Re-manufacturing networks for tertiary architectures

Innovative organizational models towards circularity

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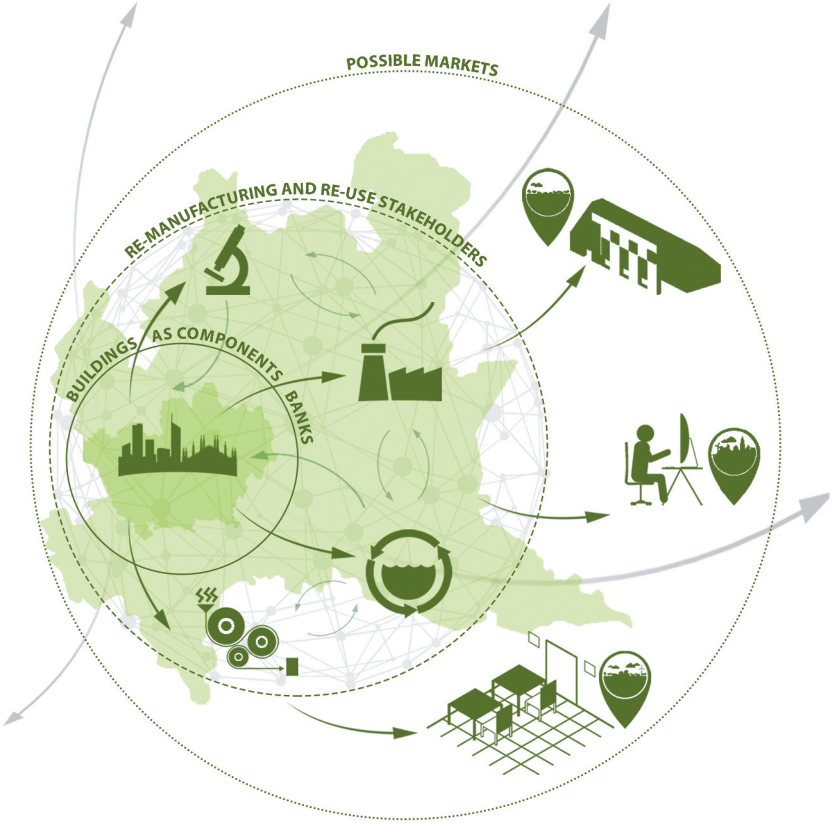

Ricerche di tecnologia dell'architettura
FrancoAngeli

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

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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 *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 microenterprises 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 nonspace 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.

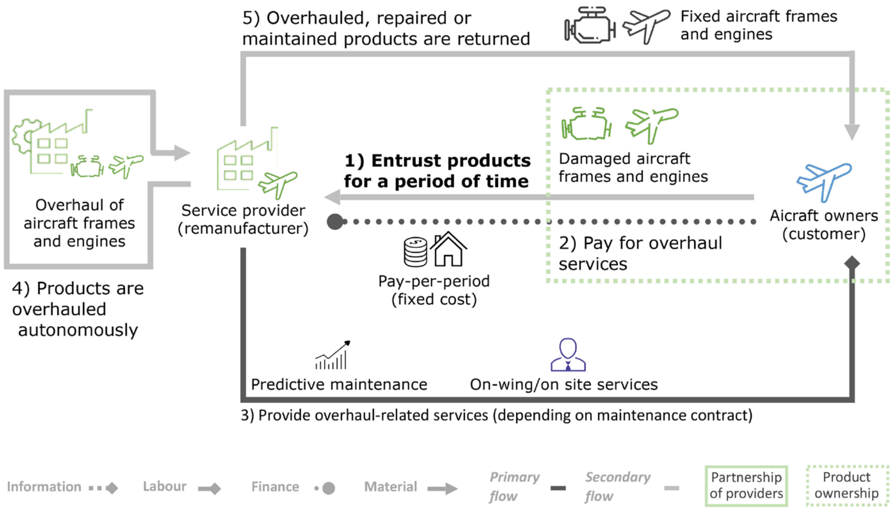

Fig. 3.1 - System map of aerospace practice – sample 1

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/

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.

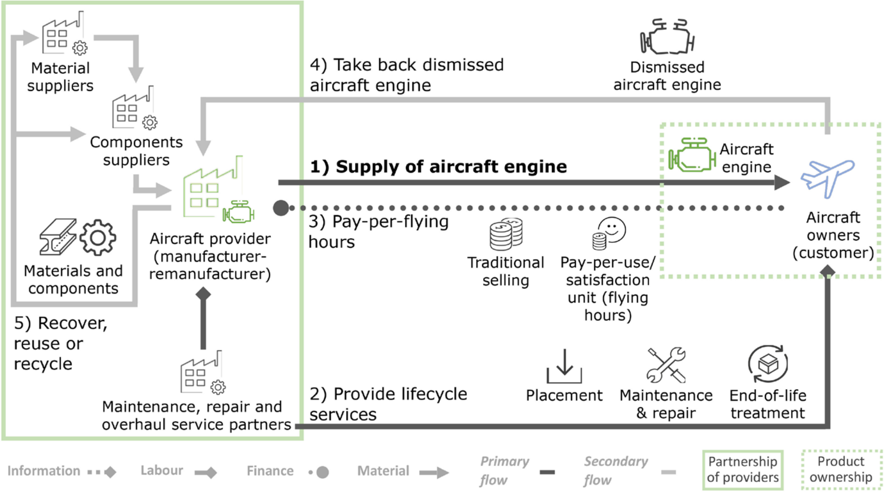

Fig. 3.2 - System map of aerospace practice – sample 2

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 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).

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.

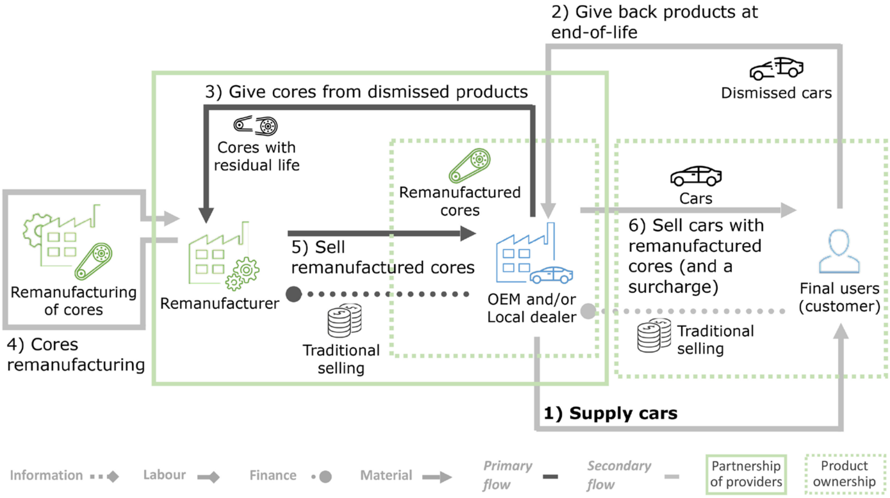

Fig. 3.3 - System map of automotive practice – sample 1

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 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

(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.

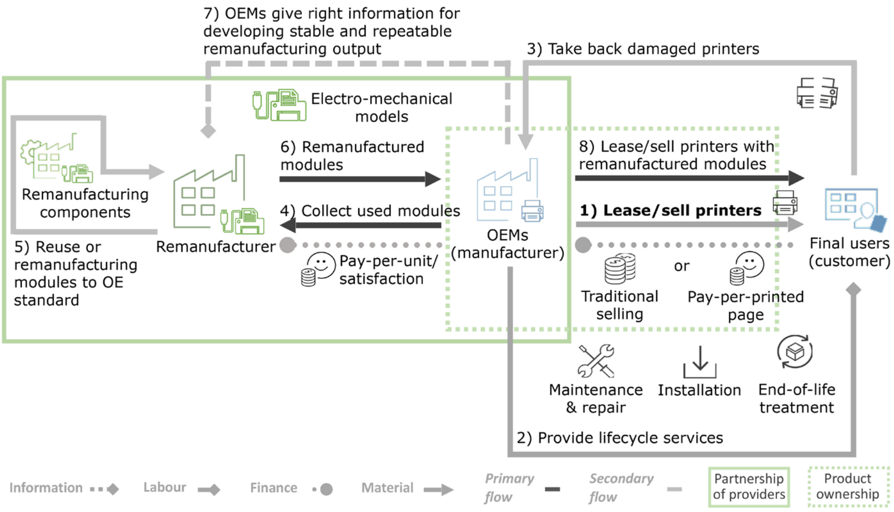

Fig. 3.4 - System map of electrical and electronic equipment practice – sample 1

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.

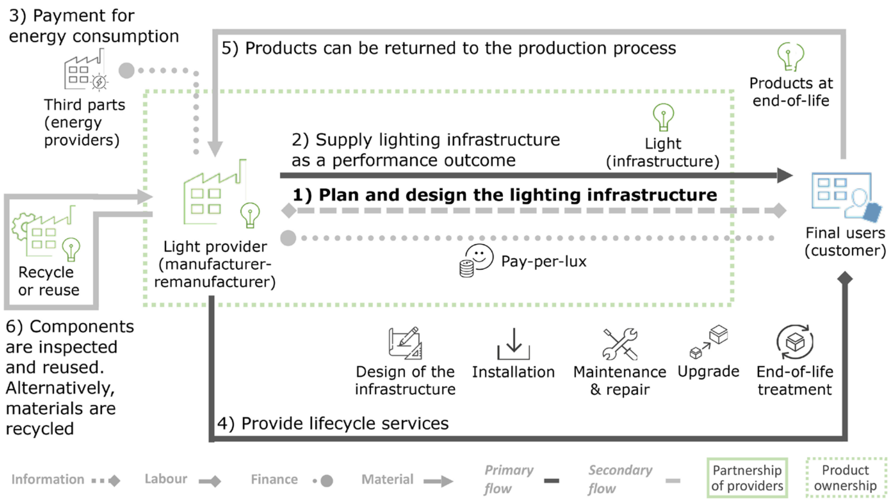

Fig. 3.5 - System map of electrical and electronic equipment practice – sample 2

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.

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.

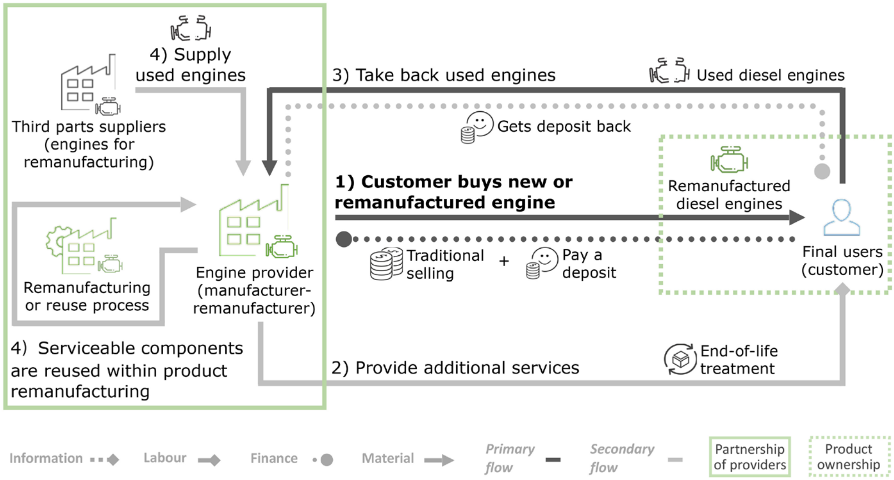

Fig. 3.6 – System map of heavy-duty and off-road equipment practice – sample 1

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 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.

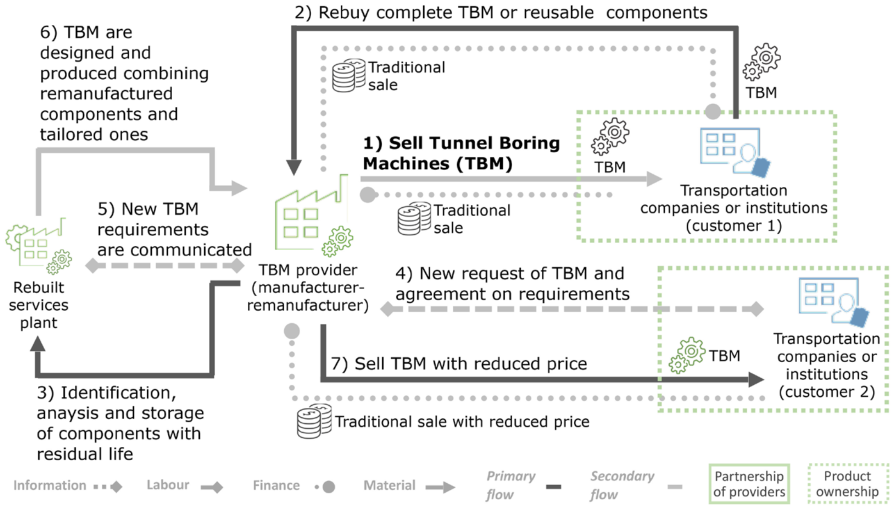

Fig. 3.7 – System map of heavy-duty and off-road equipment practice – sample 2

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.

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, 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.

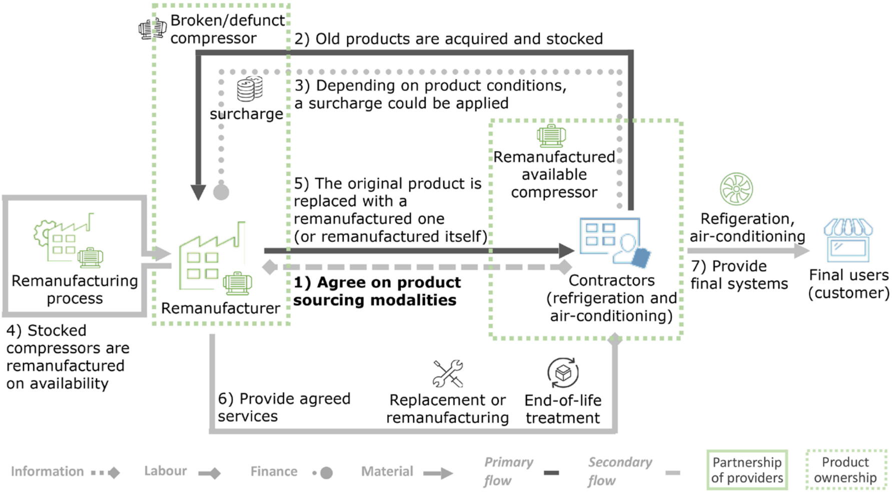

Fig. 3.8 - System map of machinery practice – sample 1

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.

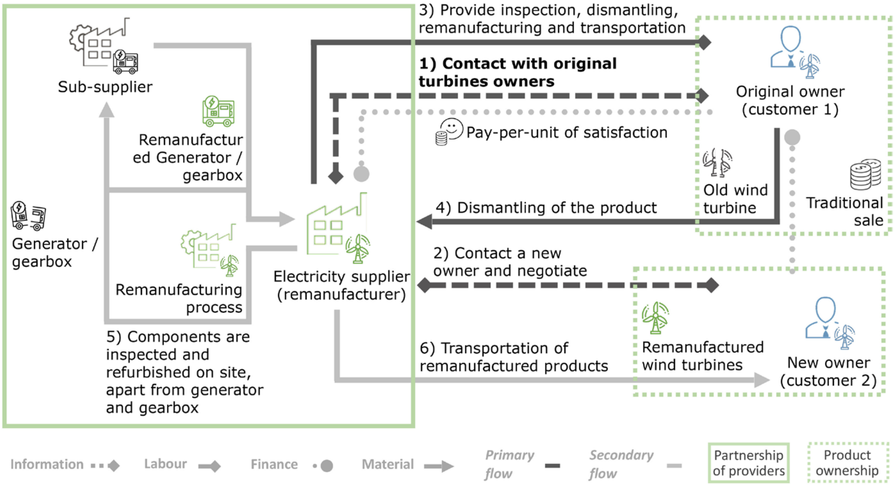

Fig. 3.9 – System map of machinery practice – sample 2

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 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.

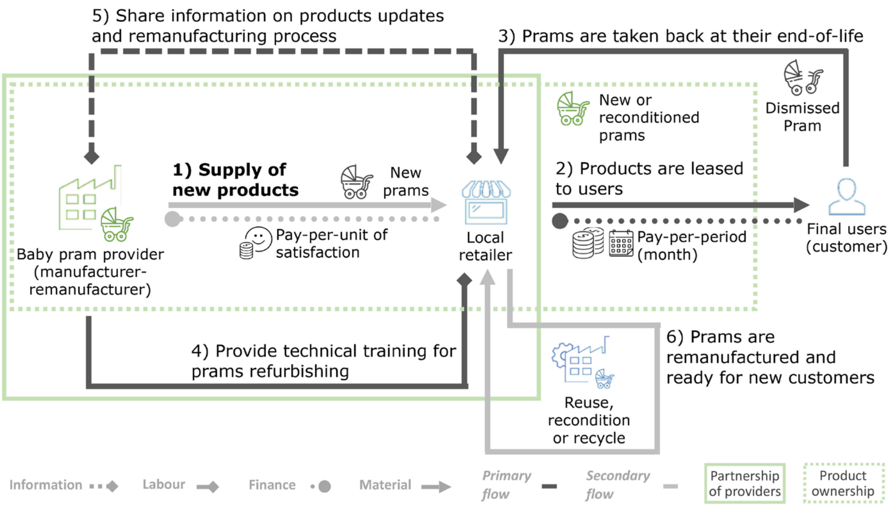

Fig. 3.10 – System map of other emerging practice – sample 1

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.

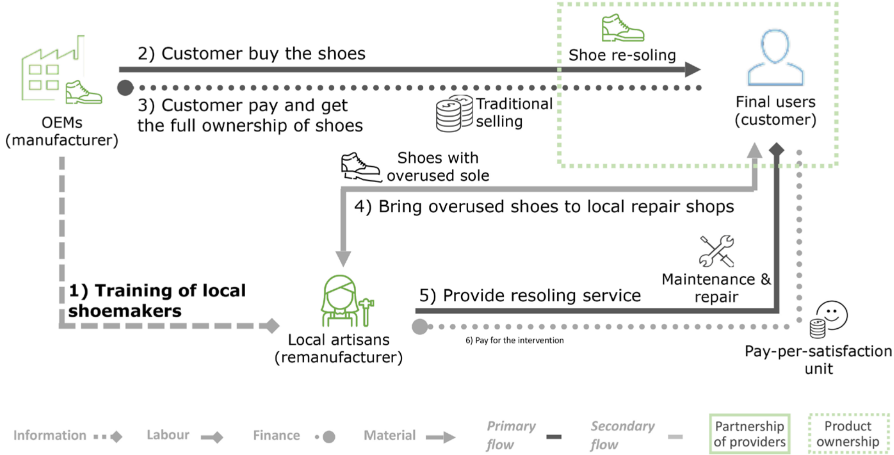

Fig. 3.11 – System map of other emerging practice – sample 2

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.

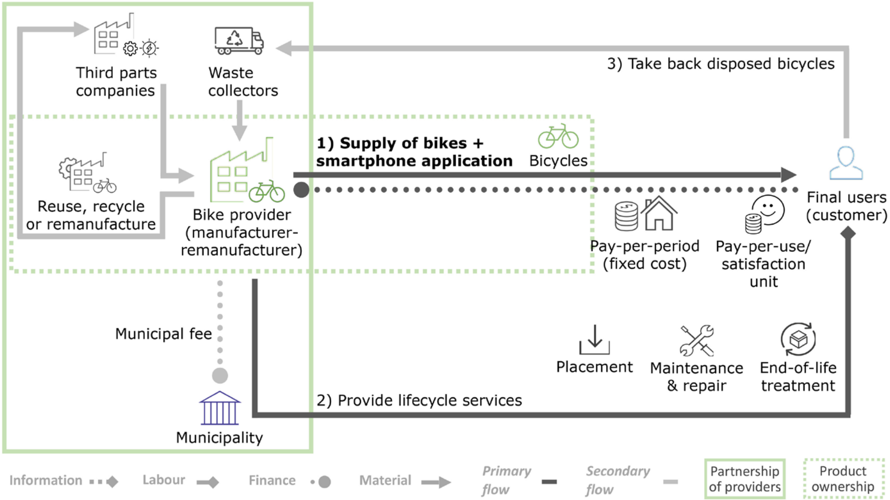

Fig. 3.12 – System map of other emerging practice – sample 3

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;

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 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;

- 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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