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Review

Unleashing the role of skills and job profiles in circular manufacturing

Elena Beducci, Federica Acerbi, Marta Pinzone *, Marco Taisch

Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Via Lambruschini 4/b, 20156, Milano, Italy

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ABSTRACT

Circular economy (CE) adoption is spreading worldwide, and it aims at decoupling the creation of value from resource consumption, leading to sustainable and responsible production and consumption as highlighted in the Sustainable Development Goal 12. The circular transition will ask for the transformation of the companies and the workforce, from both qualitative and quantitative perspectives. The set of required skills will be influenced by the circular transition, while the degree of implementation of circular activities will depend on the availability of adequate skills. Nevertheless, the extant literature has not reached a consensus on which competences are required for a circular transition, and few studies have approached this topic at all. This paper presents a systematic literature review to identify and categorize the skills that can facilitate the adoption of circular practices in manufacturing companies. The identified skills were systematically organized within a structured framework extending Porter's Value Chain. Leveraging the literature review's findings, the paper proposes a series of ideal job profiles for circular manufacturing, and it outlines some preliminary education and training paths. This research contributes to the current body of literature and practical understanding on the "human dimension" of circular manufacturing.

1. Introduction

Circular economy (CE) adoption is spreading worldwide, and it aims at decoupling the creation of value from resource consumption, thus leading to sustainable production and consumption (Ellen MacArthur Foundation, 2015). The CE paradigm is strictly connected to the Agenda 2030 which aims, through its 17 goals, at achieving sustainable development in three dimensions: economic, social and environmental (United Nations, 2015). The CE is a promising paradigm to achieve Goal 12, which is related to responsible consumption and production of resources. The circular transition will ask for new processes, business models and technologies, which companies must adopt to pursue the new production paradigm (OECD, 2016). CE adoption in manufacturing systems takes the name of Circular Manufacturing. This paradigm transfers all the circular principles into a set of circular strategies, like remanufacturing, recycling, circular design etc., to be concurrently implemented (Acerbi and Taisch, 2020). The new requirements will also ask for an adequate transformation of the job market. Circularity will affect the workforce from both qualitative and quantitative perspectives. The transition has already impacted the job market: from 2012 to 2018 in EU, jobs connected to CE reached 4 million, growing by 5% (European Commission and Directorate-General for Environment, 2018). In the future, the circular transition could create up to 700000 new jobs, increasing the GDP of almost 0,5% by 2030 (European Commission and Directorate-General for Environment, 2020). From a qualitative perspective, the circular transition will create new job profiles and will affect the characteristics of the existing ones: the new employments will require new and different skill sets. Advanced skills, that are not yet available in the market, are necessary to design, adopt and implement new circular processes and activities (Foundation, 2014). The circular transition will influence the set of required skills, and the degree of implementation of circular activities will depend on the availability of adequate competences and skills (Brown et al., 2021). This transition will heavily impact small and medium enterprises (SMEs). The transition towards CE of SMEs is crucial for the success of global circular transition: SMEs consists in 90% of world business and more than half of the population is employed in these companies (Dey et al., 2020). For SMEs, the barriers to CE are particularly imponent: investing in training and hiring of new qualified workers is economically unfeasible (Dey et al., 2020) and missing skills represent an obstacle in the adoption of initiation, creation, and implementation of circular business models (Brendzel-Skowera, 2021). According to the resource-based view

* Corresponding author.
E-mail addresses: elena.beducci@polimi.it (E. Beducci), Federica.acerbi@polimi.it (F. Acerbi), marta.pinzone@polimi.it (M. Pinzone), marco.taisch@polimi.it (M. Taisch).

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theory, competences are considered intangible resources and the presence of resources in a company affects not only the implementation of strategies, but also the selection of the strategy itself (Draganidis and Mentzas, 2006). Applying this theory to CE activities implies that the presence of adequate skills will be required not only for the actual implementation of circular processes, but also for the selection of a certain circular-oriented strategy.

Existent literature has not yet reached a consensus on which competences are required for the circular transition, and few studies had approached this topic at all (Clube, 2022). The absence of identification and comprehension of skills and jobs that will be fundamental for circular activities, will delay the implementation of the circular transition, because companies and governments will not be able to invest effectively in the development and education of workers (Dufourmont and Brown, 2020).

Recently, multiple studies started focusing on the role of skills in circular startups. Straub et al. (2023) carried on a study aimed at proposing a taxonomy for circular skills based on the clustering of analysis of self-reported skills profiles of job figures employed in circular startups. Borms et al. (2023) collected, through interviews, skills available in circular startups, focusing on hard skills.

The objective of this paper is to review the extant literature to investigate the set of skills and competences needed by manufacturing companies to embrace CE strategies, mapping and proposing a framework through which understanding the requirements for the new circular oriented jobs. Therefore, this work aims at answering the following research question: "*Which are the skills needed in manufacturing companies embracing circular economy strategies?*"

The rest of this paper is structured as follows: Section 2 illustrates the methodology applied to address the research objective, in Section 3 the results of the review have been classified and analyzed, in Section 4 the authors discuss the results obtained by proposing a framework including the job profiles needed for the circular transition. In Section 5 conclusive remarks are reported by highlighting the limitations of the study opening for future research streams.

2. Methodology

A systematic literature review (SLR) has been conducted following (Snyder, 2019), to identify and analyze the state of the art on skills for CE required by companies operating in manufacturing context. While performing the literature review, a theoretical framework has been formulated to dissect and categorize the skills identified in the SLR. This theoretical framework has been established utilizing the SLIP (Sort, Label, Integrate, and Prioritize) methodology, which has been already employed in CE-related research (Acerbi et al., 2021; Sassanelli et al., 2020).

2.1. Systematic literature review

The objective of this review was to identify the skills required to implement circular strategies in manufacturing companies. The collection of papers ended on 31st December of 2022 and was based on Scopus and Web of Science databases.

2.1.1. Keywords definition

To select the adequate keywords guiding the SLR, a preliminary general search of articles and papers on the topic has been conducted. This research led to select the keywords "circular economy" because the terms sustainability and circular* would have led to a too broad pool of papers. Even though the selection of "circular economy" as keywords concentrated the review on a limited and coherent number of papers. The addition of the keyword "manufacturing" has been excluded, because it was possible to observe that there were not additional papers to be included. Nonetheless manufacturing remained the focus of the paper. The keywords used were ("Circular Economy" AND (Skill* OR Competenc*)).

2.1.2. Eligibility criteria

The research has been conducted through the databases of Scopus and Web of Science, considering only documents available in English and published till 2022. After the first selection, through the defined keywords, the authors eliminated the duplicates resulting from the utilization of multiple databases. A further selection has been conducted by reading titles and abstract of the papers, selecting only the papers relevant for the analysis. In the end, the last screening was conducted reading the entirety of the documents, discarding papers not relevant to the research (see Fig. 1). Documents were discarded when they could not provide explicit and specific skills applicable to circular economy activities in manufacturing companies. Finally, a pool of 85 relevant paper has been selected for the review. The papers were reviewed and the results were used to develop the proposed framework (see Fig. 2), concurrently bibliometric data were analyzed, and descriptive statistics calculated by the first authors.

2.2. Theoretical framework

The authors developed the framework through iterative interactions, following the SLIP methodology (Acerbi et al., 2021; Sassanelli et al., 2020). The framework is interned to support manufacturing companies in pursuing a circular transition, thus the authors decided to take as a reference the Porter's Value Chain (Porter, 1998), which is the most diffused framework adopted by companies. The framework was then adapted through iterative interactions to adequately represents the clustered skills. During the review phase, bibliometric data and skills were extracted from the selected articles and reported in an excel file by the first author. Then two authors independently assigned each of the extracted skills to one cluster of the proposed framework to reduce potential bias. In case of disagreement between the two authors, the opinion of another author was asked to reach the final decision.

Each category of the framework represents the typology of skills required by different business areas. The categories of the framework can be divided into three different groups: specific skills required by single operations, specific skills required by workers in multiple operations facilitating the development of business activities, both transversal hard and soft skills. Below, the authors report the guiding schema used to cluster the set of skills needed while embracing CE.

- Logistic Skills: skills related to inbound and outbound logistics' operations (the storage of products and parts, warehousing operations, procurement, etc.).
- Design Skills: skills related to the design of products and services, including skills propaedeutic to the design phase.
- Manufacturing Skills: skills related to manufacturing activities, including the maintenance operations of machines.

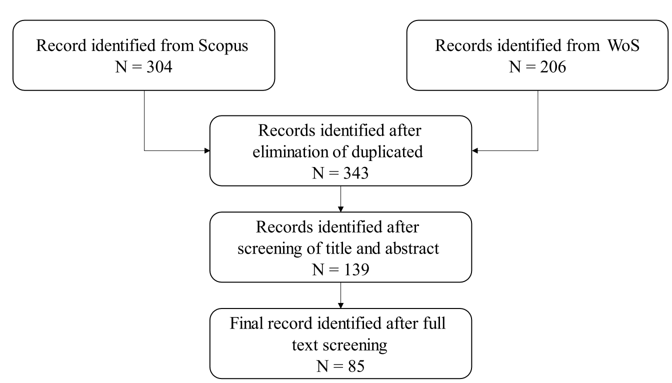

Fig. 1. Screening process.

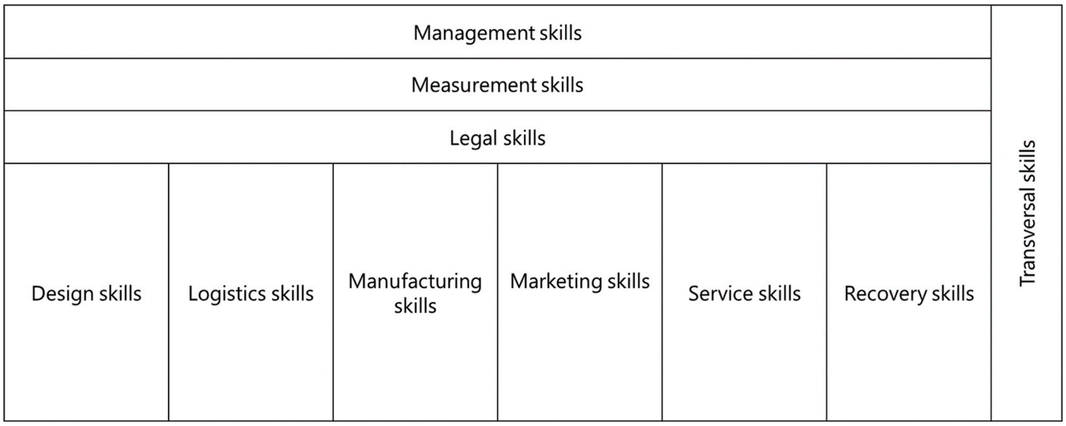

Fig. 2. Skills classification.

- Recovery Skills: skills related to the activities recovering the value of products, materials, and parts. Such activities are extrapolated from the 9 R s framework.
- Marketing and Communication Skills: skills related to marketing and communication to clients and other stakeholders.
- Service Skills: skills required to carry out the services offered by the company.
- Legal Skills: skills related to the legal and regulatory framework addressing sustainability and circularity.
- Measurement Skills: skills required to measure the sustainability of the company performance.
- Management Skills: skills required by the decision makers and managers.
- Transversal Skills: skills that are transversal and required in most job positions. This paper adopts the definition of the report "Transferability of Skills across Economic Sectors" (Balcar et al., 2011). This category is divided in three different sub-categories: Digital Hard Transversal Skills, Non-Digital Hard Transversal Skills, and Soft Skills.

3. Results

3.1. Descriptive statistics

The papers selected for the final analysis have been analyzed from a statistical perspective. From the years of publication of the paper it is possible to observe that literature's interest for the topic is quite recent. Almost all papers have been published after 2016, with a spike in publishing between 2020 and 2022 (see Fig. 3).

The papers have been published mostly on specific journals, in particular *Sustainability (Switzerland)* and *Journal of Cleaner Production*, on which almost 40% of the papers selected have been published (see Fig. 4).

VOSviewer was used to conduct a bibliometrics analysis on the selected paper. The keywords of the papers have been explored through a map based on bibliographic data. The program analyzed co-occurrence of all the keywords of the paper, through a full counting method and selected those keywords with at least 5 occurrences (see Fig. 5).

By observing the most common keywords it is possible to see that the theme of circular economy and sustainability is central, which was to be expected as CE was one of the keywords guiding the SLR. On the contrary, there is no mention of skills and competences, thus highlighting that the theme is quite unexplored, and that knowledge is still scattered. Nonetheless, a cluster of keywords (education, higher education, design education, student, students, knowledge) is strictly related to education, which appears a relevant element to achieve circular economy and acquiring the required skills.

An additional cluster is related to companies and operations involved in the circular transition (manufacturing, SMEs, resource efficiency, remanufacturing, manufacturing, supply chain and industry 4.0). The presence of a cluster related to industry, one related to education and one related to environmental sustainability well represents the necessity to build knowledge and explore how these three elements can impact each other and facilitate the circular transition.

3.2. Content analysis

From a general analysis of the paper, it is possible to draw multiple conclusions related to the perspective of current literature on the role of skills for the circular transition. The topic is still quite unexplored by the literature. Indeed, few papers focus on specific skills required for the circular transition. Literature mostly focuses on frameworks, business models, activities, and technologies which can facilitate the transition, without analyzing the skills that are required to implement those solutions. Nonetheless, from the review it was possible to observe that the topic is of recognized relevance. Literature identifies a gap between the skillset currently available in the job market and the one required by companies. The SLR highlights that the literature identifies as relevant general skills, mostly soft and hard transversal skills. Those skills are highly mentioned, even though there is space for more technical and specific skills, as the paper will illustrate later. Most of the identified skills are not unique to the CE paradigm, anyhow in the light of a circular business model those skills acquire new roles and relevance. In addition, it is possible to identify skills related to the new activities, technologies, and operations.

3.2.1. Supply chain and logistics area

Literature proposes multiple skills for logistic activities facilitating CE paradigm (see Table 1). In CE, logistic activities have new characteristics: they are not limited to the procurement of new raw material, but they include the creation of symbiotic linkages, the procurement of spare parts for recovery activities (Casper and Sundin, 2018) and the recovery of resources and products at the final stage of their lifecycles, with the objective of being re-introduced in the production (Wilson et al., 2022). The authors observed that few skills mentioned in the literature are strictly connected to circular logistic, many of which, such as transportation knowledge and distribution planning, are general logistic skills. Other skills are connected to the new activities of circular logistics. Skills related to industrial symbiosis allow to implement symbiotic linkages, translating the waste product of a company to the raw material for another (Fraccascia et al., 2021; Liu et al., 2022).

Reverse logistic skills are mentioned as well, even though there is no specificity of what literature consider reverse logistic skills. The authors expect those skills to be the ones allowing the implementation of reverse

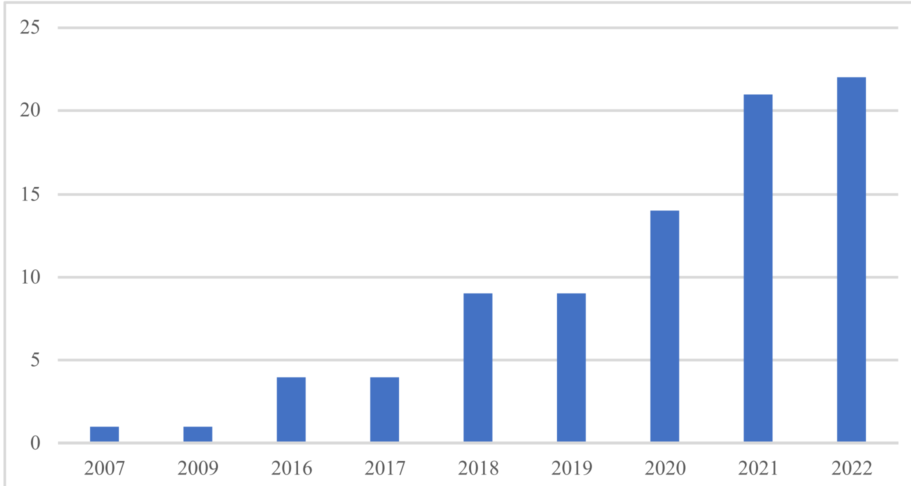

Fig. 3. Publications per year.

logistic, intended as *"The process of planning, implementing and controlling backward flows of raw materials, work-in-progress, finished goods and information, from the point of consumption to the point of recovery or proper disposal"* (Rogers, D. S.I Tibben-Lembke, 2002). Reverse logistic is characterized by a high degree of uncertainty: quality, quantity, time and place of return of products and parts are not certain and reduce the success of recovery activities (Bressanelli et al., 2018). The authors expect that skills such as implementation strategies, knowledge of partners and stakeholders, capacity to implement and manage the activities, can be crucial for the implementation of circular logistic. Relevant skills include the competence related to devices improving the traceability of material flows, such as blockchain technology.

3.2.2. Design area

Literature shows great interest in skills required by the design for CE (see Table 2). Design skills, both general and specific, are highlighted as crucial. Eco-design and Design for X are the most specific skills related to sustainability. Design for X includes multiple design strategy such as design for recovery and design for multiple use cycles. Indeed, product designers should consider the new characteristics of circular products while designing them, taking into account reuse and recyclability (Geng et al., 2009). Design for use cycle allows to predict the impact of prolonged use and multiple lifecycles: this skill facilitates the forecasting of future trends and how they will affect the design of products (Sumter et al., 2020). Modular design facilitates the disassembly of parts composed by different material and can be considered one aspect of design for recovery (Leube and Walcher, 2017). Another skill on which literature focuses is the knowledge of material. The knowledge of material is a key skill for design, manufacturing, and recovery activities. It facilitates the design of sustainable, long lasting, and gracefully aging products (Terzioğlu and Wever, 2021). Designers will require skills to find applications, determine compatibility and find recycling solution for the material (Phung, 2019). In addition, the selection of material influences the type of tools and techniques that can be implemented in the manufacturing and recovery activities, both traditional and innovative, such as additive manufacturing (Chen, 2022; Leube and Walcher, 2017). Reverse engineering enables the utilization of additive manufacturing applied to damaged products, and related skills allow to design missing parts of products (Chen, 2022). Literature proposes a set of skills also for the implementation of services and products as servitized business models. Skills, such as product service system (PSS) design and service design skills, allow to understand how to propose services and how to engage customers in the new business models. The ability to incorporate customers' feedback in design and the capability to understand users' experience and expectations allow the implementation of sharing platforms and PSS, increasing the life of products (de los Rios and Charnley, 2017). Skills for the implementation of PSS include skills for user experience, customer relations and service offers (Eisenreich et al., 2022).

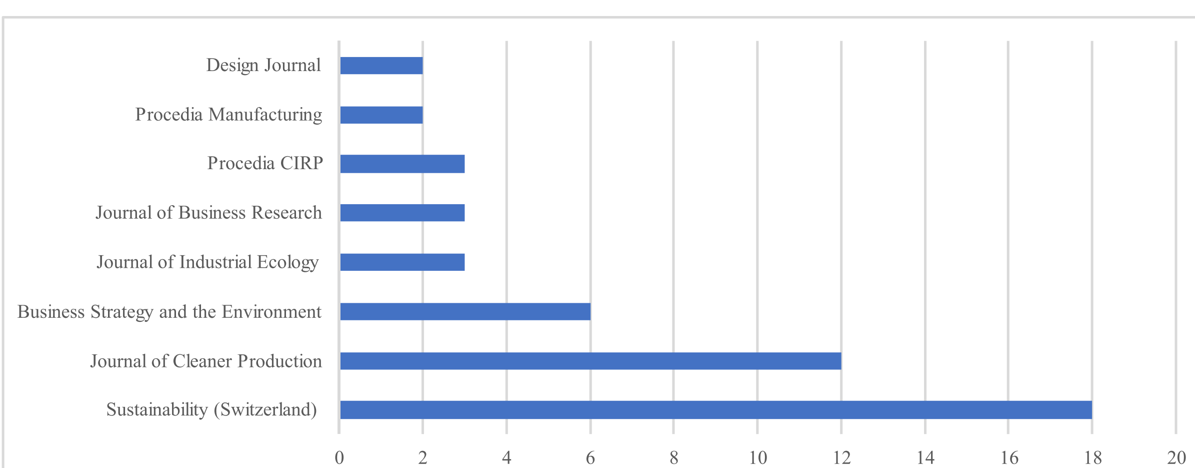

Fig. 4. Source title.

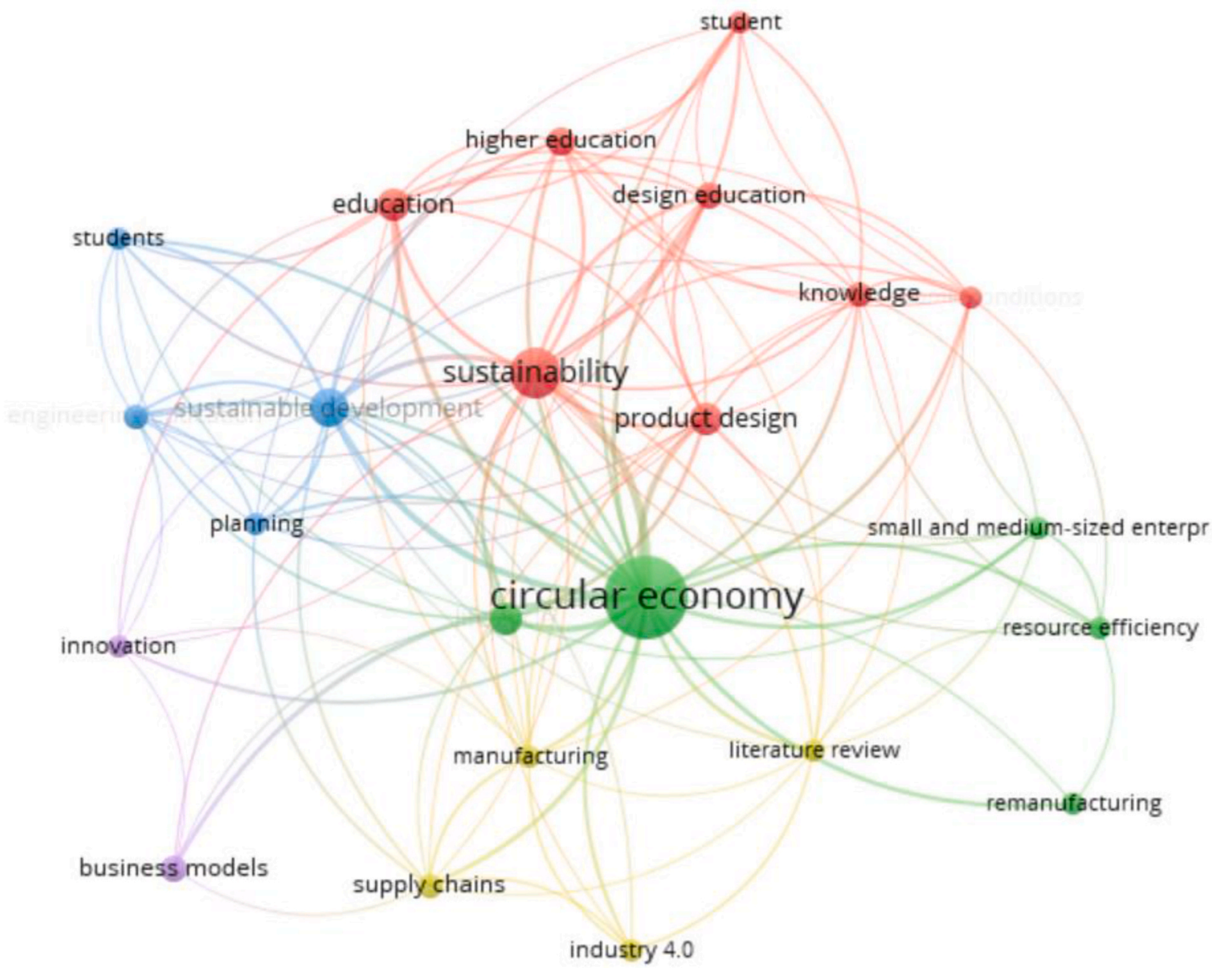

Fig. 5. Keywords analysis.

3.2.3. Production area

The literature does not identify many skills strictly related to the production activities (see Table 3). Skills such as knowledge of methods of cleaner production and circular manufacturing facilitate the implementation of adequate manufacturing processes, coherently with CE. High relevance has been given also to the implementation of new technologies in circular activities. Indeed, multiple skills are related to the knowledge of new technology. This is in line with the fact that new digital technologies, if applied properly, can facilitate cleaner production processes and solutions for waste disposal (Lopes de Sousa Jabbour et al., 2019). A more specific skill is the knowledge of lean manufacturing. Lean manufacturing has similar objectives as CE. CE aims at better utilize resources to prevent shortage of raw material, reducing environmental impact, while creating closed loops. Lean manufacturing objective is to achieve more efficient systems by eliminating waste. The two paradigms when implemented accordingly can complement each other thus increasing the benefits (Hernandez Marquina et al., 2021).

Table 1
Supply chain and logistics skills.

Supply chain and logistics skills	
Skills	Reference
Spare Parts Sourcing	Casper and Sundin (2018)
Distribution Planning	González-Domínguez et al. (2020)
Reverse Logistic Skills	(Dey et al., 2020; Kant Hvass and Pedersen, 2019; Lopes de Sousa Jabbour et al., 2019; Oliveira Silva and Morais, 2022)
Industrial Symbiosis Skills	(Fraccascia et al., 2021; Geng et al., 2009; Giannoccaro et al., 2021; Lopes de Sousa Jabbour et al., 2019)
Logistics and distribution processes skills	(de los Rios and Charnley, 2017; Janssens et al., 2021)
Transportation Knowledge	(Avadanei et al., 2020; González-Domínguez et al., 2020)
Sustainable Procurement	(Avadanei et al., 2020; Jääskä et al., 2021; Okorie et al., 2023)
Supply chain, circular and green supply chain knowledge and analysis	(Avadanei et al., 2020; Del Vecchio et al., 2021; Dokter et al., 2021; Giannoccaro et al., 2021)
Skills related to devices to improve traceability of material flow and products	(Lopes de Sousa Jabbour et al., 2019; Okorie et al., 2023)

3.2.4. Recovery area

The literature investigates skills to carry on activities for the recovery of the value of products along all stages of their lifecycles, in line with the principles of the 9R framework (see Table 4). Skills such as the knowledge of 3R framework and the benefits of recycling, reuse and biological flows are examples of the shared-based awareness that circular economy requires. For what concerns more technical skills, literature mentions remanufacturing skills. Considering the high role of uncertainty of remanufacturing processes, the skills of involved workers have a huge impact on the results of the activities (Pal et al., 2021). The knowledge of remanufacturing market is essential to support the economic feasibility of remanufacturing products, indeed the demand for

Table 2
Design skills.

Design Skills	
Skills	Reference
Knowledge Related to Material and Recycled Material	(Bigano et al., 2016; Chari et al., 2022; Chen, 2022; de los Rios and Charnley, 2017; Dokter et al., 2021; Giannoccaro et al., 2021; Janssens et al., 2021; Leube and Walcher, 2017; Phung, 2019; Sumter et al., 2021; Terzioğlu and Wever, 2021; Thorley et al., 2019; Virtanen et al., 2017; Watkins et al., 2021)
Design Skills	(Janssens et al., 2021; Leube and Walcher, 2017; Neto, 2019; Thorley et al., 2019)
Material Flow Analysis	(Avadanei et al., 2020; Bakırlıoğlu and McMahon, 2021; Ning et al., 2007)
Design for X	(Bakırlıoğlu and McMahon, 2021; Ballie and Woods, 2018; Chowdhury et al., 2022; Del Vecchio et al., 2021; Eisenreich et al., 2022; Giannoccaro et al., 2021; Joustra et al., 2022; Leube and Walcher, 2017; Lopes de Sousa Jabbour et al., 2019; Minguez et al., 2021; Ning et al., 2007; Oliveira Silva and Morais, 2022; Østergaard and Dan, 2021; Pal et al., 2021; Sumter et al., 2018, 2020, 2021; Terzioğlu and Wever, 2021; Watkins et al., 2021; Whicher et al., 2018)
Eco-Design	(Cramer, 2020; Dimante et al., 2016; Geng et al., 2009; Giannoccaro et al., 2021; González-Domínguez et al., 2020; Minguez et al., 2021; Neto, 2019; Pal et al., 2021; Rizos et al., 2016; Rodriguez-Andara et al., 2018; Watkins et al., 2021; Wolf et al., 2022)
Modular Design	Leube and Walcher (2017)
PSS Design	(Åkesson et al., 2022; Eisenreich et al., 2022; Lopes de Sousa Jabbour et al., 2019; Okorie et al., 2023; Watkins et al., 2021)
Service Design	(de los Rios and Charnley, 2017; Lopes de Sousa Jabbour et al., 2019; Sumter et al., 2018; Thorley et al., 2019; Virtanen et al., 2017)
Dematerialization Skills	(Bigano et al., 2016; Lopes de Sousa Jabbour et al., 2019; Watkins et al., 2021; Wolf et al., 2022)
Prototyping	(Nunes et al., 2018; Watkins et al., 2021)
Ability to apply big-data to eco-design	Lopes de Sousa Jabbour et al. (2019)
Understand product wear by use	(de los Rios and Charnley, 2017)
Understand engineering functions of products	(de los Rios and Charnley, 2017)
Reverse engineering	(Casper and Sundin, 2018; Chen, 2022; Terzioğlu and Wever, 2021)
Understand user experience, needs and expectation	(de los Rios and Charnley, 2017; Eisenreich et al., 2022; Giannoccaro et al., 2021; Santa-Maria et al., 2022; Sumter et al., 2018; Virtanen et al., 2017; Watkins et al., 2021)
Solve aesthetic and structural problems	(de los Rios and Charnley, 2017; Terzioğlu and Wever, 2021)

Table 3
Production skills.

Production skills	
Skills	Reference
Standardized production, operation and manufacturing processes	(Dey et al., 2020; Oliveira Silva and Morais, 2022; Pal et al., 2021; Thorley et al., 2019; Virtanen et al., 2017; Watkins et al., 2021)
Capacity to interact with machines	(de Miranda et al., 2021; Phung, 2019)
Equipment skills	Bigano et al. (2016)
Skills on technological cycles, new green technologies and capacity to use them	(Declich et al., 2020; Del Vecchio et al., 2021; Giannoccaro et al., 2021; Lopes de Sousa Jabbour et al., 2019)
Maintenance skills	(Bag and Pretorius, 2020; de los Rios and Charnley, 2017; de Miranda et al., 2021; Diez et al., 2016; Milios et al., 2019; Sumter et al., 2018; Watkins et al., 2021)
Lean manufacturing	Neto (2019)
Circular manufacturing and cleaner production	(Geng et al., 2009; Rizos et al., 2016; Rodriguez-Andara et al., 2018)
Standardized production, operation and manufacturing processes	(Dey et al., 2020; Oliveira Silva and Morais, 2022; Pal et al., 2021; Thorley et al., 2019; Virtanen et al., 2017; Watkins et al., 2021)

Table 4
Recovery skills.

Recovery skills	
Skills	Reference
Remanufacturing skills	(de los Rios and Charnley, 2017; Del Vecchio et al., 2021; Lanz et al., 2019; Milios et al., 2019; Pal et al., 2021; Sumter et al., 2018; Vogt Duberg et al., 2020; Wolf et al., 2022)
Knowledge of Remanufacturing Market	Vogt Duberg et al. (2020)
Closed Material Loop Knowledge	(Giannoccaro et al., 2021; Lanz et al., 2019)
Ability to Monitor Process Reliability and quality	Pal et al. (2021)
Cleaning	(Casper and Sundin, 2018; Jørgensen and Remmen, 2018)
Assembly/Disassembly	(Jørgensen and Remmen, 2018; Nian et al., 2022; Pranadya et al., 2022)
Repairing	(Beyeler and Jaeger-Erben, 2022; Del Vecchio et al., 2021; Milios et al., 2019; Phung, 2019)
Regeneration Monitoring	Diez et al. (2016)
Resource Recovery	(Giannoccaro et al., 2021; González-Domínguez et al., 2020; Weissbrodt et al., 2020)
Ability to propose flexible planning of production to deal with disassembly and remanufactured components due to uncertainty of supply	Lopes de Sousa Jabbour et al. (2019)
Recycling and reuse	(Del Vecchio et al., 2021; Giannoccaro et al., 2021; Nunes et al., 2018; Oliveira Silva and Morais, 2022; Wolf et al., 2022)
Refurbishment	Jørgensen and Remmen (2018)
Intuitive skills for comparison in interaction with AI	Schlüter et al. (2021)
3R Framework	(Dey et al., 2020; Minguez et al., 2021)
Technical Skills	Burger et al. (2019)

those products is lower and they are usually sold at a lower price (Vogt Duberg et al., 2020). The ability to propose flexible planning of production to deal with disassembly and remanufactured components is crucial to deal with the uncertainty of supply (Lopes de Sousa Jabbour et al., 2019). More technical skills are cleaning skills, which are considered core skills for remanufacturing companies (Casper and Sundin, 2018). Disassembly skills are useful to deal with the disassembly of components of unknown quality, specifically when the components are not designed for disassembly (Pawlik et al., 2022). Recycling skills include also those related to sorting and grading products for the correct disposal (Oliveira Silva and Morais, 2022).

3.2.5. Communication and marketing area

Literature often mentions marketing and communication skills in relation to CE (see Table 5). Marketing skills must be analyzed from a new circular perspective. Marketing skills are essential to understand how to propose circular products to the market and how to sell or use by-products (Geng et al., 2009). The objective of marketing campaigns is not only related to the advertisement of products and services, but also to the education of clients on the circularity of the products and services of the company, involving them in their role of circular stakeholders (Leube and Walcher, 2017). These skills have social implications: marketing can educate clients on topics of sustainability and circularity, people are more influenced by the market than by the education received (Alonso-Calero et al., 2022). Communication, both classic

Table 5
Communication and marketing skills.

Communication and Marketing skills	
Skills	Reference
Eco-Labelling	(Avadanei et al., 2020; Rodriguez-Andara et al., 2018)
Marketing	(Bassi and Guidolin, 2021; Beyeler and Jaeger-Erben, 2022; Dey et al., 2020; Geng et al., 2009; Giannoccaro et al., 2021; Janssens et al., 2021; Leube and Walcher, 2017; Minguez et al., 2021; Summerton et al., 2019; Weissbrodt et al., 2020)
Communication to clients and other stakeholders	(Bag et al., 2021; Bag and Pretorius, 2020; Bakırlıoğlu and McMahon, 2021; de Miranda et al., 2021; Dey et al., 2020; Eisenreich et al., 2022; Fernandez de Arroyabe et al., 2021; Giannoccaro et al., 2021; Jääskä et al., 2021; Janssens et al., 2021; Jørgensen and Remmen, 2018; Konietzko et al., 2020; Liu, 2020; Minguez et al., 2021; Phung, 2019; Rodriguez-Andara et al., 2018; Summerton et al., 2019; Watkins et al., 2021; Weissbrodt et al., 2020)
Circular economy communication	(Minguez et al., 2021; Sumter et al., 2020, 2021)

communication and the one explicitly related to CE, is highly mentioned in literature. CE communication is defined as the ability to tell coherent stories about circular economy. The effective communication of circular solutions is necessary for the implementation of those activities required by the circular transition (Sumter et al., 2020).

3.2.6. Service area

Literature does not particularly focus on skills to propose services to clients, since most skills are generic skills (see Table 6). CE user engagement is defined as the ability to engage clients in the usage and return of products: in this way it is possible to enable and facilitate recovery activities allowing the extension of products lifecycles (Sumter et al., 2020).

3.2.7. Legal area

Skills related to the legal context and regulatory framework are essential for companies that are interested in the implementation of circular practices (see Table 7). The knowledge of environmental regulations allows to properly implement environmental management strategies (Minguez et al., 2021). Many jurisdictions, such as Europe and China, adopt circular economy regulation at national and international levels (Otwong et al., 2021). Literature proposes skills related to environmental policies and standards. Standards mentioned are ISO 14040 and 14044 (Neto, 2019), 14001,2015 (Rodriguez-Andara et al., 2018) and ISO 5000:2018 (Neto, 2019).

3.2.8. Monitoring and measuring area

Monitoring and analysis of the impact of activities is crucial to be coherent with the principle of CE. Literature proposes skills related to impact assessment and reporting of performance (see Table 8). Indeed, the lack of knowledge in the measurement of environmental impact is one of the main barriers in the application of impact assessment (Das et al., 2022). Skills with similar role are those related to the knowledge of footprint techniques. The capacity to redact sustainable reporting is another skill highlighted by the literature.

Table 6
Service skills.

Service skills	
Skills	Reference
Customer Relationship/service Management	(Bag and Pretorius, 2020; Eisenreich et al., 2022)
Capacity to provide Effective After-Sale Services	Dey et al. (2020)
Circular Economy User Engagement	(Minguez et al., 2021; Sumter et al., 2020, 2021)

Table 7
Legal skills.

Legal skills	
Skills	Reference
Expertise in working in a regulatory framework and legal knowledge	(Dey et al., 2020; Janssens et al., 2021; Minguez et al., 2021)
Environmental Policy and Legislation	(Avadanei et al., 2020; Bassi and Guidolin, 2021; Del Vecchio et al., 2021; Eisenreich et al., 2022; Giannoccaro et al., 2021; Ning et al., 2007; Rodriguez-Andara et al., 2018; Santa-Maria et al., 2022; Wolf et al., 2022)
Policies and Standards	(Avadanei et al., 2020; Del Vecchio et al., 2021; Neto, 2019; Oliveira Silva and Morais, 2022; Rodriguez-Andara et al., 2018)

Table 8
Monitoring and measuring skills.

Monitoring and Measuring skills	
Skills	Reference
Impact Assessment	(Ballie and Woods, 2018; Del Vecchio et al., 2021; Dokter et al., 2021; Janssens et al., 2021; Minguez et al., 2021; Rodriguez-Andara et al., 2018; Sumter et al., 2018, 2020, 2021; Wolf et al., 2022)
Life Cycle Assessment	(Avadanei et al., 2020; Ballie and Woods, 2018; Dimante et al., 2016; Giannoccaro et al., 2021; González-Domínguez et al., 2020; Khan et al., 2020; Konietzko et al., 2020; Lara et al., 2021; Minguez et al., 2021; Neto, 2019; Ning et al., 2007; Rizos et al., 2016; Sanchez et al., 2020; Santa-Maria et al., 2022; Summerton et al., 2019; Watkins et al., 2021)
Sustainable Reporting and Accounting	(Bag and Pretorius, 2020; Dimante et al., 2016; Sánchez-Carracedo et al., 2020; Santa-Maria et al., 2022)
Financial Skills	Janssens et al. (2021)
Carbon, Environmental, Ecological Footprint Techniques	(Avadanei et al., 2020; Minguez et al., 2021; Rodriguez-Andara et al., 2018; Wolf et al., 2022)

3.2.9. Management area

To successful achieve the circular transition, it is required to shift from linear business models and processes to circular ones: these processes require specific skills (see Table 9). Circular business model knowledge is intended as the capacity to concurrently develop business models, products, and related intangible services. Developing a circular business model also implies the designing of the business infrastructure, identifying partnerships, reverse logistics channels, pricing of spare parts and revenues and costs streams (Sumter et al., 2020). To achieve sustainable circular business models, companies must rely on many profitable actors for collaboration (Khan et al., 2020). For this reason, the capacity to manage a complex network of stakeholders is particularly critical. Literature identifies many skills related to management, in particular lifecycle management is critical to identify losses along the life of products and to understand how to adopt cleaner production processes and technologies to reduce them (Geng et al., 2009).

3.2.10. Transversal digital area

The adoption of industry 4.0 technologies has a positive relation with the achievement of circular economy (Bag et al., 2021). Indeed, industry 4.0 technologies can be implemented to optimize the utilization of resources, achieving economic and environmental benefits (Lopes de

Table 9
Strategic management skills.

Strategic management skills	
Skills	Reference
Stakeholders and Network Management	(Bakırlıoğlu and McMahon, 2021; Dokter et al., 2021; Fraccascia et al., 2021; Jääskä et al., 2021; Joustra et al., 2022; Santa-Maria et al., 2022)
Circular and Sustainable Business Model and Business model	(Avadanei et al., 2020; Del Vecchio et al., 2021; Dokter et al., 2021; Eisenreich et al., 2022; Giannoccaro et al., 2021; Janssens et al., 2021; Joustra et al., 2022; Khan et al., 2020; Lanz et al., 2019; Minguez et al., 2021; Rizos et al., 2016; Santa-Maria et al., 2022; Sumter et al., 2018, 2020, 2021; Watkins et al., 2021)
CSR	(Avadanei et al., 2020; Bag and Pretorius, 2020)
Entrepreneurial Skills	(Buch et al., 2021; Cramer, 2020; de Miranda et al., 2021; Dimante et al., 2016; Janssens et al., 2021; Liu, 2020; Obrecht et al., 2022; Weissbrodt et al., 2020)
Value Management	Phung (2019)
Data Driven Scenario Planning	Woschank and Pacher (2020)
Planning and Implementation	(Avadanei et al., 2020; Jääskä et al., 2021; Sanchez et al., 2020)
Project Management and Implementation	(Dey et al., 2020; Jääskä et al., 2021; Janssens et al., 2021)
Management	(Casper and Sundin, 2018; Nunes et al., 2018)
Environmental and Energy Management	(Avadanei et al., 2020; Neto, 2019; Nudurupati et al., 2022; Santa-Maria et al., 2022)
Life Cycle Management	Geng et al. (2009)
Green Human Resources Management	(Avadanei et al., 2020; Del Vecchio et al., 2021)
International Politics	Avadanei et al. (2020)
CE Risk Management	Giannoccaro et al. (2021)
Product/Service and Process Management	Dey et al. (2020)

Table 10
Transversal digital skills.

Transversal Digital skills	
Skills	Reference
Cloud Service	Lindström et al. (2018)
Service Oriented Architecture	Lindström et al. (2018)
Arrowhead Framework	Lindström et al. (2018)
Sensor	(Lindström et al., 2018; Lopes de Sousa Jabbour et al., 2019)
Data Modelling	(Janssens et al., 2021; Lindström et al., 2018)
Data Analytics	(Bag et al., 2021; Bag and Pretorius, 2020; Chari et al., 2022; de Miranda et al., 2021; Janssens et al., 2021; Lindström et al., 2018; Woschank and Pacher, 2020)
Data Privacy and Security	(Bag et al., 2021; Lindström et al., 2018; Panghal et al., 2022; Phung, 2019)
Big Data skills	(Chari et al., 2022; de Miranda et al., 2021; Lopes de Sousa Jabbour et al., 2019; Phung, 2019)
Mobile Communication	Lindström et al. (2018)
Industrial IoT	Lindström et al. (2018)
Additive Manufacturing	(Chen, 2022; Hettiarachchi et al., 2022; Lopes de Sousa Jabbour et al., 2019)
Cyber-security	(Bag et al., 2021; de Miranda et al., 2021; Lindström et al., 2018; Phung, 2019)
Artificial Intelligence	(Bag et al., 2021; Chari et al., 2022; Phung, 2019)
Machine Learning	(Bag et al., 2021; Phung, 2019)
Programming	(Bag et al., 2021; Bag and Pretorius, 2020; Chari et al., 2022; de Miranda et al., 2021; Phung, 2019)
Industry 4.0 Skills and knowledge	(Bag et al., 2021; Eisenreich et al., 2022)
Understanding M2M	de Miranda et al. (2021)
ICT Know-how	(Antikainen et al., 2018; de Miranda et al., 2021)
STEM Skills	(Janssens et al., 2021; Rizos et al., 2016)
Simulation Techniques	(Janssens et al., 2021; Watkins et al., 2021)
Blockchain	(Panghal et al., 2022; Phung, 2019)
Automation	Phung (2019)
Digital and Digitalization Knowledge	(Antikainen et al., 2018; Kioupi et al., 2022)
Cloud Service	Lindström et al. (2018)

Sousa Jabbour et al., 2019). Literature focuses on many diversified digital skills for the implementation of new technologies for circular solution (see Table 10). Nonetheless, few papers focus on the specific skills required by the new technologies. The relevance of technology and the industry 4.0 paradigm can be perceived by the presence, in the literature, of skills such as digitalization knowledge, ICT know-how and the ability to adapt to industry 4.0. Digital skills will be required by the workers involved in the circular economy, even by those in roles that were previously not deemed scientific (Phung, 2019). Big Data and artificial intelligence are promising technologies and require adequate skills such as big data analysis skills, data mining, machine learning and programming (Bag et al., 2021). Big data skills can be used in the context of environmental impact assessment, in the selection of raw material, in fostering recycling techniques (Bag et al., 2021) and can be used to promote sustainable design (Lopes de Sousa Jabbour et al., 2019). The utilization of big data requires skills in data privacy and security and cyber-security. Sensors, cloud service and data skills can be used to implement real-time monitoring of processes, allowing the optimization of production time (Lindström et al., 2018).

3.2.11. *Transversal hard area*

Hard transversal skills, critical for CE, are mentioned in the literature (see Table 11). Economical thinking and knowledge of the economical aspect of environment and ecology are required to achieve economic feasibility of circular activities and to scout and identify markets and opportunities for products with multiple lifecycles (Weissbrodt et al., 2020). Understanding of optimization and resource efficiency and energy skills allow the reduction of waste and resource consumption. Energy skills are related to the understanding of energy issues, the utilization of energy efficiency measures (EEM) and energy audits (EA),

Table 11
Transversal hard skills.

Transversal Hard skills	
Skills	Reference
Optimization (Material, energy and waste) and Resource Efficiency	(Bag et al., 2021; Ballie and Woods, 2018; Bassi and Guidolin, 2021; Burger et al., 2019; Dey et al., 2020; Geng et al., 2009; Giannoccaro et al., 2021; González-Domínguez et al., 2020; Janssens et al., 2021; Lanz et al., 2019; Rodriguez-Andara et al., 2018)
Energy skills	(Avadanei et al., 2020; Bigano et al., 2016; Declich et al., 2020; Del Vecchio et al., 2021; Dey et al., 2020; Giannoccaro et al., 2021; Janssens et al., 2021; Rodriguez-Andara et al., 2018; Wolf et al., 2022)
Lifecycle Thinking	(Cramer, 2020; Dimante et al., 2016; Eisenreich et al., 2022; Lara et al., 2021; Liu, 2020; Minguez et al., 2021; Nunes et al., 2018; Santa-Maria et al., 2022; Sumter et al., 2018; Whicher et al., 2018)
R&D skills	(Khan et al., 2020; Santa-Maria et al., 2022)
Understanding of economic aspect of environment and ecology	(Avadanei et al., 2020; Giannoccaro et al., 2021; Jääskä et al., 2021; Janssens et al., 2021)
Economical Thinking	(Janssens et al., 2021; Weissbrodt et al., 2020)
Uncertainty Analysis, Modelling and management	(Jääskä et al., 2021; Weissbrodt et al., 2020; Wolf et al., 2022)
Statistics	(Bag et al., 2021; Janssens et al., 2021)
Knowledge in CE innovations	Cramer (2020)
Biology And Ecology	Dokter et al. (2021)

knowledge of the energy market and clean energy sources (Declich et al., 2020). It is relevant also the ability to identify energy flow improvement and manage energy waste (Wolf et al., 2022). In the context of CE, understanding products from a lifecycle perspective is critical. It is also possible to observe a high attention to lifecycle thinking in the studied literature, intended as the ability to consider the whole lifecycle of products and the lifecycle cost.

3.2.12. Transversal soft area

In the context of CE, soft skills are required and will be as important as hard skills (Dufourmont and Brown, 2020). Indeed, literature proposes many soft transversal skills for workers in the circular context (see Table 12). A high number of papers focuses on the circular and sustainable mindset required from workers in the CE. The knowledge of circular and sustainable principles and environmental and social awareness are highly mentioned soft skills. All workers in the circular context should be able to apply circular thinking, regardless of their role (Jalava et al., 2021). System thinking, intended as "*the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks*" (Wiek et al., 2011), is crucial to understand problems and find solutions (Sumter et al., 2020). In the circular context, systemic thinking implies to envision that actions will have systemic impact (Sumter et al., 2021). Multidisciplinarity and the ability to handling complexity have similar implications. To overcome the complexity of circular economy, the literature proposes problem solving and critical thinking skills. Great focus has been given also to skills for the strategic mindset such as strategic thinking and strategic alignment. In the sustainable context, strategic skills are defined as the abilities to "*collectively design and implement interventions, transitions and transformative governance strategies toward sustainability*" (Wiek et al., 2011). In the sustainable context, anticipatory skills, intended as the ability to "*to collectively analyze, evaluate and craft rich pictures of the future related to sustainability issues and sustainability problem-solving framework*" (Wiek et al., 2011), are useful to propose solutions which take into consideration future trends and the impact that the activities will have during their lifecycles. In circular contexts, interpersonal skills are required, given the high number of stakeholders involved. Finally, circular economy collaboration is the capacity to identify, support and manage stakeholders' collaboration in operationalizing a circular business model (Sumter et al., 2020).

4. Discussion and conclusions

4.1. Job profiles

From the analysis of the literature, it was possible to observe that workers employed in the CE are characterized by heterogeneous levels of skills and education. According to the analysis carried out by levels (Burger et al., 2019), circular jobs strictly related to core circular activities usually employ workers with lower education levels but with high technical skills. Instead, jobs that enable circular activities are skill intensive and require higher education.

However, the reviewed literature does not offer companies clear guidelines on the different job profiles that will be required to facilitate the circular transition. Therefore, through an elaboration of the findings from the SLR, this paper proposes a list of job profiles (see Fig. 6). The job profiles are ideal profiles modelled on the most relevant skills mentioned in the literature. The profiles can be easily adapted to the specific necessities of the companies, and they currently offer guidelines for the training of workers and recruiting processes.

In the logistic area, operators will be required to carry on traditional, renewed activities and additional circular practices. Circular logistic operators will manage all direct and reverse flows related to materials,

Table 12
Transversal soft skills.

Transversal Soft skills	
Skills	**Reference**
Understanding Concept of Circularity	(Antikainen et al., 2018; Avadanei et al., 2020; Ballie and Woods, 2018; Brendzel-Skowera, 2021; Chari et al., 2022; Cramer, 2020; Del Vecchio et al., 2021; Eisenreich et al., 2022; Fraccascia et al., 2021; Geng et al., 2009; Giannoccaro et al., 2021; González-Domínguez et al., 2020; Jääskä et al., 2021; Janssens et al., 2021; Lanz et al., 2019; Lara et al., 2021; Minguez et al., 2021; Nunes et al., 2018; Østergaard and Dan, 2021; Watkins et al., 2021)
Understanding sustainability	(Åkesson et al., 2022; Bakırlıoğlu and McMahon, 2021; Chari et al., 2022; Geng et al., 2009; Giannoccaro et al., 2021; Jääskä et al., 2021; Janssens et al., 2021; Østergaard and Dan, 2021; Santa-Maria et al., 2022; Weissbrodt et al., 2020)
Sustainable Development and Environmental Awareness	(Avadanei et al., 2020; Brendzel-Skowera, 2021; de Miranda et al., 2021; Del Vecchio et al., 2021; Dimante et al., 2016; Giannoccaro et al., 2021; Janssens et al., 2021; Lara et al., 2021; Napathorn, 2021; Nunes et al., 2018; Obrecht et al., 2022; Rodriguez-Andara et al., 2018; Sánchez-Carracedo et al., 2020; Wolf et al., 2022)
Social And Community Sustainability	(Obrecht et al., 2022; Rodriguez-Andara et al., 2018; Santa-Maria et al., 2022; Watkins et al., 2021; Weissbrodt et al., 2020)
Problem Solving	(Abina et al., 2022; Burger et al., 2019; de Miranda et al., 2021; Graf et al., 2022; Jääskä et al., 2021; Janssens et al., 2021; Lanz et al., 2019; Summerton et al., 2019; Watkins et al., 2021; Weissbrodt et al., 2020)
Pitching and Presentation	(Bakırlıoğlu and McMahon, 2021; Del Vecchio et al., 2021; Liu, 2020; Summerton et al., 2019)
Negotiation Skills	(Dimante et al., 2016; Fernandez de Arroyabe et al., 2021; Fraccascia et al., 2021; Watkins et al., 2021)
Teamwork and Cooperation	(Cramer, 2020; de Miranda et al., 2021; Janssens et al., 2021; Kioupi et al., 2022; Rodriguez-Andara et al., 2018; Sanchez et al., 2020; Summerton et al., 2019; Watkins et al., 2021; Weissbrodt et al., 2020)
Critical Thinking	(Abina et al., 2022; Ambrus, 2017; Bag et al., 2021; Bag and Pretorius, 2020; Graf et al., 2022; Kioupi et al., 2022; Liu, 2020; Rodriguez-Andara et al., 2018; Summerton et al., 2019; Watkins et al., 2021; Wolf et al., 2022)
Decision Making	(de Miranda et al., 2021; Diez et al., 2016; Giannoccaro et al., 2021; Graf et al., 2022; Jääskä et al., 2021; Watkins et al., 2021; Wolf et al., 2022; Woschank and Pacher, 2020)
Argumentation Skills	Rodriguez-Andara et al. (2018)
Innovativeness	(Bag et al., 2021; Giannoccaro et al., 2021; Janssens et al., 2021; Napathorn, 2021)
Knowledge on human behavior	Thorley et al. (2019)
Collaboration and Circular Economy Collaboration	(Eisenreich et al., 2022; Graf et al., 2022; Jääskä et al., 2021; Khan et al., 2020; Minguez et al., 2021; Santa-Maria et al., 2022; Sumter et al., 2018, 2020, 2021)
Coordination	(Bag et al., 2021; Fernandez de Arroyabe et al., 2021)
Multidisciplinarity	(Dimante et al., 2016; Janssens et al., 2021; Lara et al., 2021; Obrecht et al., 2022; Sanchez et al., 2020; Watkins et al., 2021; Weissbrodt et al., 2020)
Leadership and Public Engagement	(Bag and Pretorius, 2020; Graf et al., 2022; Nunes et al., 2018; Sanchez et al., 2020; Weissbrodt et al., 2020)
Adaptability and Ability to Change	(de Miranda et al., 2021; Janssens et al., 2021; Nudurupati et al., 2022; Sanchez et al., 2020)

(*continued on next page*)

Table 12 (*continued*)

Transversal Soft skills	
Skills	Reference
Lifelong Learning	(Bag and Pretorius, 2020; de Miranda et al., 2021; Janssens et al., 2021; Watkins et al., 2021)
Creativity and Permanent Curiosity	(de Miranda et al., 2021; Dimante et al., 2016; Janssens et al., 2021; Watkins et al., 2021)
Long-term, Anticipatory and Future Thinking	(Abina et al., 2022; Fraccascia et al., 2021; Janssens et al., 2021; Kioupi et al., 2022; Nunes et al., 2018; Sanchez et al., 2020; Santa-Maria et al., 2022; Terzioğlu and Wever, 2021)
Handling complexity	(de Miranda et al., 2021; Sanchez et al., 2020)
Self-motivation and Ability to Motivate Others	Sanchez et al. (2020)
Systemic Thinking	(Abina et al., 2022; Burger et al., 2019; Chowdhury et al., 2022; Cramer, 2020; Dimante et al., 2016; Janssens et al., 2021; Kioupi et al., 2022; Lara et al., 2021; Rodriguez-Andara et al., 2018; Sanchez et al., 2020; Santa-Maria et al., 2022; Summerton et al., 2019; Sumter et al., 2021; Watkins et al., 2021; Weissbrodt et al., 2020)
Strategic Thinking	(Kioupi et al., 2022; Minguez et al., 2021; Sanchez et al., 2020)

parts, and products. The three identified figures are for this area are: **Industrial Symbiosis Facilitator, Circular procurement operators and Reverse Logistic Operators.**

Reverse Logistic Operators will be responsible of reverse logistic activities for the retrieval of products at the end of their lifecycles. The technical skills these figures will require are the awareness of different retrieval strategies, the ability to select adequate partners, and the knowledge related to the normative environments for the retrieval of products at the end of their lifecycle. To manage new and complex network, reverse logistic operators will require transversal skills such as the capacity to handle complexity, decision making, critical and strategic thinking. Skills such as teamwork skills, coordination and multidisciplinarity can support them in the interaction and collaboration with a high number of stakeholders. The implementation of digital technologies, such as IoT, big data and blockchain, and the related needed skills can facilitate the traceability of products and the retrieval of related information.

Industrial Symbiosis Facilitators and Circular supply chain managers will be responsible for the creation and management of industrial symbiosis linkages for the exchange of resource (Lopes de Sousa Jabbour et al., 2019; L. Schlüter et al., 2022). They require skills of industrial symbiosis such as the ability to understand the landscape of possible local partnerships, available resources and how to manage the symbiotic linkages. They require normative and legal knowledge related to the regulation affecting exchanges of resources at the end of their lifecycle. Transversal skills such as optimization and resource efficiency skills can help to understand how to utilize waste of their companies and partners. Teamwork skills and CE collaboration can facilitate the interaction with relevant stakeholders. Digital skills, such as big data related knowledge, can support the creation of the shared network of information facilitating industrial symbiosis.

Circular Procurement Operators will be the figure managing the new procurement operations, that must be sustainable and include procurement of spare parts for recovery activities. The technical skills required are related to spare parts sourcing, the ability to identify suppliers and to forecast the requirement of recovery activities. Big data skills will help in facilitating the selection of the kind of spare parts to source and store, supporting recovery operations and the optimization of logistic resources.

In CE, designers will oversee activities like those in the linear economy, even though the objectives, tools, perspectives and procedures will be different. **Circular designers** should have knowledge in the principles of CE and should have skills in raw material and LCA to guide conscious decisions according to the impact of products during the design phase (Lopes de Sousa Jabbour et al., 2019). Designer should be

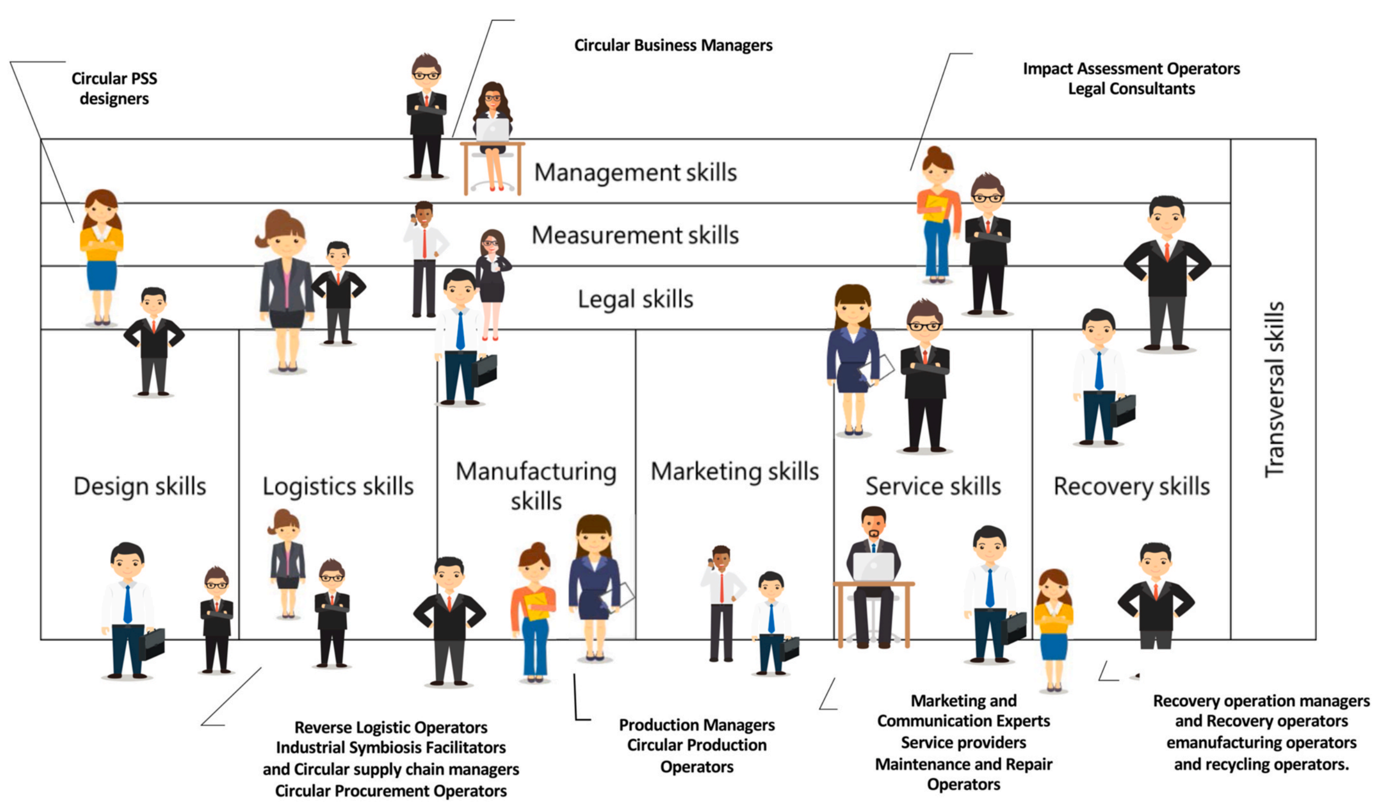

Fig. 6. Circular job profiles.

aware of all the design for X approaches available and their implementation methodologies. Moreover, designers are expected to collaborate with the different business areas to take decisions with systemic impact. Lifecycle thinking, systemic thinking and future thinking can enhance the design processes in this perspective.

Manufacturing operators will be responsible for the production activities for the first product lifecycle. The activities will be similar to those in the linear economy, nonetheless new principles and technologies will be applied to follow CE.

Production Managers must organize, plan, and implement sustainable production process, both from an economic and environmental perspective (Lopes de Sousa Jabbour et al., 2019). Manufacturing operation managers will be expert in standardized production, with a specific attention to cleaner production techniques. Given the high energy consumption of industrial processes, manufacturing operation managers should have energy skills to implement energy efficient technologies. Decision making skills, lifecycle thinking, systems thinking can support them in taking informed decisions. Moreover, they should acquire skills related to the normative frameworks, such as those related to production processes, energy management and technical standards. Industry 4.0 and related technologies can be leveraged to increase the efficiency of production processes, skills in sensors, cloud and mobile technologies, IoT, big data, artificial intelligence and additive manufacturing can be used to facilitate technological implementation.

Circular Production Operators are blue collar workers operating the machines. They will need specific technical skills for their daily activities. For them, it will be useful to have knowledge in the principles of sustainability and CE, to understand their role and relevance to the CE.

Maintenance and Repair Operators are responsible for the maintenance activities of the industrial machinery. They will require specific maintenance skills and familiarity with the equipment. They will be familiar with circular innovations and new technologies, which will require new maintenance skills. Internet of things, big data and artificial intelligence skills can facilitate the adoption of the technology to implement preventive and predictive maintenance.

The CE principles will heavily impact business areas related to recovery activities, intended as those to recover the value of products after the first lifecycle. The authors identify two main job profiles related to these activities: **recovery operation managers** and **recovery operators**.

Recovery Operation Managers are in charge of the implementation and management of activities aiming at recovering the value of products, such as remanufacturing, repairing, and recycling. Many skills are common between manufacturing operation managers and recovery operation managers. They require skills in recovery processes, closed material loop, energy issues and legal knowledge related to the specific operations they oversee. Skills in data, artificial intelligence and uncertainty analysis and modelling can facilitate the selection and planning of recovery strategies. Lifecycle thinking and systems thinking can facilitate the implementation of strategies to keep products in the loop for subsequent recovery activities.

Recovery Operators are responsible for the daily technical recovery activities. From the literature review three main role can be extrapolated: **repairing operators, remanufacturing operators, and recycling operators.** They will require specific technical skills related to their activity such as disassembly and cleaning for repairing and remanufacturing operators and sorting capacity for recycling operators. Digital skills, like artificial intelligence, big data, and visual aids can support the implementation of related technologies enhancing the recovery activities.

Marketing and Communication Experts can communicate with a complex network of stakeholders and create new market niches. The understanding of the stakeholders is supported by transversal skills such as strategic thinking, knowledge of human behavior and critical thinking. Knowledge in the principles of circular economy will help to create a common base of knowledge for CE communication and to better inform relevant stakeholders. Moreover, long term vision related to products can support experts in creating market niches and engaging costumers in returning and recovery activities.

Service providers are responsible for the services offered by the companies. Technical skills are strictly connected with the kind of services and products offered, such as repairing of products. Service providers will require soft skills such as knowledge of human behaviors to deal with customers.

Impact Assessment Operators oversee the monitoring, measuring, assessing, and reporting of the activities of the company. The required technical skills are related to assessment and reporting methodologies and tools, and skills related to big data, which can help accessing punctual product and process information to be internally and externally to the company shared. They are expected to interact with different business areas to collect relevant data, thus collaboration skills can support them.

Legal Consultants are experts in the strict regulatory framework shaping circular operations. For this reason, they should have knowledge in the standards and policies that apply to the company. Considering the wide area of influence of their positions and the high numbers of personnel of different areas they will have to collaborate with, legal consultants can be supported in their activities by teamwork and collaboration skills, multidisciplinarity and system thinking.

Circular Business Managers are profiles with the mindset and skills for the management of circular business models. Skills in the elaboration of circular business models, knowledge of circular principles and sustainability and system thinking can support them in the decision-making process. They will be asked to interact and manage complex and heterogeneous networks of stakeholders. Therefore, leadership, ability to motivate others, negotiation, teamwork, and collaboration skills can support them in these activities.

4.2. Education and training

After analyzing the required skills as well as the evolving and emerging job profiles, it is necessary to identify which educational and training paths are more appropriate to develop those skills (Pinzone et al., 2016). In this respect, two main perspectives can be highlighted (Burger et al., 2019): on one hand, it is needed to include circular manufacturing skills in education programs targeting the new generation of workers, on the other hand, training and lifelong learning are crucial to up-skill and re-skill workers currently employed in manufacturing.

Education providers, especially universities, are progressively introducing sustainability and circular economy-related topics - such as LCA, eco-design, impact assessment and reporting – in their curricula (Whicher et al., 2018). In addition, interdisciplinary education in the field of circular manufacturing is gaining importance (Obrecht et al., 2022) as the combination of multiple disciplines. The involvement of different stakeholders is crucial to promote a holistic and systemic view on CE (Antikainen et al., 2018). Moreover, the combination of theoretical and practical approaches can be further exploited to help develop both soft and hard skills. Experiential learning, problem-based and project-based instructional strategies should be encouraged to facilitate the acquisition of new knowledge and the application of circular skills to industrial case studies and activities with companies (Dimante et al., 2016). Similarly, game-based learning can facilitate the acquisition of specific sustainability competences, as well as transversal skills, by learning how to apply theoretical knowledge and to try decision making procedures and distinct strategies (Fraccascia et al., 2021; Jääskä et al., 2021).

More limited is the research addressing training paths that companies can pursue to identify and develop appropriate skills (Pinzone and Taisch, 2023). Green human resource management, which consists in developing green abilities, motivating green employees, and providing green opportunities (Pham et al., 2020), can be considered a promising approach for the enhancement of circular skills in companies. By means of vocational training and on-the-job training, such as mentoring, job shadowing and study visit, manufacturing companies can re-/up-skill their employees and improve their performance (Napathorn, 2021; Pinzone et al., 2019).

4.3. Conclusions

This study conducted a SLR with the objective of identifying and categorizing the full spectrum of skills that can facilitate the advancement of manufacturing companies in their journey towards circular manufacturing. These identified skills were systematically organized within a structured framework that extends Porter's Value Chain (Porter, 1998) by seamlessly integrating circular activities alongside the conventional Value Chain model. Additionally, leveraging the insights gleaned from the literature review, this paper introduced a series of ideal job profiles required to undertake manufacturing activities in line with the principles of CE and it outlined some preliminary education and training paths to enable the development of current and future manufacturing workers' skills.

In doing so, the research makes a meaningful contribution to the current body of literature and practical understanding, furthering insights into the "human dimension" of CE in manufacturing, as named by several researchers (e.g., (Chiappetta Jabbour et al., 2019; Clube, 2022; Lopes de Sousa Jabbour et al., 2019), policy makers (Cedefop, 2021; European Economic and Social Committee, 2023) and industrial stakeholders (e.g. (World Manufacturing Forum, 2021),).

First, the research findings provide a valuable contribution to the existing literature by enhancing our understanding of the skills required for the transition toward circular manufacturing. The SLR underscored the presence of both general skills, encompassing soft and hard transversal skills, as well as more specialized technical abilities. Many of the identified skills are not exclusive to the CE paradigm, but within the context of circular business models and strategies, they take on fresh significance and greater relevance. Moreover, the SLR identified emerging skills closely linked to specific circular manufacturing activities and technologies, which are gaining prominence in CE literature.

Second, the suggested classification of skills within a structured framework, which is rooted in an enhanced rendition of Porter's Value Chain incorporating various circular activities, sets itself apart from existing skill classifications (e.g. (Borms et al., 2023; Straub et al., 2023),). It distinguishes itself by offering a comprehensive perspective that goes beyond startups and a more articulated framework that specifically addresses the value-added activities associated with circular manufacturing.

Lastly, to date, research has predominantly concentrated on quantifying the impact of CE on employment. In contrast, there has been a scarcity of qualitative investigations regarding the transformation of existing job profiles and the emergence of novel job profiles within the CE context (Burger et al., 2019). The collection of ideal job profiles presented in this study marks an initial step in this direction.

The research also presents significant practical implications for managers and professionals involved in competency management, as well as education and training practitioners, and individuals working or willing to work in manufacturing companies. Industry hence can use the identified skills and job profiles as guidelines to assess whether the necessary skills already exist within the organization or need to be developed from scratch or acquired from outside. Similarly, workers can leverage the results of the study to map their skills and plan their future learning and development activities.

Besides, some recommendations for policy makers stem from the study findings. Policy makers can use our findings to identify current and future skill needs and determine policy priorities to avoid the emergence of skill gaps and mismatches in the labor market under the umbrella of SDG12. The relevance of adequate competences and the skillset identified in this paper highlight the necessity to transform not only internal processes, but also the job market to achieve the implementation of circular practices in manufacturing. Policy makers can use the findings to propose incentives for manufacturing companies to pursue the adequate and CE-oriented re-/up-skilling of the workforce. Finally, education and training providers can take advantage of the research outcomes to update their curricula and/or create new ones to address the demand of circular skills coming from companies.

The findings of the current research should be interpreted considering the limitations of the study. Researchers interested in circular manufacturing are encouraged to address those limitations in the future. First, it is important to acknowledge the potential presence of bias that may influence the results derived from the literature analysis. Second, although the literature mentions skills related to remanufacturing, disassembly, and repair, there remains a lack of a precise and operational definition for these skills. Similarly, digital skills, while widely recognized as important, are described in a rather generic manner. To enhance the skill set derived from the literature, empirical data from industrial case studies or surveys could be incorporated. Finally, this research primarily centers on the manufacturing industry, thus lacking specific insights into the unique needs and requirements of various industry segments (e.g. automotive). Future studies have the potential to augment our findings by exploring both the commonalities and distinctions among the skills necessary for different industry segments.

CRediT authorship contribution statement

Elena Beducci: Writing – review & editing, Writing – original draft, Formal analysis, Data curation, Conceptualization. **Federica Acerbi:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Marta Pinzone:** Writing – review & editing, Writing – original draft, Validation, Supervision, Funding acquisition. **Marco Taisch:** Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Beducci, Elena; Acerbi, Federica; Pinzone, Marta; Taisch, Marco (2024), CE skills - SOTA sample, Mendeley Data, V1, doi: 10.17632/9vjc4ggnrp.1

CE skills - SOTA sample (Reference data) (Mendeley Data)

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