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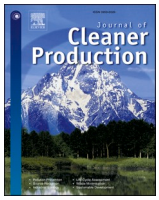

The design and servitization of products according to the circular economy principles: An ecosystem perspective in the building industry

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ABSTRACT

The transition from linear to circular economy is still far from being completed, particularly in the building industry. Indeed, its specific characteristics – such as the fragmentation of its business ecosystem – hinder the implementation of circular economy practices, and, particularly, circular product design and servitization practices. This paper analyses the collaborations among the companies involved in the design and servitization of one of the major elements of a building, the building façade, and it leverages on an action research methodology based on the "Envelope for Service" research project. The role of companies involved in the design and servitization of the circular building façade has been investigated. A novel research framework has been developed to match the circular practices implemented by the ecosystem of involved companies along the useful life phases of the building façade. The research framework highlights the paramount importance of collaborations within the business ecosystem of the building façade and shows how the interactions among companies take place and facilitate circular product design and servitization. We argue and provide evidence that the engagement of the whole business ecosystem is needed in fragmented industries, like the building industry, to implement circular product design and servitization practices. Finally, a hint of the relevance of digital technologies in enabling the implementation of circular practices in such industry is provided.

1. Introduction

The building industry contributes heavily to environmental problems, such as environmental pollution, climate change, resources depletion, wastes generation. The building industry is responsible for almost the 34% of global final energy consumption (including construction and operations) (International Energy Agency, 2023). Emissions from buildings' operations and construction amounted to 12.3 Gt CO_2 globally in 2022 (over one third of total worldwide energy-related emissions) (International Energy Agency, 2023). Construction and demolition wastes accounted for 37.5% of total wastes and construction products were responsible for 32.8% of total raw material consumption in the European Union in 2020 (Eurostat, 2023a, 2023b).

Circular Economy (CE) can be a promising approach to tackle these figures and increase the building industry's sustainability (Leising et al., 2018). Also the European legislators, with the new European Circular Economy Action Plan, acknowledge the building industry as one of the seven key product value chains to be prioritized in the transition towards circularity (European Commission, 2020). CE is an alternative to the current linear economy model and it has been defined as "a multi-level resource use system that stipulates the complete closure of all resource loops" (Figge et al., 2023, p. 2). The ultimate goal of CE is fulfilling economic, environmental, and societal targets (Aarikka-Stenroos et al., 2022; Kirchherr et al., 2023). In this paper, we investigate how to implement CE principles in the building industry from two perspectives: product design and servitization.

First, product design for implementing CE principles has been recognized as a paramount practice and studied in academic research (see e.g., Bocken et al., 2016). Existing literature identifies several circular product design practices and classifies them in different ways. For instance, Morseletto (2020) classifies circular product design practices according to the 10Rs' perspective[1] and Chen and Rau (2023) classify them distinguishing between forward and reverse operations. Even though classifications differ, circular product design practices aim to

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[1] The 10R perspective refers to "10 common circular economy strategies (i.e. recover, recycling, repurpose, remanufacture, re-furbish, repair, re-use, reduce, rethink, refuse)" (Morseletto, 2020, p. 1).

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consider the whole product's useful life from the beginning. Thus, they enable to avoid mismatches among subsequent product's useful life phases. Accordingly, circular product design practices need to be implemented by engaging the whole business ecosystem (Bocken et al., 2016; Sassanelli et al., 2020).

Second, servitization is crucial to preserve resources' value. Servitization has been analyzed in various research streams (Rabetino et al., 2021), and it can be defined as "the innovation of an organisations capabilities and processes to better create mutual value through a shift from selling product to selling [product-service-system] PSS" (Baines et al., 2009, p. 555). Accordingly, servitization is strictly related to the transition from selling products to PSS (Rabetino et al., 2018) and it is positively correlated with sustainable approaches (Kohtamäki et al., 2024). CE does not deliver ownership but functionalities. The traditional linear economy ownership model is based on customers owning the product. The CE ownership model is based on users getting access to the product. The focus is not on traditional selling strategies but on pay-per-use or pay-per-performance strategies. Servitization-based strategies, such as pay-per-use or pay-per-performance, already well known and studied in academic literature (Boons and Lüdeke-Freund, 2013), are therefore particularly suitable to be implemented in CE context. Through servitization, producers can retain the products' (and resources') ownership. Producers are thus incentivized to extend products and components' useful life. Literature converges in identifying PSS as one of the main practice to implement servitization in CE (Khitous et al., 2022a). However, PSS alone is not sufficient to implement CE principles. Resources' value must be preserved also through take-back-system (TBS) (Centobelli et al., 2020). TBS enable to collect used products and retain resources' value by implementing different technical cycles (e.g., remanufacturing). PSS together with TBS enable the development of the ownership model based on servitization according to CE principles. Indeed, these two circular aspects support the reduction of resources consumption and a more efficient usage of materials. Both PSS and TBS require collaboration among different companies to be implemented and they also require customers' engagement (Centobelli et al., 2020; Charef et al., 2022; Farooque et al., 2019).

The transition from linear to CE is though and still far from being completed (Franzò et al., 2021). The implementation of CE principles is particularly challenging in industries characterised by long, fragmented value chains and complex, durable products, such as the building industry (Dewagoda et al., 2022; Khitous et al., 2022b). In this industry, materials and information flows are interrupted frequently along the value chain, and short-term goals prevail on long-term ones. Consequently, it is more difficult to engage the whole business ecosystem to jointly implement circular product design and servitization practices. The implementation of CE principles in the building industry calls for collaboration and an ecosystem-view to engage the whole business ecosystem (Dewagoda et al., 2022). Collaborations, as well as the engagement of all the several companies belonging to business ecosystem, could be an enabler of circular product design and servitization in the building industry (Giorgi et al., 2022; Khitous et al., 2022b; Köhler et al., 2022).

Literature in the interplay between CE and the building industry is mainly focused on (i) circular strategies that could be applied to facilitate the transition of this industry from linear to CE (Charef et al., 2022; Q. Chen et al., 2022; Dewagoda et al., 2022), (ii) the actual level of implementation of CE principles in buildings (Giorgi et al., 2022), (iii) circular building design tools and strategies (Antwi-Afari et al., 2022; van Stijn and Gruis, 2020), and (iv) life cycle assessment analysis (Antwi-Afari et al., 2022). Even though literature focuses on the implementation of design and servitization strategies, studies deepening the design and servitization of buildings' elements through companies' collaborations are much more scattered and provide mainly anecdotic contributions (see, e.g., Giovanardi et al., 2023; Hartwell et al., 2021). The understanding of how companies collaborate to implement design and servitization practices deserves additional research efforts and could develop relevant contributions to both scholars and practitioners (Oluleye et al., 2022). From an academic standpoint, the recently defined concept of "circular ecosystem" (Aarikka-Stenroos et al., 2021) could be further advanced by understanding which players (and how) could collaborate to implement the servitization of buildings' elements. From a managerial standpoint, managers could leverage on this research to understand with which companies circular design and servitization practices should be jointly implemented to fully benefit from CE benefits.

Starting from the premise above, our aim is to address the following research question: *"How do companies in the building industry implement circular product design and servitization practices while collaborating from an ecosystem perspective?"*

Our unit of analysis is represented by the building façade for two main reasons. First, the building façade is characterised by a high environmental impact: it is responsible for 10%–20% of the total embodied carbon emissions of the building (Giovanardi et al., 2023). Second, the building façade is an external building element: it is easily accessible, and thus maintenance, repair, and disassembly operations are facilitated. Therefore, environmental, technical, and business benefits are merged, and they make the building façade one of the most suitable buildings' elements in which implementing CE principles (Giovanardi et al., 2023; Hartwell et al., 2021; Wouterszoon Jansen et al., 2022).

To address the research question above, the paper leverages an action research methodology. This methodology aims to provide not only theoretical contributions but also practical contributions through the involvement not only of scholars but also of practitioners. Scholars and practitioners closely collaborate in a practical project, and they follow the whole project from its setting to its conclusion (Coughlan and Coghlan, 2002). We deploy this methodology to the "Envelope for Service" research project, a project involving both academic and industry partners, and aimed to investigate the role of the several players involved in the joint design and servitization of the building façade.[2]

The remainder of this paper is organized as follows. Section 2 presents the state of research pointing out the main practices for circular product design and servitization, as well as the enabling role of the ecosystem perspective. Section 3 reports the rationale and detailed description of the methodology used for this research. Section 4 shows the main findings and discusses them against the existing research. Section 5 draws the theoretical and managerial contributions. Finally, Section 6 highlights the concluding remarks, acknowledges limitations, and suggests possible avenues for further research.

2. State-of-the-art

2.1. Circular practices for product design and servitization in the building façade industry

Practices related to circular product design are the main ones to implement CE (Bocken et al., 2016; Centobelli et al., 2020; Sassanelli et al., 2020). Existing literature identifies different circular product design classifications. The seminal contribution by Bocken et al. (2016) distinguished circular product design practices according to three main strategies: slowing, narrowing, and closing. The final objectives are to design products that last longer, use less resources, and are easy to be recycled. This seminal classification has been recently updated and extended to include strategies aimed to use clean, renewable resources and leverage on digital technologies (Aguiar and Jugend, 2022; Konietzko et al., 2020a). The most relevant circular product design practices, stemming from current literature, aim thus to extend products' useful life and could entail the development of novel technologies. Therefore, circular product design practices require a joint effort of the

[2] Detailed information about the project is reported in Section 3.

companies involved in the related business ecosystem to benefit from the combination of their complementary skills and resources in the circular design process (Aguiar and Jugend, 2022; Bocken et al., 2016; Charef et al., 2022; Eberhardt et al., 2022; Urbinati et al., 2019).

Likely, to implement servitization, ad hoc circular practices should be considered, such as PSS and TBS (Centobelli et al., 2020). To effectively implement servitization practices, the involvement and collaboration among the several ecosystem's companies – and, eventually, new companies that are not yet part of the ecosystem – is key to convey CE principles all along the business ecosystem (Charef et al., 2022; Eberhardt et al., 2022; Munaro et al., 2021). To be effective, indeed, these circular practices have to be spread to the business ecosystem (Farooque et al., 2019).

The importance of circular product design and servitization is evident also in the building industry. CE principles applied to buildings have been defined as "a lifecycle approach that optimizes the buildings' useful lifetime, integrating the end-of-life phase in the design and uses new ownership models where materials are only temporarily stored in the building that acts as a material bank" (Leising et al., 2018, p. 977). This definition contains the two key concepts: design and ownership model. However, the implementation of CE principles in the building industry is challenging because buildings are complex, durable products, composed by several elements (Dewagoda et al., 2022; Khitous et al., 2022b). Among these elements, the building façade stands out given its high environmental impact and accessibility. These two characteristics make the building façade a suitable building element in which to implement CE principles (Giovanardi et al., 2023). Accordingly, we take the building façade as our unit of analysis. Both building façade design and ownership model must be redefined to implement CE principles. We report in Table 1 the circular product design and servitization practices that current literature identifies as suitable to be generally implemented and more specifically in the building façade industry (see Azcarate-Aguerre et al., 2022; Hartwell et al., 2021; van Stijn et al., 2022; Wouterszoon Jansen et al., 2022).

Table 1 distinguishes between circular product design practices and servitization practices. Considering circular product design practices, for instance, a circular building façade needs to be easily assembled and disassembled to enable and ease repair, maintenance activities. Considering servitization practices, PSS is the main circular practice to be considered and coupled with TBS to focus on functionalities rather than ownership and to enable resources' value preservation.

2.2. The ecosystem perspective: origins, key characteristics, and the concept of circular economy ecosystem

The concept of ecosystem is rooted in biology, where it has been defined as one of the fundamental unit of natural environment including both organic and inorganic factors (Tansley, 1935). More recently, the concept of ecosystem has become popular in managerial literature inspired by the biological concept of ecosystem (Moore, 1993). Similarly to the variety in size and forms acknowledged in biological ecosystems (Tansley, 1935), also the concept of ecosystem in managerial literature is characterised by a variety of different forms and types (Aarikka-Stenroos et al., 2021; Thomas and Autio, 2020). Ecosystems differ mainly based on the type of participants included and of the achieved system-level outcome, resulting in business ecosystems, innovation ecosystems, entrepreneurial ecosystems, platform and service ecosystems (Aarikka-Stenroos and Ritala, 2017). In particular, the concept of business ecosystem was introduced by the seminal contribution of Moore (1993) and "can be considered a generic overarching concept for

Table 1
Main circular practices for the design and servitization of circular building façade.

	Circular practices	Circular practices related references	Circular practices implemented to the building façade industry	Building industry and building façade industry related references
Circular product design	Design for assembly/ disassembly	(Aguiar and Jugend, 2022; Bocken et al., 2016; W. C. Chen and Rau, 2023; den Hollander et al., 2017; Gunasekara et al., 2023; Konietzko et al., 2020a; Lüdeke-Freund et al., 2019; Sassanelli et al., 2020; Uvarova et al., 2023; Wang et al., 2022)	Designing façade that can be easily assembled and disassembled to ease e.g., repair and remanufacturing.	(Charef et al., 2022; Q. Chen et al., 2022; Eberhardt et al., 2022; Hartwell et al., 2021; van Stijn et al., 2022; Wouterszoon Jansen et al., 2022)
	Design for modularity		Designing façade that can be easily, for instance, upgraded by substituting single components.	
	Design for prefabrication		Designing façade that optimize construction times and eases assembly and disassembly operations.	
	Design for standardization		Designing façade with limited materials to ease e.g., recycling, to prolong materials' useful life and to maximize materials' recovery.	
	Design for accessibility		Designing façade with eased access to the connection among the several façade components to ease e.g., maintenance, disassembly.	
	Design for manufacture		Designing façade considering manufacturing requirements from the start to ensure manufacturability.	
	Design for reuse		Designing façade whose existing components can be reused in new building façade.	
	Design for flexibility/ adaptability		Designing façade that can easily be adapted to changes in building use and/or building occupants' needs with the objective to prolong the façade useful life.	
Servitization	Product-service-system (PSS)	(Bressanelli et al., 2018; Centobelli et al., 2020; Kjaer et al., 2019; Tukker, 2015)	Circular façade is offered as a service to the final users (i.e., the building occupant). Final users pay for the performance guaranteed by the façade.	(Azcarate-Aguerre et al., 2022; Charef et al., 2022; Ghafoor et al., 2023; Hartwell et al., 2021; Munaro et al., 2021)
	Take-back system (TBS)		Façade components are recollected at the end of their useful life to value resources and enable the implementation of the most suitable technological cycle	

distinct types of interdependent and co-evolving systems of actors, technologies, and institutions" (Aarikka-Stenroos and Ritala, 2017, p. 25). From a managerial standpoint, scholars identify four key characteristics of ecosystems: participant heterogeneity, participant interdependence, non-contractual agreement, and ecosystem output. First, a heterogeneous set of participants with different roles – even customers – are included in the ecosystem. Second, the participants included in the ecosystem are interdependent among each other from a technological, economic, or cognitive perspective. Third, the relationship among the participants included in the ecosystem is not characterised by formal contracts but it is characterised by a co-alignment structure in which the heterogeneous set of included participants proactively contribute to face mutual challenges. Fourth and last, the ecosystem generates a system-level output, which is characterised by a higher value than the sum of the single outputs that could have been achieved by single participants (Thomas and Autio, 2020).

Recently, managerial literature about CE and ecosystem collides. The concept of CE ecosystem has been defined "as communities of hierarchically independent, yet interdependent heterogeneous set of actors who collectively generate a sustainable ecosystem outcome, […] defined as a system-level outcome typified by circular processes of recycling, reuse, and reduction" (Aarikka-Stenroos et al., 2021). The concept of ecosystem has been introduced in the debate about CE due to several reasons. First of all, the natural environment and the business ecosystem are strictly interconnected and a change in the conditions of the former leads to a change in the conditions of the latter (Winn and Pogutz, 2013). In particular, resource scarcity represents one of the conditions which could trigger a change in the business models towards approaches such as product service system (Boons, 2013). Thereafter, the implementation of CE practices, such as circular product design and product service system, requires a broader perspective other than the perspective of the single company and therefore calls for an ecosystem approach also to avoid burden shifting among the participants included in the ecosystem (Bocken et al., 2016; Kjaer et al., 2019).

The transition towards CE requires to redesign not only the product but also the ownership model according to CE principles. Both practices related to circular product design and servitization have to be implemented at the same time (Centobelli et al., 2020; Urbinati et al., 2017). The joint implementation of both circular product design and servitization practices enables to consider the whole product's useful life. Therefore, mismatches between subsequent phases of the product's useful life, managed by different companies, can be avoided. The product's useful life phases have long since been analyzed (Maxwell and Van der Vorst, 2003; Paton and Andrew, 2019) and difference classification are available in academic literature ranging from straightforward (Bressanelli et al., 2018; Rusch et al., 2022) to complex classifications (Luz et al., 2018). In this paper, we consider a straightforward classification, more suitable to spot and understand the interaction among the different companies involved in the business ecosystem (coherently with, e.g., Silva and Fontana, 2021). We distinguish among three main façade useful life phases: (i) pre use phase: it refers to all the activities performed before the façade is used (e.g., resources retrieval, production, distribution); (ii) use phase: it refers to the actual usage of the façade; (iii) post use phase: it refers to all the activities performed after the façade is used (e.g., reverse logistics, remanufacturing).

In this paper, we aim to investigate the transition towards CE from an ecosystem perspective to identify the heterogeneous and interdependent set of actors, which operate throughout the product useful life phases, and how they collaborate to achieve circularity.

3. Methodology

3.1. Action research

We applied action research methodology to define our empirical setting. Action research methodology has been defined as "an approach to research that aims both at taking action and creating knowledge or theory about that action" (Coughlan and Coghlan, 2002, p. 220). The objective of action research is to advance both theory and practice by involving both scholars and practitioners. Academics and managers collaborate closely in a real-world project from research setting to results (Checkland and Holwell, 1998; Whyte, 1991). The building industry has already been investigated through action research gaining useful insights from an academic and managerial perspective (see, e.g., Eriksson, 2010). This methodology is suitable to investigate the building industry and to answer our research question (also reported in the Introduction), i.e., *"How do companies in the building industry implement circular product design and servitization practices while collaborating from an ecosystem perspective?"*. In particular, we followed the three main steps which comprise action research as identified by Coughlan and Coghlan (2002): pre-step, main steps, and meta-step.

Pre-step. In the pre-step, the purpose and the context were defined. Two main reasons led to the deployment of action research. On the one side, the interplay between CE and the building industry is still under development in academic research and in the real-world, the transition towards CE is still tough and far from being completed. On the other side, action research represents an opportunity to delve into this interplay, collect first-hand data and contribute to CE implementation. Second, a suitable context was identified in a global company active in the built environment industry. Two authors of the present paper successfully approached the company and were invited to join and actively participate to a research project – called "Envelope for Service" – which aimed to investigate the implementation of CE principles in the building façade context (Andaloro et al., 2022). The research project was funded by the global company active in the built environment industry through own funding and it was about to kick-off when the authors were invited to join the project. It deserves to be mentioned that the global company active in the built environment industry developed skills and competences on CE and, after the end of the project, it established a competence centre specialised in CE. The research project was led by a team of six researchers and three practitioners representing three different entities: the global company active in the built environment industry, one applied research institution, and two universities. The research team was multidisciplinary as it involved practitioners with technical skills and expertise in the building façade industry, engineering researchers with technical competences in the building façade industry and managerial researchers experienced in CE practices. The research project lasted two years (i.e., 2020 and 2021). Some project activities were conducted mainly by researchers (e.g., academic literature review) or practitioners (e.g., empirical testing), at the same time, the project was carried out in a collaborative setting. Recurrent meetings were arranged involving all the multidisciplinary team members to review in-progress results and discuss next steps. Confidential project reports were jointly written by the multidisciplinary team members to present the project advancements and results.

Main-steps. The main steps consisted in data collection, feedback, analysis, action planning, implementation, and evaluation. Data collection focused on gathering information on the building façade value chain and the main circular practices for the design and servitization of circular building façade and it was conducted by researchers and practitioners. Both academic literature and grey literature (e.g., sectorial reports, consultancy reports) were considered not to miss relevant information and valuable contributions. On the one side, academic literature was considered and reviewed by researchers, on the other side, grey literature was scanned by practitioners. Considering the academic literature, a narrative literature review methodology was deployed, suitable to investigate the interplay between different domains. It refers to reviewing current literature with an incremental knowledge expansion starting from a small sample of theoretical contribution and enlarging it through a backwards and forward snowball sampling approach until saturation is reached (Fan et al., 2022). Considering grey literature, professional databases, such as LexisNexis,

were used to gather data and information. Thereafter, the data feedback and analysis steps were conducted. The data collected through different sources were triangulated and jointly validated by the multidisciplinary research team, involving both researchers and practitioners, and integrated through semi-structured interviews with external key experts. Semi-structured interviews were selected as they allow to provide empirical information in a flexible setting with the possibility to focus on particular aspects of each peculiar interviewee (DiCicco-Bloom & Crabtree, 2006). Semi-structured interviews were conducted with employees with managerial roles employed by two façade manufacturers, a facility management company, a real estate development company, a general contractor and three Energy Service Companies. An interview protocol was initially drafted by the researchers and reviewed by the practitioners, according to three main sections to be investigated: (i) the identification of the companies involved in the business ecosystem of the building façade industry, (ii) the role performed by each identified company in circular product design and servitization, and (iii) the circular design and servitization practices jointly implemented. The interviews were conducted online and in Italian and they lasted approximately 45–60 min. A content analysis (Weber, 1990) was performed by the researchers on the collected material to triangulate the different sources of information with the objective to identify the companies involved in the business ecosystem of the building façade industry and how they should collaborate to jointly implement circular design and servitization practices. Thereafter, a demo-case study was conducted to perform the action planning, implementation, and evaluation steps leveraging on the competences, experience and assets of the practitioners involved in the multidisciplinary team. The final objective of the demo-case study was to evaluate the joint implementation of circular design and servitization practices in the business ecosystem of the building façade industry. The researchers involved in the multidisciplinary team directly observed and collected data on the collaborative implementation of these practices. Monitoring and feedback loops were crucial for the researchers in order to integrate the evidences gathered though the literature reviews and interviews and, ultimately, to identify which companies collaborate with each other to implement each circular design and servitization practice. Therefore, the demo-case study allowed for a second cycle of data collection and analysis with direct, empirical and actionable observations. The empirical base refers to a real-world Italian testing project: the retrofitting of an existing building with innovative circular façade. The existing building is a residential social housing condominium, almost forty years old. It is in central Italy, and it has four floors and more than ten flats. The building is characterised by over eight hundred squared meter of walkable heated floor and over three hundred and fifty square meters of roof. The total façade surface of the building amounts to one thousand and one hundred square meters. Almost forty rooms have at least one external wall, of which 70% are living rooms, South-East oriented, and 30% are bedrooms, North-West oriented. Data collection, feedback and analysis steps lasted approximately 16 months, and the action planning, implementation and evaluation steps lasted approximately 8 months.

Meta-step. The meta-step was followed to continuously monitor the research project advancements and implement feedback loops. For instance, the feedback gathered during the semi-structured interviews were useful to validate and enrich the data and information gathered in the data collection step. Accordingly, we adopted an abductive approach. Fig. 1 shows a graphical representation of the applied action research steps.

3.2. The Envelope for Service research project

"Envelope for Service" research project aimed to: (i) identify the most suitable technological solution with which to implement CE principles in the façade industry, (ii) identify the companies involved in the business ecosystem of the building façade industry and (iii) identify the circular practices to be jointly implemented for circular product design and servitization. A demo-case study was included to gain even more practical and real-world evidence. Two authors of the present paper actively contributed to the last two objectives of the research project (i.e., the identification of the companies involved in the business ecosystem and circular practices).

Thanks to the collaboration of academics and managers in "Envelope for Service" research project, it was possible to identify not only the companies involved in the business ecosystem of the building façade

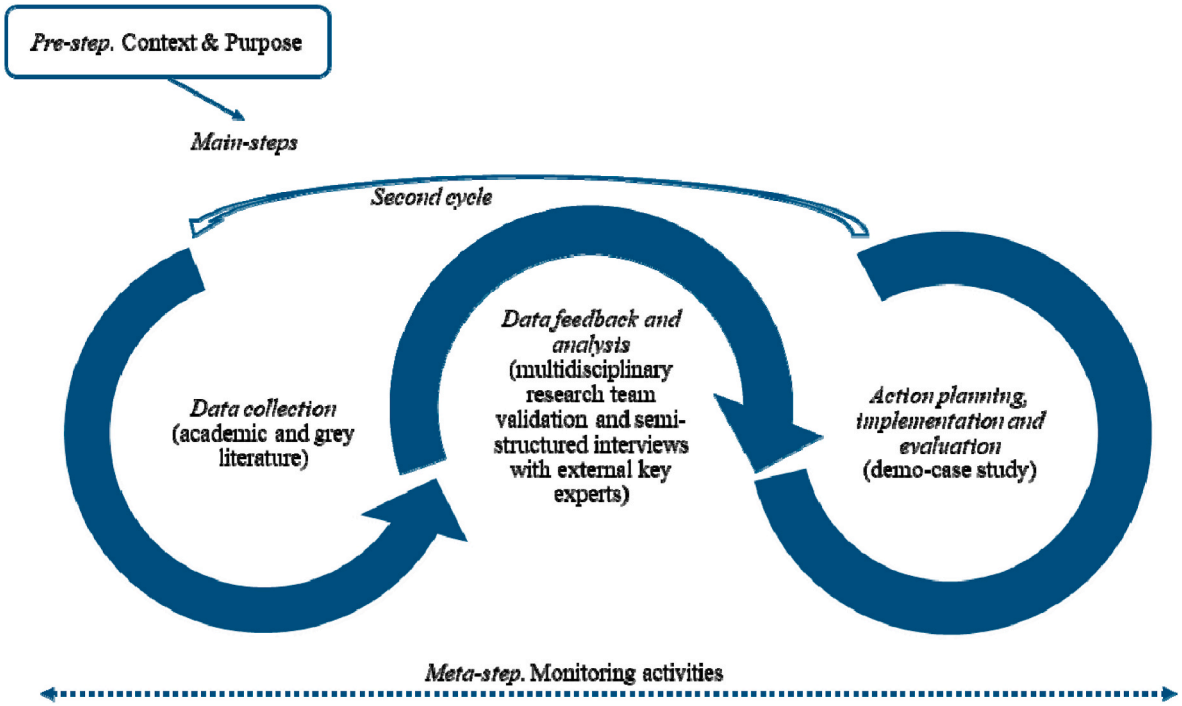

Fig. 1. Action research methodology applied to the context of the "Envelope for Service" research project (adapted from Coughlan and Coghlan, 2002).

industry but also their roles to jointly design the circular innovative façade and define the ownership model based on servitization. The companies involved in the business ecosystem of the building façade industry were jointly identified by the project's partners as: integrated design consultancy company, façade manufacturer, service provider, facility manager, and asset owner.

The innovative circular façade was designed to be modular. It was composed by controllable blinds, a decentralized ventilation machine and a building integrated photovoltaic system. Besides, digital technologies were embedded into the innovative circular building façade. These digital technologies enable to track and monitor the building façade performance. They enable to increase the building occupants' comfort and the environmental sustainability of the building façade. They optimize daylight control, thermal heat transfer and, consequently, energy consumption and perceived comfort. Quantitative and qualitative benefits are provided by the innovative circular façade. On the quantitative side, energy consumption is reduced. On the qualitative side, building occupants' comfort is improved. However, the demo-case study highlighted that the innovative circular façade is not yet competitive, from an economic perspective, when compared to traditional façade. The investment cost difference is in favor of the traditional façade, and it cannot be compensated with the additional benefits provided by the innovative circular façade.

4. Findings

Findings are organized as follows. We report in Section 4.1 the role played by each company involved in the design and servitization of a building façade. We report in Section 4.2 the research framework, in which we match each involved company in the business ecosystem of the building façade industry with the circular practices implemented, considering both circular product design and servitization practices.

4.1. The role of the companies involved in the business ecosystem of the building façade industry

The companies involved in the business ecosystem of the building façade industry, jointly identified by the "Envelope for Service" research project partners, operate in different façade useful life phases according to their peculiarities. The integrated design consultancy company operates only in the pre use phase, given its involvement in the façade design process. The façade manufacturer operates not only in pre use phase, given its involvement in the façade manufacturing (in alignment with the linear economy model), but also in the post use phase, given the need (in the CE model) to close-the-loop, for example, through remanufacturing activities. The facility manager and the asset owner operate only in the use phase, given that their involvement is related to the management and the ownership of the building, respectively. Finally, the service provider operates in the whole façade useful life phases given its coordination activities performed among the different companies involved in the business ecosystem of the building façade industry.

The façade useful life phases in which the companies involved in the business ecosystem of the building façade industry operate is reported in Table 2. Table 2 describes also the role performed by each company in the circular design and servitization practices for a circular building façade.

Considering circular product design, the service provider acts as the focal point supporting the development of the innovative circular façade by coordinating all the companies involved in the business ecosystem of the building façade industry and merging their different knowledge,

Table 2
The role of involved companies in circular design and servitization for a circular building façade.

Companies involved in the business ecosystem of the circular building façade industry	Integrated design consultancy company	Façade manufacturer	Facility manager	Asset owner	Service provider
Typical activities of the company	It is involved in the design of the building and its components (e.g., building façade).	It is involved in the manufacturing of the building façade.	It is involved in ensuring proper building operations (e.g., functionality, comfort, safety).	It is the owner of the building and its components (e.g., building façade).	It is involved in the development and offering of the building façade according to the CE approach.
Façade useful life phase in which the company operates	Pre use phase	Pre use phase Post use phase	Use phase	Use phase	Pre use phase Use phase Post use phase
The company's role in circular product design	Its involvement in the design process is relevant. It takes care of design activities to design the façade according to CE principles. Moreover, it considers the whole façade useful life in the design process and, therefore, it enables the early identification of issues and threats.	Its involvement in the design process prevents the risk of a mismatch between the design, the manufacturing, and the installation processes, and leads to the development of manufacturing activities according to circular practices.	It is not involved in circular product design.	It is not involved in circular product design.	It provides strategic guidance on the whole design process. It acts as the technical project manager, gathering and providing all the relevant information (e.g., façade requirements needed by the final user, needs of the different companies involved in the business ecosystem of the building façade industry) to the companies involved in the design process.
The company's role in servitization	It supports the service provider to define the KPIs to be monitored to track the façade's performance.	Its involvement is needed to close-the-loop of the façade. It performs indeed renovation activities (e.g., remanufacturing) aimed to extend the façade useful life.	It acts in close collaboration with the service provider. It supports monitoring and maintenance activities and ensures the adequacy of the façade's performances.	It acts in close collaboration with the service provider. It enables the service provider to take back the façade after its usage and thus supports to close-the-loop and extend the façade useful life.	It retains the façade responsibility and ownership throughout the whole façade useful life. Hence, it provides the circular façade based on servitization principles and provides performance-based contracts to the final users.

skills, resources. The involvement of both the façade manufacturer and the integrated design consultancy company enables to overcome mismatches among design, manufacturing, and installation activities, reducing wastes and inefficiencies (in accordance with Charef et al., 2022; Eberhardt et al., 2022). Besides, also the final users – not usually involved in the business ecosystem of the traditional, linear building façade industry – have a role in this design process. Indeed, they provide to the service provider the desired characteristics to be met by the innovative circular façade during its use phase.

Considering servitization, again the service provider acts as the hub of the business ecosystem, as the customer's single point of contact. It retains ownership and responsibilities over this innovative circular façade during the whole façade useful life, enabling façade disassembly, refurbishment, and reuse. The façade is thus offered through a one-stop-shop and performance-based service model, leveraging on different partners, each providing specific competences. Integrated design consultancy company supports the service provider by defining the Key Performance Indicators (KPIs) to be monitored. The KPIs' definition activity is performed by the integrated design consultancy company in the pre use phase, in accordance with the façade design and the reachable performance. The facility manager and the asset owner collaborate with the service provider. The former supports monitoring and maintenance activities and ensures the adequacy of the façade's performances. The latter supports to close-the-loop by enabling the service provider to take back the used façade and extend the façade useful life. In addition, the façade manufacturer's involvement is also crucial to extend the useful life of the taken back façade through renovation activities, such as remanufacturing.

The service provider emerges then as a focal player not only to implement circular design practices but also to implement servitization practices. It provides strategic guidance throughout the whole design process and retains ownership of the façade. Each company involved in the industry contributes to the flows of information, materials, and resources according to its needs, skills, competences. These flows are integrated and orchestrated thanks to the service provider, which enables not to have mismatches among subsequent phases of the product useful life and acts as the central reference point for the several companies involved in the industry.

4.2. *Matching roles and circular practices: a comprehensive view of the business ecosystem for a circular building façade*

Fig. 2 reports the circular practices implemented by the ecosystem of the involved companies for the design and servitization of the building façade according to the CE approach.

Three companies in the business ecosystem of the building façade industry are involved in circular product design, namely integrated design consultancy company, façade manufacturer, and service provider. Interestingly, six out of eight circular product design practices are jointly implemented by all the three companies. The joint implementation of six circular product design practices enables to consider at the same time final users' needs and manufacturing process' requirements from the beginning of the façade's useful life. The integrated design consultancy company collaborates with both the façade manufacturer and the service provider. The former provides the manufacturing process requirements to be met. The latter provides the final users' needs to be fulfilled. Thanks to the joint implementation of design practices, the overall façade's useful life is consistently designed to avoid mismatches among the consequent façade's useful life phases. For instance, the integrated design consultancy company designs the façade to be easily assembled, disassembled, and accessible, to facilitate the installation and maintenance activities performed by the service provider. The involvement of the façade manufacturer enables to embed these requirements in the façade manufacturing process.

Conversely, the remaining two circular product design practices (i.e., design for prefabrication and design for manufacture) are implemented solely by the façade manufacturer. These two circular practices are particularly focused on manufacturing activities and do not interconnect with the other companies of the business ecosystem.

All the companies involved in the business ecosystem of the building façade industry are involved in redefining the ownership model according to servitization principles. They collaborate to implement PSS and TBS. Service provider, facility manager, and integrated design consultancy company are involved in the implementation of PSS. The service provider is the focal company, and it provides the pay-per-use or pay-per-performance contract to the final user. The facility manager supports the service provider in guaranteeing the agreed performances. The integrated design consultancy company supports the service provider in the design of the KPIs through which monitoring the façade's performance.

In a similar vein, TBS requires the coordination of three out of five

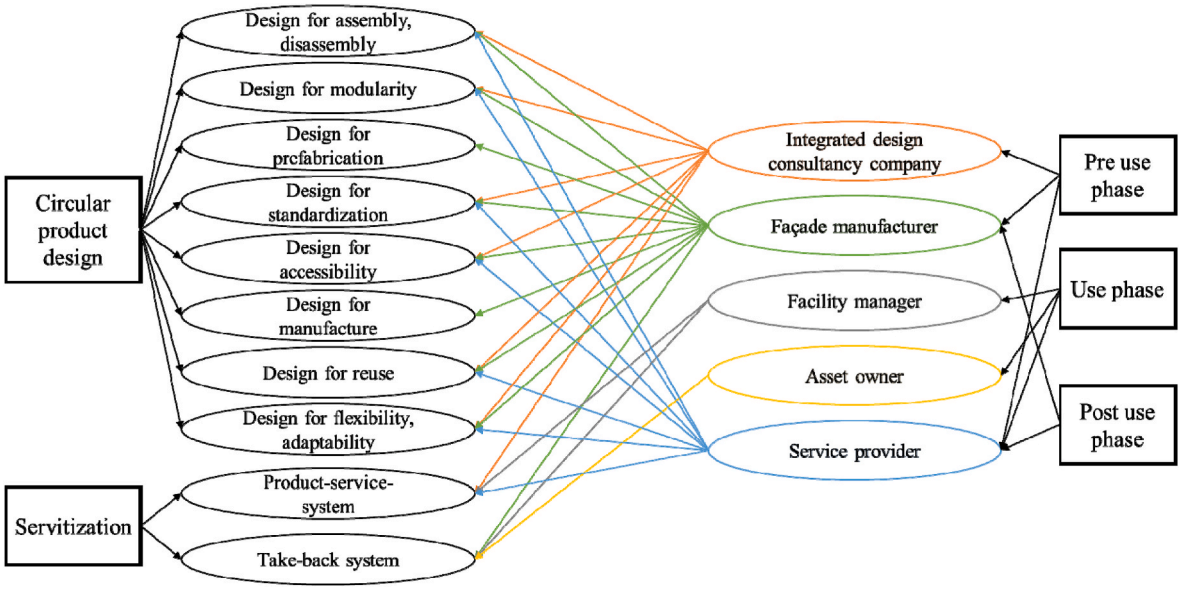

Fig. 2. Linkages between the circular product design and servitization practices for a circular building façade and the related ecosystem of involved companies.

companies involved in the business ecosystem of the building façade industry, namely asset owner, facility manager, and façade manufacturer. These companies must collaborate to disassemble the building façade, when agreed performance is no longer met, and to extend the façade useful life, through close-the-loop activities (e.g., remanufacturing).

The joint implementation of circular product design practices leads to the design of an innovative circular building façade. This innovative circular building façade is also embedded with digital technologies, that enable to track performances over time and share performance data. The integration of digital technologies in design and manufacturing activities favours the actual implementation of the "pay-per-performance" contract. Thanks to performance tracking, it is possible to measure the actual performances and compare them to the target performance guaranteed under "pay-per-performance" contract (Yi et al., 2017). Circular product design and servitization are thus strictly related and must be jointly and consistently designed by the companies involved in the business ecosystem.

Three out of five companies involved in the business ecosystem of the building façade industry (i.e., integrated design consultancy company, façade manufacturer and service provider) collaborate in both circular product design and servitization. The collaboration among these three companies in circular product design emerged also before in literature (see, e.g., Hartwell et al., 2021). However, we observe their collaboration not only takes place in circular product design but also extends in servitization covering the whole façade useful life.

In addition, it is clear in our case the focal role in the business ecosystem played by the service provider, who acts both as technical project manager and single contact point for the final users, merging what stems from Hartwell et al. (2021) and Giovanardi et al. (2023). The former emphasizes the service provider focal role in circular product design and the latter emphasizes the service provider focal role in servitization. We observe the focal role of the service provider in both circular product design and servitization. Interestingly, this claim for the service provider possessing both technical and managerial skills to be able to apply performance-based contracts. These characteristics are similar to the ones already applied by energy service companies, currently offering performance-based contracts leveraging on technical and managerial competences in the energy efficiency market (Carbonara and Pellegrino, 2018; Yi et al., 2017). Therefore, energy service companies could be identified as the proper service provider not only in the energy efficiency market but also in the circular building façade market.

The two remaining companies involved in the business ecosystem of the building façade industry – namely facility manager and asset owner – are involved only in servitization in accordance with previous results of Giovanardi et al. (2023) and Hartwell et al. (2021), that we further advance by making clear not only their involvement in the ecosystem but also their role of collaboratively establishing circular practices.

5. Theoretical and managerial contributions

In the next Sections, we report the main contributions of this paper. From a theoretical standpoint, the main contributions for academic researchers are reported in Section 5.1. From a managerial standpoint, the main contributions for practitioners are reported in Section 5.2.

5.1. Theoretical contributions

The contribution of this paper to the literature in the interplay between CE and the building industry is fourfold.

First, companies need not only to know which circular practice they have to implement but also with whom they need to collaborate to implement those practices. To undergo the transition towards circularity, companies need not only to understand what to do but also who to involve. Therefore, companies cannot operate in separate "silos". Collaboration is needed to avoid potential mismatches throughout the different product's useful life phases managed by different companies. We therefore not only posit the relevant role of collaboration (in accordance e.g., with Konietzko et al., 2020b). but also we posit that collaboration could enable potential benefits such as the avoidance of burden shifting, merging what stems from previous contributions (see e.g., Kjaer et al., 2019, on the need to avoid burden shifting; Leising et al., 2018, on the relevance of collaborations).

Second, we posit the paramount role of the service provider in the transition towards Circular Economy in a fragmented industry, such as the building façade industry. The service provider could act as the focal point of the business ecosystem providing strategic and managerial guidance to the companies involved in the business ecosystem. We further advance the relevance of the service provider in the Circular Economy field, as a crucial company to be considered to fully achieve Circular Economy benefits. We acknowledge that servitization alone is not enough to fully implement Circular Economy principles (in accordance e.g., with Alcayaga et al., 2019). Indeed, it should be coupled with other circular practices, such as TBS (as also pointed out e.g., by Centobelli et al., 2020). Therefore, not only servitization but also other circular practices should be implemented to fully achieve the transition towards Circular Economy. The service provider should have both technical and managerial competences (Tukker, 2015) and should orchestrate the implementation of circular practices among the companies involved in the whole ecosystem (Parida et al., 2019) to turn it from a traditional business ecosystem to a circular ecosystem. Therefore, we posit that the service provider could act as an enabler of collaboration and ultimately of the implementation of the Circular Economy principles.

Third, we posit the importance of an ecosystem perspective to allow for the effectiveness of CE implementation. The several companies involved in the design of the building façade perform a specific role in this collaborative setting. Collaborations among the involved companies enable the joint and consistent implementation of different circular practices. Each company is required to implement a specific circular practice based on its specific needs and requirements.

Fourth, a hint into the role of digital technologies in enabling the CE approach through servitization is provided (in accordance with, e.g., Giovanardi et al., 2023). Indeed, the innovative circular product is jointly designed to embed digital technologies enabling to track performance and apply pay-per-performance contracts.

All that said, our results confirm the relevance of collaborations, of the service provider and of an ecosystem perspective to enable the transition towards circularity, in accordance with previous literature (see, e.g., Aarikka-Stenroos et al., 2022). We believe that our results could be applied to other parts, components, and materials typically employed in the building industry, such as heating system or roofing, because they share the same characteristics of the building façade and are strictly linked to the building lifecycle. In addition, we believe that our results could be a valuable contribution also to other industries characterized by long, fragmented value chains and complex products (e.g., automotive industry). We highlight how the collaborations, the strategic guidance provided by the service provider, and an ecosystem perspective are even more needed in fragmented value chains and complex products. The objective is to align the whole business ecosystem towards the same target: achieving circularity. This could lead to the transition from a mere business ecosystem to a real circular ecosystem. A recent stream of literature goes into this direction and defines the concept of circular ecosystem (Aarikka-Stenroos et al., 2021). We reinforce the need of circular ecosystems' development to fully benefit from CE potentialities, especially in complex and fragmented industries.

5.2. Managerial contributions

The main and underlying takeaway for managers trying to implement circular product design and servitization practices is the need for

collaborations. Indeed, a collaborative business ecosystem is needed to fully exploit CE potentialities. Managers of independent companies must not only consider the possibility of implementing circular practices for their individual companies but also reflect about the necessity to jointly implement these practices with other companies involved in their business ecosystem if they want to fully achieve the benefits and potentialities of CE.

This paper provides insightful contributions for the companies involved in the building industry (and we believe also for those involved in fragmented industries as defined by Dewagoda et al., 2022), which are trying to implement CE principles. More specifically, the companies involved in the business ecosystem of the building façade industry could grasp from our paper not only the circular practices to be implemented for circular product design and servitization, but also the set of companies with which they should collaborate. We believe that our research framework, presented in Fig. 2, could support managers in the building façade industry. Fig. 2 provides information on both the circular practices to be implemented and the companies with which to collaborate. The research framework shows how the companies, which collaborate to implement circular product design and servitization practices. Besides, it shows the central role of the service provider: the sole company involved throughout the whole product useful life and involved in most of both circular design and servitization practices.

6. Conclusions

The objective of our paper was to investigate ecosystem-wide collaboration to implement circular practices. Accordingly, we developed a novel research framework (see Fig. 2). The research framework matches the companies involved in the business ecosystem, the circular practices implemented, and the product's useful life phases. The research framework highlights the relevance of the collaboration among the several companies involved in the business ecosystem of the building façade industry. The implementation of circular practices by the single company could not be sufficient to fully achieve CE potentialities. Therefore, an ecosystem-wide implementation of circular practices is needed to facilitate circular products design and servitization by the companies involved in the building façade industry. Policy makers could grasp from our research framework the relevance of a wider perspective and could favor the ecosystem-wide implementation of circular practices though policies aimed to support and require companies to think outside of their boundaries and collaborate with the other companies involved in their industry.

We reached the above conclusions by applying the action research methodology and gathering evidence from the "Envelope for Service" research project, which considered the façade as unit of analysis and was leaded by a multinational market leader operating in the building construction industry. We believe that the obtained results could be a valuable contribution not only to the industry under investigation in the "Envelope for Service" research project but also for (i) other building components (e.g., roofing) and for (ii) other fragmented industries with complex and durable products (e.g., automotive industry). Fragmented industries could better understand not only the rationale behind the need for establishing a circular ecosystem (e.g., avoid potential mismatches among subsequent phases of the product useful life, access to complementary skills and competences) but also what it practically means to jointly implement CE design and servitization practices (e.g., the central role of a service provider to orchestrate all the information, materials, and resources flows).

Despite the above contributions, this paper comes with several limitations. Firstly, the main limitation could be represented by the applied methodology. Action research results can only be cautiously generalized. Action research results are strictly related to the peculiarities of the project under analysis. For instance, project-specific bias could be given by (i) the perspective of the companies and experts involved in the "Envelope for Service" research project, (ii) the specific project's contextual factors, such as societal, industrial, and regulatory factors. In addition, it should further be enriched through an iterative reflective cycle perpetuating data collection, reflection, and action. Moreover, the project's scope and objectives did not enable the authors to further test the actual offering of the innovative circular façade as a service to a broad market. Secondly, other limitations are not linked to the methodology applied. A non-methodological limitation is related to the stage of development of the building façade, which is still embryonic and deserves further empirical applications. Moreover, the collaboration dynamics were not deepened and analyzed in terms of the contractual agreements through which the companies involved in the business ecosystem collaborate. These limitations could represent promising avenues for future research. Further academic activities could focus on other qualitative methodologies to advance literature in the interplay between CE and the building industry. Moreover, additional research areas could be represented by a focus on: (i) a broader or larger geographical scope, (ii) collaboration forms and contracts to ensure a long-term perspective (and long-term objectives), (iii) the changes in the companies' relationships and collaborations as the circular product advances along successive phases of its useful life. Considering the second research area, different contractual arrangements (e.g., partnerships, joint ventures, special purpose vehicle) could be investigated to understand how they can ensure alignment and consistency among all the companies involved in the business ecosystem in the long term.

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CRediT authorship contribution statement

Lucrezia Sgambaro: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Davide Chiaroni:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Andrea Urbinati:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

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

The authors do not have permission to share data.

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