Lombardy 18/2019 as well as by the state legislation on tax incentives for energy saving, including the well-known D.L. 34/2000 conv. L. 77/2020 (so-called "*Ecobonus 110%*").

Concluding, the diffusion of this new field in the construction sector requires a revision of the current regulatory framework together with a review of the design and production practices of the construction elements toward reusability, placing at the center of construction activities the principles of sustainability.

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Conclusions

Re-manufacturing, re-condition, re-purpose, reuse, repair (the integrated “re-actions”) are potentially winning strategies of circular economy in the building sector.

However, at present, some main barriers to a full development of those five integrated “re-actions” are still present in the building sector. Considering tertiary buildings – but these considerations can be extended to many other fields – some main aspects can be highlighted:

– inadequate information and knowledge to share among the stakeholders of the re-manufacturing processes mainly due to the absence of proper communication channels and the lack of technical information on those building products intended to become re-manufactured products.
– The re-manufactured building products still have a limited market, uncertain costs and consumers are not yet fully confident in their quality. Moreover, a common concern may rise among manufacturers, fearing that the re-manufacturing may cannibalize their primary market, possibly reducing the higher profit margin obtained from the sale of new building products.
– It is still difficult to identify common rules for the definition of those features that should characterize a product suitable for re-manufacturing. This could lead to an increase of the costs required to make these products warrantable.
– Current legal ambiguity over re-manufacturing (also thinking to trans-national delivery that may involve different jurisdictions). In general, there is still a lack of clarity in legislation about the re-actions processes, especially for what concerns the declaration of re-manufactured products and the use of re-manufactured items in new products.

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Anyway, reducing the generation of waste and the consumption of raw materials and energy in the building sector is such an important goal that it is necessary to identify and strengthen as soon as possible all the possible leverages for the full development of the various strategies of circular economy.

To face partially these barriers researches and experimentations should converge on some key concepts:

- organizational and business models appropriate for the building sector. At a first level, the deployment of the paradigm of the circular business model in the construction sector requires a deep change in actors' behaviours, to realize the "downside" of ownership. New collaborative business and organizational models may allow the "access to" instead of the "ownership of" products, increasing the capacity of utilisation and thus the efficiency of the deployed resources. Relevant examples from this point of view are provided by other sectors of application of the so-called sharing economy. In this regard, it must be underlined that nowadays there is not a comprehensive framework supporting organizations (of any kind) in the design of circular business and organizational models in the construction sector. In this direction, this book tries to deepen some specific and realistic key aims, all converging towards the creation of a systemic approach for promoting and managing longer life-cycles of building products and the development of a new marketplace for re-manufacturing. These goals can be pursued in many ways. This book proposes, for instance, some scenarios of the organizational relationships between the various key operators and of the chains of supply, describing steps, roles, skills, responsibilities, risks, services supports and kinds of information exchanged;
- sustainable Product-Service Systems (S.PSS) and Life Cycle Thinking. Product manufacturers might not always be economically incentivised in adopting strategies to reduce product environmental impact, i.e. adopting reuse, but sometimes they are interested in accelerating replacement for selling more products, thus increasing profits. Sustainable Product-Service Systems (S.PSS) are "an offer/business model providing an integrated mix of products and services that are together able to fulfil a particular customer demand ("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 its life cycle responsibilities remain in the hands of the provider/s". The S.PSS models are based on radical innovations, not so much on technological ones, but more on new interactions/partner-

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ships between the stakeholders of a particular satisfaction production chain (life cycle/s);

- shared rules and tools. The involved practitioners from different areas in the tertiary architecture sector – exhibitions, office, retail – and from industry agree on the need for frameworks enabling multi-sectoral stakeholders through: a common terminology, relationships rules, methods, procedures, KPIs (Key Performance Indicators), information to be exchanged and shared between different kinds of operators, methods of analysis for choosing the most appropriate and feasible process (re-manufacturing, recondition, reuse, repurpose), list of parameters and methods for the assessment of the benefits (economic, environmental, social), criteria to identify and address the barriers;
- design guidelines for re-manufacturing and broadly for lifespan extension. Criteria and tools for designing for long-term value must become a common heritage for designers both in the design of a building and in the development of industrial products. This implies to identify rules, requirements, procedures and standards for environmental labelling and declarations, operative models, indicators, business leverage strategies (sales channels, re-manufacturing services connected to the products, re-manufactures supply chains, criteria for pricing) for supporting eco-innovative approaches and for designing and producing building components taking into account reuse and re-manufacturing aspects. Staring from the general Life Cycle Design criteria and guidelines it is necessary to develop and disseminate specific guidelines and tools for DfRem (Design for Re-manufacturing) and to collect from multiple sources and share good practices;
- multi-sectoral networking. The creation and strengthening of multi-sectoral networks of re-manufacturing are a priority. This means linking different categories of key operators: those dealing with the management and transformation of spaces for the tertiary sector (operators in the field of design and facility management services), those of disassembling, recovery of materials and systems (construction companies, logistics providers, transport and storage operators, disassembling operators and scrap collectors), the existing or potential operators of re-manufacturing (craftsmen and manufacturing SMEs, i.e. original building products manufacturers, original building products re-manufacturers, independent re-manufacturers, spare part providers), those of the marketing of new types of re-manufactured building products characterized by being economically and environmentally beneficial, those of the final use on a regional and extra-regional scale

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(designers, construction companies, public and private clients, building cooperatives, social housing operators, etc.). The aim is to put all the stakeholders in touch at the same time in order to: highlight market potentialities for the integrated “re-actions”; collaborate exchanging information about availability, characteristics and flows of building products to re-manufacture; improve economic viability of closed-loop life cycles; support business strategies; activate the interests of third party investors or of other kinds of financial operators (leasing, assurance).

The challenge is open, let’s “re-act”…

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This book deals with re-manufacturing, recondition, reuse and repurpose considered as winning strategies for boosting regenerative circular economy in the building sector. It presents many of the outcomes of the research *Re-NetTA (Re-manufacturing Networks for Tertiary Architectures). New organisational models and tools for re-manufacturing and re-using short life components coming from tertiary buildings renewal*, funded in Italy by Fondazione Cariplo for the period 2019-2021.

The field of interest of the book is the building sector, focusing on various categories of tertiary buildings, characterized by short-term cycles of use.

The book investigates the most promising strategies and organizational models to maintain over time the value of the environmental and economic resources integrated into manufactured products, once they have been removed from buildings, by extending their useful life and their usability with the lower possible consumption of other materials and energy and with the maximum containment of emissions into the environment.

The text is articulated into three sections.

Part I BACKGROUND introduces the current theoretical background and identifies key strategies about circular economy and re-manufacturing processes within the building sector, focusing on tertiary architectures. It is divided into three chapters.

Part II PROMISING MODELS outlines, according to a proposed framework, a set of promising circular organizational models to facilitate re-manufacturing practices and their application to the different categories of the tertiary sectors: exhibition, office and retail. This part also reports the results of active dialogues and roundtables with several categories of operators, adopting a stakeholder perspective.

Part III INSIGHTS provides some insights on the issue of re-manufacturing, analyzed from different perspectives with the aim of outlining a comprehensive overview of challenges and opportunities for the application of virtuous circular processes within building sector. Part III is organized in four key topics: A) Design for Re-manufacturing; B) Digital Transformation; C) Environmental Sustainability; D) Stakeholder Management, Regulations & Policies.

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