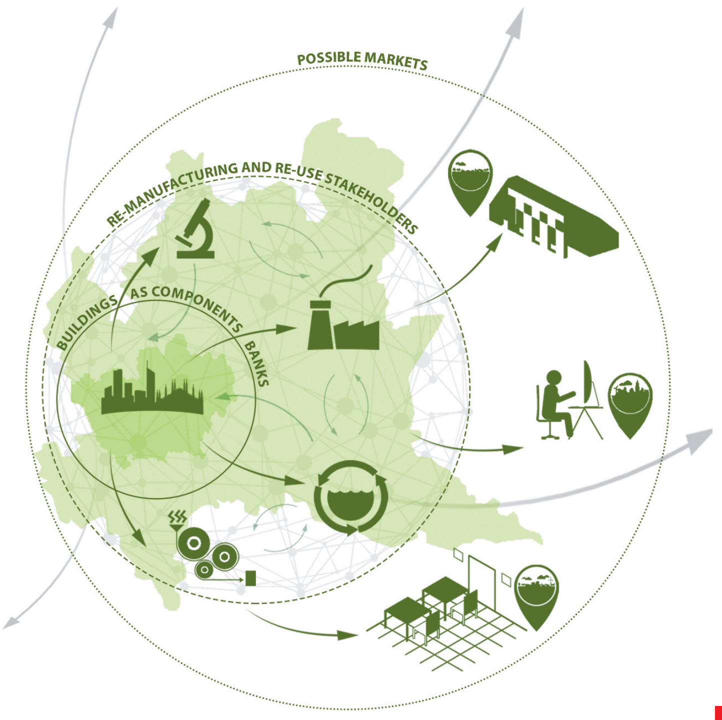
Re-manufacturing networks for tertiary architectures

Innovative organizational models towards circularity

edited by Cinzia Maria Luisa Talamo



Ricerche di tecnologia dell'architettura
FrancoAngeli

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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

Contents

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 construction 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:

- 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:

– 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

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).

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.

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

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 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 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.

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):

– 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).

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.

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

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

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.

– *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

Tab. 11.4 - continued

Strategy	Organizational 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);

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, 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.

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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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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La passione per le conoscenze