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Exploring synergies between Circular Economy and Asset Management

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Abstract. Circular economy (CE) has been recently considered one of the most promising sustainable strategies for industrial companies, aiming at reducing resources consumption, extending resources life cycle and making recirculate resources within the life cycle stages. The transition from a linear economy towards a circular one requires the internal reorganization of companies without limiting the focus on product life cycle management, also considering how to appropriately manage internal assets, both physical, e.g. machines, and social, e.g. workforce. Indeed, the objective of the present work is to investigate the adoption of CE in industrial asset management (AM), thus focusing on the physical assets. A systematic literature review has been performed with a two-fold goal: firstly, to envisage the synergies between CE and AM and, secondly, to identify existing research gaps. Through this review, it was possible to notice the shared life cycle orientation of the two theories but the still embryonic adoption of it in the AM for a circular aim. Indeed, the major focus in the AM theory, from a CE perspective, is on the role of maintenance activities to extend asset life cycle during its Middle of Life stage while CE adoption at the Beginning of Life of industrial assets is still lagging. This limits a life cycle orientation which would boost industrial companies' sustainability. In order to encounter policymakers' expectations these two theories should be furtherly integrated.

Keywords: Circular Economy, Asset Management, Literature Review.

1 Introduction

Nowadays, due to the scarcity of resources registered in the last decades, forecasted to further increase together with the augment of pollution generation [1], the entire society looks towards sustainable development. Out of all the sectors, industrial companies are considered one of the major responsible of materials and energy usage, while undeniably leading also towards the augment of emission generations [2]. Indeed, the attention on industrial companies has been increased and the adoption of a new industrial economy, called circular economy (CE), has been widely supported by policymakers too [3]. CE is defined as an "*industrial economy that is regenerative and restorative by intension and design*" [4]. This definition is reflected into the adoption by industrial companies of strategies willing to modify the entire organization structure in order to address the CE values of slowing (extending), narrowing (reducing) and closing (recirculating) resources loops [5]. As stated by Stahel (2007) "*the shift from a linear manufacturing economy to a circular or service economy means a change in economic thinking, from flow (throughput) management to stock (asset) management*" [6]. Thus, according to this vision, this transition requires to adequately manage not only products flows, but also all the internal assets, both physical, like machineries, and social, like workforce, necessary to enable the circularity of resources flows.

Asset Management (AM) is a novel approach focusing on the management of physical assets (such as machineries, industrial equipment and plants) in an integrated and holistic way along their life cycle [7]. The corresponding body of international standards about AM [8] pushes towards the adoption of sustainable strategies to support AM. Nevertheless, it does not provide any practical way to correlate them.

For these reasons, it is interesting to study how CE can contribute for sustainable AM practices. In this paper, the extant scientific literature is analyzed addressing the following research question: "What are the synergies and gaps on the adoption of CE strategies in AM?".

To this end, the paper is structured as follows. Section 2 is the basement of the research and both CE and AM are briefly introduced. Section 3 provides the research methodology adopted explaining the motivations behind it. Section 4 presents the major results out of the state-of-the-art (SOTA) of the scientific literature. In section 5 the discussion about the SOTA of the extant scientific literature is proposed. Section 6 presents the conclusions and the main limitations of the present work.

2 Theoretical Background

This section creates the grounding of the present research by reporting the theoretical background of the two areas of investigation, separately, that are CE and AM.

2.1 Circular Economy

CE is defined as an "*industrial economy that is regenerative and restorative by intension and design*" [4]. CE is driven by three main CE values of slowing, narrowing, and closing resources loops, which aim to limit resources consumption, extend resources

life cycle and enable the reintroduction of resources in new life cycles, respectively [5]. Over the years, relying on these CE values, different strategies have been adopted by companies to undertake the transition towards CE. Among them, some strategies are more AM-related such as reuse (e.g.[9]), remanufacturing (e.g. [10]), recycling (e.g. [11]), disassembly (e.g.[12]) and circular design (e.g.[13]). CE strategies aim to cover all the CE values and, they all foster a life cycle orientation by going beyond the single interested life cycle stage, in order to understand the related consequences in the next stages.

2.2 Asset Management

AM, defined as "*the coordinated activities of an organization to realize value from assets*" [8], is a quite recent theory that finds its roots in maintenance management (MM), considering both Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM) approaches [7], [14]. MM is considered one of the main function within AM [15] and it promotes sustainable manufacturing since it enables asset reliability and availability during its usage [16] [2]. Nevertheless, AM goes beyond the traditional MM goals – mainly related to the operational phase of the assets – looking for an integrated methodology to govern the assets over the entire life cycle – thus covering the whole life from Beginning of Life (BoL), through Middle of Life (MoL) up to the End of Life (EoL) stages. Moreover, AM is not only characterized by a life cycle orientation. Other principles, besides life cycle orientation, are at its background: system orientation, risk orientation and asset centric orientation. Based on such principles, AM takes place at the three main control levels within organizations [7]:

- strategic control level refers to long-term strategy definition, guiding the tactical level towards business objectives;
- tactical control level involves the medium-term planning, planning tasks and reporting performance to support higher strategic level;
- operational control level refers to shop-floor activities driven by tactical-dictated tasks and report current performance.

3 Literature review methodology

A systematic literature review has been performed in order to envisage, in a structured and systematic way, the current scientific advances in the adoption of CE strategies in AM. Scopus was chosen as search engine for this review, being it widely used for industrial engineering researches. The first set of keywords considered appropriate to query the search engine were: "Circular Economy" AND "Asset Management", nevertheless these led to only six documents. Indeed, considering the theoretical background above reported about AM, the final string selected is: "Circular Economy" AND ("Asset Management" OR "Maintenance"). This enabled to identify 85 documents, out of which, after a screening process, 37 were selected to perform the review. Indeed, the documents discarded consider the "asset" as a "product" and, thus, their focus is on the

"traditional" CE perspective on product life cycle management, starting from the products newly developed and then managed throughout their life cycle, and not on asset life cycle management with a circular aim, considering the assets as portfolio/systems of assets and individual assets to be managed throughout the life cycle within industrial facilities [8]. Last, the sample of the selected papers was analyzed through a theoretical framework, as discussed in section 4. Indeed, the framework was used to develop a reasoning around the SOTA to envisage the synergies already exploited, and to deductively propose envisioned gaps. In particular, each CE strategy is analyzed through the AM lenses, which are control levels and asset life cycle stages.

4 Theoretical framework and results

Fig. 1 represents the theoretical framework developed by relying on the SOTA of the extant scientific literature. The CE strategies in each paper have been analysed and framed according to the suitable asset control level and asset life cycle stage considered. In some cases, the same paper covers more than one life cycle stage or more than one CE strategy and, thus, it is reported more than one time in the framework.

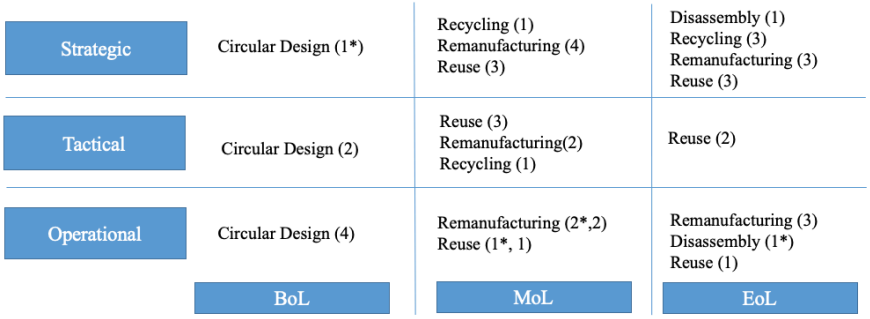

Fig. 1 CE and AM: theoretical framework. (The numbers next to the CE strategies represent the amount of papers focused on a certain control level and a certain life cycle stage; * represents those papers focused on AM, while the others, without *, are focused on MM within AM.)

The analysis and mapping of the CE strategies, reported below, allowed to draw first results regarding the goal of this research work.

Concerning the synergies between the two theories, as visible in Fig 1, a prominent position is gained by remanufacturing, reuse and recycling. These CE strategies are investigated homogeneously at different control levels and, in most of the cases these strategies are adopted both during asset MoL and EoL. Referring to the asset and its components, these strategies take over maintenance as a mean towards asset regeneration with a long term orientation to enable the extension of the life cycle [17], [18]. Disassembly too has been adopted in AM as a CE strategy. Indeed, AM also understands the need to pay attention on asset disassembly performances, such as time, to ease maintenance activities [19]. Nevertheless, disassembly under this perspective has been considered in few papers and only one paper claims a strategic vision of its adoption [17].

Concerning the missing synergies, the life cycle orientation with a circular vision is still not comprehensive of all the asset life cycle stages. It is especially lagging under the concept of industrial AM in BoL. Indeed, circular design has been proposed only by few researches and the most diffused ones are in non-manufacturing industry. For instance, reporting some works, major appliances have been designed to ease their maintenance and their components replacement [20], and buildings have been designed to ensure their robustness, durability [21] and adaptability [22]. In industrial AM, the most CE oriented work with a long term orientation is the one developed in [23], in which environmental oriented appraisal is conducted during asset acquisition at BoL. This latter work has a higher circular long-term vision of the asset life cycle, but it is still not exhaustive, being it only partially focused on CE values. Indeed, the appraisal is limited on environmental issues, close to the narrowing value, and does not include the other CE values that have been covered in other industries through for instance design for adaptability and durability [21], [22].

In addition to the above mentioned strategies, others emerged from the extant review to have potentialities in supporting AM sustainability. Among them, servitization, cleaner production, material efficiency and waste management gain momentum in the scientific literature even though less asset-related strategies and more enterprise and operating business models oriented ones.

Servitization is implemented to provide to the asset user all the maintenance services required to optimize the asset utilization and extend its life cycle [24]. Indeed, service maintenance activities are in fact performed by the asset producers to optimize assets utilization through preventive or predictive maintenance [25] during the MoL of the asset, i.e. with a limited life cycle orientation and a more operational vision. Nevertheless, it is also underlined the usefulness of servitization in order to support maintenance activities to enable more responsible production and consumption from a strategic viewpoint [26]. As final remark, servitization is proposed, taking a long term orientation, only within the construction industry, with the goal to provide a maintenance service of assets already designed with a circular aim [27].

As opposed to servitization, which involves the asset provider, maintenance activities might be undertaken also by the asset users themselves [2]. In this latter case, the maintenance activities are no more considered under the service perspective and are performed in order to increase machines reliability by optimizing production processes to reduce inefficiencies and scraps. The CE strategy adopted in these cases are cleaner production and resources efficiency since the goal is to enable the assets to be more reliable during its MoL by limiting avoidable resources consumption due to inefficiencies [28] or by monitoring asset material corrosion [29].

5 Discussion

From the SOTA of the scientific literature emerged that the synergic point between CE and AM is majorly found in the “maintenance” scope. Maintenance has been already considered a way to support industrial companies’ sustainability [2], and, with a CE orientation, maintenance activities are performed through different CE strategies.

On the other hand, the gaps envisioned through this review are mainly of four categories: (i) General gap, (ii) CE-related gap, (iii) CE-AM related gap, (iv) AM-related gap.

(i) General gap. There is a shortage of scientific researches dealing with the synergic vision of CE and AM, that is expressed by the limited number of papers identified during the research process. AM is still a relatively recent theory, not deeply investigated yet. Instead, in CE adoption, there is limited attention on physical assets as machineries, being CE more focused on the management of products.

(ii) CE-related gap. Although CE strategies are driven by the three main CE values, used as further lenses for the analysis, the wide number of papers are focused on only two out of the three values – "slowing" and "narrowing" – to manage the physical assets; these are the most coherent ones with the traditional sustainable vision. Indeed, through maintenance activities it is supported the extension of asset life cycle and asset components' life cycle (i.e. slowing), and the improvement of industrial efficiency through the reduction of resources consumption, thus also pollution generation (i.e. narrowing) [30]. The "closing" value is still lagging, and it is addressed only in those works aiming to make recirculate obsolete resources.

(iii) CE-AM related gap. Looking at Fig.1, it is evident that not all the CE strategies were resulting in the AM research; for instance, closed-loop supply chain is not considered (which might also support the life cycle orientation), this is still missing as reported below in the AM-related gaps.

(iv) AM-related gap. The asset life cycle orientation vision integrated with CE values is still embryonic. The majority of the papers focus the attention on the asset MoL and EoL, and very few on BoL (see Fig. 1), while, from a CE perspective, BoL would facilitate CE adoption along asset life cycle. Indeed, although the great impact on companies productivity is caused by machines inefficiencies [31], which inevitably impacts also on the increase of resources consumption, there is still not a long term vision anticipated in the asset BoL. Maintenance activities are then performed during the MoL, or in the worst cases, when components or machines need to be replaced in the EoL, whereas sustainability might be improved by including CE values during the asset BoL. Therefore, CE may gain momentum by giving value to CE-related decisions and information in the asset selection and acquisition: all this would boost a life cycle orientation, aiming at including CE values appraisal during asset acquisition or leasing.

6 Conclusion

AM has an inherent life cycle orientation which is coherent with the CE one. Nevertheless, in the extant scientific literature has not yet emerged the exploitation of this synergy as the majority of the researches remains still mainly focused on asset MoL, searching solutions to act during the asset usage to extend its useful life. Therefore, further researches should be developed to include a CE long term orientation and, thus, CE values, starting from the BoL of the asset. Indeed, including at BoL considerations on asset MoL and EoL, which will inevitably arise in the future, would foster industrial

companies' sustainability. Considering the valuable role of physical assets in an industrial company, and considering the current need to embrace CE to improve industrial companies' sustainability, further researches should be developed to integrate CE values in AM. To this end, it could be useful to investigate CE strategies adopted for products to transfer and adapt those concepts to physical assets, whenever possible.

The gaps identified within this paper can be used for paving the way for future researches. They would be particularly relevant to develop empirical investigations and, at the same time, important to attract the attention of policymakers to meet their expectations too on new areas, such as AM and MM, where to implement CE.

It is worth remarking that the present literature review might be biased by the choice of the keywords, especially "Maintenance", which narrows the eligible papers in the MoL and EoL.

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