Industry 4.0 Enabling Technologies Supporting the Social Sphere of Circular Manufacturing

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Abstract: Circular Economy (CE) paradigm may contribute in enhancing the sustainability of the manufacturing sector, and in this context CE takes the name of Circular Manufacturing (CM). The extant literature highlighted the several benefits characterizing this paradigm, but most of the studies aimed at investigating especially those benefits enhancing the environmental and the economic performances of manufacturing companies. Instead, the social sphere has been usually neglected even though it represents one of the main aspects to be considered while moving towards sustainability and circularity. Indeed, CM can be embraced only though the engagement of consumers and the involvement of the whole company, which thus requires the active participation of both users and workers. The social benefits might be reinforced by the introduction of technologies, such as the Industry 4.0 (I4.0) ones, which might support both physically and cognitively the workers and the establishment of the relationships with consumers. Hence, the aim of this contribution is to investigate how I4.0 technologies enable the enhancement of the social benefits obtainable by manufacturing companies while adopting CM. This analysis has been performed through the review of the extant literature which has been conducted relying on both Scopus and Web of Science as scientific databases. 42 selected contributions have been analyzed to identify the specific I4.0 technologies required to enhance the social benefits obtainable from the adoption of CM. From a managerial perspective, this contribution enables to define the key technologies adoptable to enhance the social benefits obtainable from the adoption of CM and to clarify what these benefits are. From a scientific perspective, this contribution enables to cover the envisioned gap about the need to further explore the social benefits obtainable from CM adoption.

Keywords: Circular Manufacturing, Social Sustainability; Industry 4.0; Literature Review

I. INTRODUCTION

Nowadays more than ever, our society is asked to urgently cope with the increased need of resource consumption and the augment in the pollution generation [1]. In addition to these issues, also the social sphere of the triple bottom line (i.e., environmental, social and economic sustainability [2]) must be included in the strategic plans of our society to finally address all the sustainable development goals promoted by the United Nations [3]. In particular, the manufacturing sector, being one of the most resource intensive sectors, requires to pursue a transition towards sustainability [4]. Among all, the Circular Economy (CE) paradigm is contributing to the sustainability of the manufacturing sector taking the name of Circular Manufacturing (CM) [5]. This paradigm, based on the values of slowing, narrowing and closing the resources loops [6], has been especially evaluated as a means enabling to cope with the economic and environmental sustainability while the social aspects are often neglected in the extant literature. Moreover, the diffusion of this paradigm has been widely encouraged by policymakers worldwide and they promote to rely on technological and digital advancements to enhance the benefits obtainable from CE adoption [7]. On this direction, several contributions have been published in the extant literature evaluating the integration especially between CE and Industry 4.0 (I4.0) technologies [8], [9], considering these technologies the most promising ones for a sustainable future [10]. Actually, while the social benefits obtainable from the introduction of I4.0 technologies in the factories have been clarified [11], looking at CE, only the social challenges coming from the simultaneous introduction of CE and I4.0 technologies have been analysed [12]. Therefore, there is still an open point about the evaluation of the social benefits obtainable from the embracement of CM when supported by the I4.0 technologies. This analysis would facilitate the proper embracement of the twin transition (i.e., digital, and circular) opening the perspective towards the social dimension usually positioned behind the environmental and economic considerations. For this reason, this research aims at investigating what I4.0 technologies might help manufacturing companies in obtaining the social benefits coming from the adoption of CM by digging deeper in the identification and clarification of the specific obtainable social benefits.

The present contribution is structured as follows. Section 2 explains the research methodology adopted to address the research objective. Section 3 elucidates the literature review results. Section 4 discusses the results obtained from the review and last, Section 5 concludes the contribution elucidating the main outcomes and limitations.

II. METHODOLOGY

The present contribution relies on a systematic literature review to evaluate what technologies might support manufacturing companies in grasping the social benefits obtainable from the introduction of CM highlighting the key obtainable social benefits. To do that, both Scopus and Web of Science have been queried with the following string: (("Circular Economy" OR "Circular manufacturing") AND "Technolog*" AND "Social"). This string, used in the first quarter of 2021, enabled to collect 418 publications in total. After the elimination of the duplicates only 386 remained. A screening process was performed on these remaining contributions reading first the title and the abstract and then the integral paper to evaluate the coherence with the scope of the research. The eligible criteria are the following: English written contributions; manufacturing sector focused contributions; digital or I4.0 technologies focused contributions; presence of the social sphere of sustainability in the contribution looking at CM. In Fig.1 the screening process is reported.

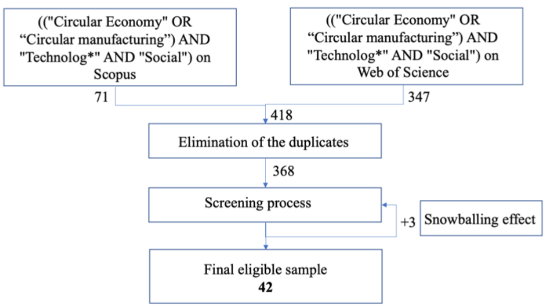

Fig. 1. Selection process of the eligible contributions for the review

The eligible 42 contributions were reviewed first from a quantitative perspective providing some statistics about their distributions in terms of years and keywords (by using for instance Vos Viewer). Then, the eligible contributions were reviewed from a qualitative perspective to evaluate what technologies can benefit manufacturing companies in reaching social benefits while applying CM.

III. LITERATURE REVIEW RESULTS

A. *Preliminary quantitative analysis*

The eligible contributions have been first analyzed looking at the year of publication to evaluate the diffusion and the interests by scholars and looking at the keywords distribution analysis to see the keywords used by scholars and to evaluate the related trends in the extant literature. Starting with the distribution of the publications over year, it is visible from Fig. 2 that the trend is positive expressing an increase of interest around these topics even though the total number is low, underlining a still limited attention over the positive social impacts generated from the integrated adoption of CM and technologies.

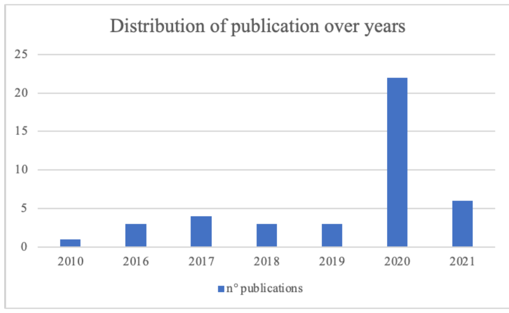

Fig. 2. Distribution of publications over years

The second quantitative analysis over the eligible contributions have been performed on VosViewer (see Fig. 3) to evaluate the keywords adopted by scholars, their distribution, and their links. The analysis was based on 65 keywords, 5 cluster and 595 links among the keywords. Among the most diffused keywords there are: "circular economy" and "manufacture" (red), "sustainable manufacturing" (violet), "environmental technology" and "economic and social effects" and "pollution" (blue), "competition" (green), "natural resource" (yellow). Indeed, also from the keywords analysis, it appears evident the still dominant position of the economic and the environmental perspectives reducing the space of the social-related contributions. Nevertheless, the social keyword is connected not only with manufacturing and circular economy ones, but also with the technological advancements and competition. These links underline an unexplored potential in this context opening the way to this research.

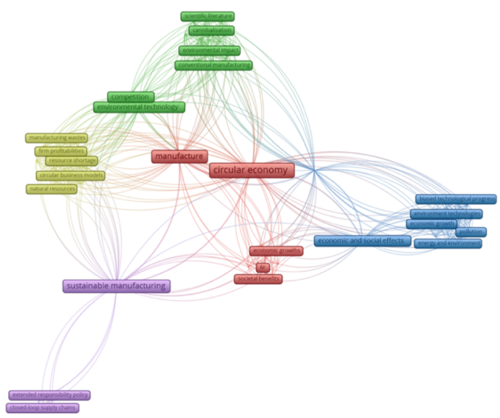

Fig. 3. Keywords distribution analysis

B. Qualitative analysis

The eligible contributions have been also qualitative reviewed to address the research objective of this contribution. The analysis dimensions considered for the review are an updated version of those described in the framework proposed by Ghobakhloo [11] which studied the sustainability functions of Industry 4.0. This choice enabled to start with an initial classification of the potential social dimensions paving the way to enter in detail about the detailed social benefits.

Therefore, the analysis dimensions are the following: human resource development, supply chain digitization and integration to involve customers and suppliers, risk and safety management, increased production efficiency and productivity empowering the workforce's decision-making process, job creation and social welfare enhancement. All these dimensions have been employed in this contribution since are aligned with the values of slowing, narrowing, and closing the resources loops characterising CM and the CM ecosystem perspective.

B.1. Human resources development

The introduction of I4.0 technologies can represent an opportunity for the improvement and enlargement of the workforce skills [13] required in CM adoption, and for the talent management [14]. Indeed, I4.0 technologies can be supporting tools to empower low-medium skilled workers in terms of learning possibilities [15] and this can be even improved if the firm culture promotes learning and knowledge sharing [16]. Actually, the type of skills update, and upgrade will be different according to the industry considered, both regarding the technical skills, sector specific but backed by programming, big data analytics, robotics [17], and soft skills which are needed to empower the critical thinking and continuous improvement [18].

Among the different technologies, Augmented and Virtual Reality can be used to train operators [19], especially relevant in the maintenance activities, also backed by Digital Twins, to evaluate how to extend product and assets lifecycles [20]. Moreover, technologies like Artificial Intelligence can be used to match the job profile skills requirements with the right candidate having the skills needed for that specific job profile [21]. Currently, the two diffusing visions are the "ecopreneur", focused on environmental-related problems to be solved reaching economic prosperity, and the "sustainable entrepreneur" aiming at supporting a social and environmental sustainability in their business [22].

B.2. Supply Chain Digitization and Integration to involve customers and suppliers

Across the supply chain it is becoming essential to collect and analyze data to keep aligned all the stakeholders involved and take informed decisions, appropriate for the external ecosystem. Among all, sensors can facilitate the real-time gathering of data, the several protocols can facilitate the correct data integration and Artificial Intelligence can drive meaningful insights to take decisions [11]. In this regards, once data have been collected, Additive Manufacturing can facilitate the creation of circular designed products [23].

The relevant element to take sustainable and circular oriented decisions is to have under control all the processes. More specifically, to have visibility across the entire value chain, from suppliers to end customers, it is necessary to control material and information flows which is possible thanks to a technological advancement also reinforcing information traceability and reliability [24]. Industrial Internet of Things, of Services and Cloud Computing can facilitate information integration and sharing empowering the management capabilities [25][26], and the misinformation can be overcome through Internet of People creating interactive communication and knowledge sharing also within the boundaries of a company [27]. Externally, peer-to-peer network based on blockchain would enable suppliers to share extra resources [24] and to facilitate the end-of-life management of products [28].

Cloud Computing can facilitate waste management [29] together with the introduction of 3D printers [30], [31], while RFID can facilitate the monitoring of return products quantity and quality to be correctly treated [32]. Finally, privacy and security issues must be considered to ensure reliable and secure information sharing across the entire value chain [33].

B.3. Risk and safety management

The introduction on the shopfloor of intelligent collaborative robotics reduces the safety concerns of the workforce [34] by also reducing the human interventions, errors, and risks [35]. Information and Communication Technologies support the creation of a sate working environment [36], together with Industrial Internet of Things which allows to provide real-time hazard warning and coherent maintenance solutions improving the safety of equipment and operators [37].

The concurrent introduction of Industrial Internet of Things and Smart Robotics facilitate operators in performing disassembling tasks [38]. To facilitate operators in the proper end-of-life management, Augmented and Virtual Reality are considered great enablers to visualize relevant integrated information [39].

B.4. Increased production efficiency and productivity empowering the workforce's decision-making process

I4.0 technologies allows to predict and optimize manufacturing operations by analyzing data acquired from the physical world to be used in simulation models of smart components across the value network [40], [41]. Among all, decisions about the type of remanufacturing activities to be made are facilitated when information about product quality are certain [42], and in case the uncertainty level is still high, collaborative Robots and Cyber Physical Systems enhance operators in improving flexibility to properly treat products [43], [44].

Moreover, Blockchain facilitates the companies’ sustainability reporting systems through a reliable monitoring and management of their reporting activities [45]. CE requires to be always aligned with customers’ requests and needs which is facilitated by the usage of Augmented and Virtual Reality, industrial Robotics, and Additive Manufacturing [46], [47]. Moreover, the simulation of customers behaviors is possible thanks to the introduction of Internet of People and Big Data Analytics. Indeed, hidden trends and life cycle knowledge can be retrieved from sensors providing real time Big Data [48], [49].

B.5. Job creation

The introduction of CE in manufacturing companies will lead to the creation of several local business network models promoting the generation of local job creation [29]. I4.0 technologies adoption can facilitate the upgrade and modification of job profiles if adopted with a worker-centric approach [17].

B.6 Social welfare enhancement

The introduction of CE requires to strengthen the relationships with consumers and Internet of Service, Internet of People and Data Mining can streamline the interaction and communication with them [50] leading towards a mass personalization production [51]. Moreover, product personalization can be done thanks to these technologies [52] and the production of eco-friendly products can be facilitated through the introduction of the Additive Manufacturing [47],[53]. Additive Manufacturing can facilitate also in the waste treatment to transform it into value added products, and this can be also useful to be used to treat municipal waste [54]. Indeed, I4.0 technologies allow to create and reactive and proactive manufacturing environment which contribute to the development of environmental friendly products [55] and Blockchain, though tokenization approaches, can be used to remunerate eco-friendly behaviors [56] .

IV. Discussion

The above reported review enabled to highlight the distinctive technologies required in manufacturing companies to obtain specific social benefits while applying CM based on an updated version of the framework proposed by Ghobakhloo [11]. In Table 1 a detailed list of the different I4.0 technologies supporting manufacturing companies in obtaining social benefits from the adoption of CM is reported. More specifically, the contributions have been critically reviewed and by clustering them in the social dimensions, it has been possible to clarify the I4.0 technologies required to address each specific social dimension and the obtainable social benefits, summarized in the “social outcomes” column, coming from the introduction of CM.

TABLE I
Summary of link between social outcomes in CM and I.40 technologies

Analysis Dimension	Technology	Social outcomes	References
Human Resource Development	Industrial Internet of things	Screening and scouting for specific talents towards CM	[11], [14]
	Big Data Analytics	Ad hoc training sessions and activities	[17], [19]
	Artificial Intelligence		[21]
	Augmented Virtual Reality	Industrial training on the job	[11], [19], [19],
Supply Chain digitization and integration to involve customers and suppliers	Industrial Internet of things	Improved communications and cooperation across the value chain	[23]–[25]
	Internet of Services		
	Internet of People	Better information traceability and management	[11]
	Artificial Intelligence	Supporting the decision-making process	
	Cloud Computing	Waste and returned product management	[29], [30], [31]
	Additive Manufacturing	Circular product design	[23],
	Blockchain	Enhanced trust	[24], [28], [45]
		Better information traceability and management	
		Enhanced trust	
		Improved knowledge sharing	
		Market power distribution	
		Bullwhip effect mitigation	
Risk and safety management	Industrial Internet of things	Real-time maintenance	[37]
		Real time warnings and alert	
	Robotics	Human errors and risks reduction	[34], [35], [37], [38]
		Automation of dangerous tasks	
		Operators cognitive and physical support	
	Augmented and Virtual	Human interventions,	[37], [39]

	Reality	errors and risks reduction	
Increased production efficiency and productivity empowering the workforce decision-process	Big Data Analytics Cloud Computing Cyber Physical Systems	Data management support Decision-making support Life-cycle knowledge	[19], [35], [36], [43], [44], [48], [49], [52]
	Robotics Augmented Reality	Alignment with customers' requests and needs	[46], [47]
	Blockchain	Increased company performances thanks to an improved sustainability reporting enabling to enhance the stakeholders awareness	[45]
Job creation	Robotics	Human substitution for low skills activities	[17]
	Artificial Intelligence	Automation of standard decisions	[17]
Social welfare enhancement	Internet of service Internet of people	Product and service Customization	[50], [51]
	Additive Manufacturing	Production of environmental friendly products Recycling and reuse culture creation	[27], [47], [53] [49], [53]–[55]
	Blockchain	Incentives for customers through tokenization to promote eco-friendly behaviors	[45], [56]

As visible from Table 1, the adoption of CM when supported by I4.0 technologies can facilitate different social outcomes which provide benefits on local communities, workforce, suppliers, and customers as reported in Fig.4. Therefore, it is essential to ensure the simultaneous introduction of CM and I4.0 technologies otherwise the potential social benefits obtainable by manufacturing companies and their ecosystem might be limited. Among all, the most relevant I4.0 technologies enabling to obtain social benefits in CM adoption are summarized in Fig. 4.

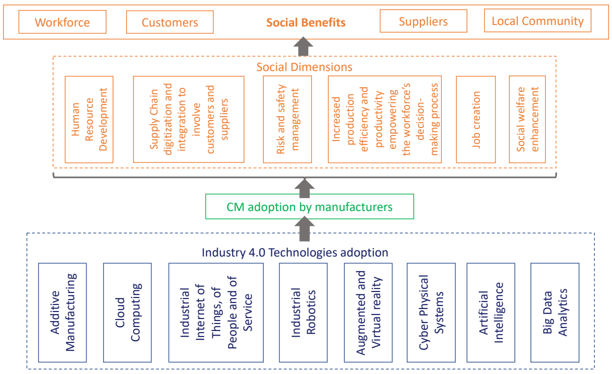

Fig. 4. Theoretical Framework about I4.0 technologies as enablers for social CM

V. CONCLUSIONS

The diffusion of CM in the manufacturing sector is requiring companies to modify their operations influencing their workforce, value chain (suppliers and customers) and the local community. Indeed, a manufacturing company alone cannot limit the transformation looking at their internal operations by introducing remanufacturing and recycling processes only, but it requires to involve the whole ecosystem. For this reason, considering the potentialities of I4.0 technologies in supporting both physical and cognitive activities in CM context, it has been studied how these technologies facilitate manufacturing companies in embracing social benefits, by looking at the entire ecosystem in which companies are immersed during this CM-oriented transformation path.

Indeed, once selected the eligible contributions for the review, these papers were analysed to provide a complete and detailed investigation of the specific social benefits obtainable from the introduction of distinctive I4.0 technologies while embracing CM.

Therefore, this contribution has twofold implications: scientific and managerial.

- From a scientific perspective, the present research aimed at covering the scientific gap envisaged in the extant literature about a limited attention over the social outcomes coming from the adoption of CM especially when integrated with I4.0 technologies. Indeed, the review enabled to classify the already published contributions from a social-CM perspective highlighting the key social benefits.

- From a managerial perspective, the present research allows to clarify to manufacturers embracing CM, what are the needed technologies to grasp the social outcomes generated from CM adoption. Therefore, considering that they are currently incentivized in investing in I4.0 technologies to improve their economic performances, thanks to this contribution they can be also aware about the potential social benefits that these technologies can bring if adopted to support CM embracement.

In future works, this analysis needs to be empirically evaluated and validated.

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