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Mapping of Circular Construction Ecosystems' Characteristics: Interconnections, Relationships, and Synchronization of Stakeholders at the Micro, Meso, and Macro Scales

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Abstract: The application of circular strategies in the architecture, engineering, construction, and operations (AECO) sector has been extensively researched, demonstrating the significance of technical approaches. However, research also focuses on the organizational challenges that arise within circular networks. Recent studies emphasize the importance of collective action in fostering cooperation across the value chain to achieve circular economy (CE) goals. Nevertheless, a considerable amount of research, including EU policies, tends to concentrate on "end-of-pipe" solutions, while failing to adequately address the socio-ecological challenges inherent in the transition to a CE. This study aims to explore collective activities and work in circular construction ecosystems at the macro, meso, and micro scales, identifying their interconnections. The findings of the literature review indicate that a successful transition to a CE requires a deeper commitment from stakeholders, which is influenced by the structure and relationships within the ecosystem. The increasing complexity of these ecosystems necessitates a redefinition of stakeholder roles and competencies, emphasizing a collective perception of value. Given the lack of tools and research on collaboration, we propose developing a map of circular construction ecosystems to improve the visualization and understanding of their dynamics.

Keywords: ecosystems; circular construction; collaborations; relationships; synchronization

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1. Introduction

1.1. Challenges for the Construction Sector and Growing Interest in a CE

The construction sector is confronted with considerable challenges pertaining to its substantial resource and energy consumption, emissions of greenhouse gases, and generation of waste, particularly within the European Union. The aging and energy-intensive building stock is a significant contributor to direct emissions, prompting the development of European-level strategies such as the "renovation wave", with the objective of enhancing buildings' energy efficiency. These initiatives have the objective of reducing waste and resource demand, while fostering a circular economy (CE) where materials are reused and recycled across multiple life cycles. However, reuse faces numerous technical, logistical, and regulatory obstacles, and demolition remains common. In order to achieve true material flow closure, it will be necessary to implement a fundamental shift in practices and to establish close collaboration among all stakeholders in the construction value chain [1–5].

In relation to the above issues, there has been a discernible **increase in interest in the CE** in recent years, particularly within the architecture, engineering, construction, and operations (AECO) sector [3,6]. The number of discussions, debates, and articles on this subject has almost tripled over the past five years [7]. A recent literature review indicates that the majority of publications pertaining to circular construction (CC) originate from Europe [8]. This interest can be attributed to a joint initiative by the European Commission, the World Economic Forum, and the Ellen MacArthur Foundation [6,9,10]. **Despite the growing interest in circularity**, the use of secondary materials continues to decline, falling below 10% in 2023 for the first time since 2018, while our economy continues to consume more virgin resources. The period from 2018 to 2024 saw the consumption of over half a trillion tonnes of materials, a figure approaching that of the entire 20th century [7].

The obstacles to circular practices have been extensively studied in the literature in recent years [9,11–20]. Some research has identified up to 95 barriers to the adoption of a CE in construction [19]. Ref. [16] conducted a comprehensive and systematic examination of the obstacles to the implementation of CE principles in the construction industry. Six major categories were identified and analyzed in detail: economic, sociological, political, organizational, technological, and environmental. While environmental considerations are significant, they are frequently eclipsed by economic concerns and a paucity of robust evidence demonstrating the environmental benefits of circular approaches. Furthermore, this category is poorly integrated into other studies [8,18].

Nevertheless, **organizational obstacles** are the most prevalent impediments to circularity [16]; they concern the circulation of information between stakeholders and project phases, impeding efficiency and entailing additional efforts, time, and resources. The challenges are several: operational processes modification, multidisciplinary teams' coordination, and the lack of expertise, training, and experience. Obstacles to the CE that occur at the **macro scale** (e.g., regional, national) have a significant impact on CE implementation at the **meso scale** (industrial, sectoral) and at the **micro scale** (project) [16,18]. The macro scale (political, regulatory, economic) provides the general framework that is conducive to the circular transition; however, the implementation thereof relies on the actions and decisions taken by the stakeholders involved in a particular project (micro scale) and by sector-specific organizations (meso scale). Consequently, the scales of analysis are mutually reinforcing. The challenges encountered at the micro scale inform adjustments at the meso and macro scales, while macro-scale guidelines and support influence behavior at the micro and meso scales. As shown by Baldasarre et al. [18], despite the existence of regulatory incentives to use recycled materials at the macro scale, the technical and administrative difficulties associated with ensuring compliance with safety standards may result in manufacturers (meso, micro) continuing to employ virgin materials. Nevertheless, enterprises (micro) will encounter technical difficulties in incorporating these innovations into their production processes (for instance, adapting machinery to use recycled plastics). Ultimately, while macro-scale policies foster collaboration between stakeholders in the value chain (e.g., manufacturers, suppliers, recyclers), with the objective of closing resource loops, companies (micro) may be hesitant to engage in such partnerships, either due to a lack of trust in potential partners or to safeguard their own interests. Thus, the CE's challenges need to be understood as an **interconnected network** among the three scales, operating across the whole CE systems, which requires a "holistic view" [8].

1.2. Systemic Vision

The circular transition and adoption of circular practices in AECO must be understood as a fundamental and deep systemic change in the whole system [3], considering the siloed working practices that characterize it, and considering factors and pressures on projects (coercive), from industry (mimetic), and from government (normative) [21,22]. To achieve this objective, it is necessary to understand the manner in which stakeholders **work together**. Additionally, it is essential to comprehend the **references, values, and goals** that they share, as well as the **business models** in which they operate. A systemic approach to a CE, which engages all relevant stakeholders throughout the life cycle of the built asset, has the potential to mitigate rebound effects by emphasizing the interconnections between the system's components, including the constraints and interdependencies associated with crises [7,16]. This systemic approach will facilitate an analysis of technology and innovation, which are often cited as potential solutions to climate and environmental challenges. This analysis will be conducted in light of the paradox of the rebound effect, which suggests that technology and innovation may not be sufficient to address the complex challenges associated with ecological degradation [7,23,24]. Furthermore, this approach will also facilitate the identification of the uses of technology in collective circular practices, as well as the limitations and potentialities thereof. Systems thinking must inform the ways in which circular solutions are deployed, including the identification of root causes, key levers, and enablers, highlighting the interconnectivity within barriers, scales, and dimensions of business [18,25].

The academic research and grey literature on the CE have predominantly focused on material flows, with limited attention paid to the interactions and relations among stakeholders in CC projects. The objective of this study is to provide a novel perspective by examining collective activities (including collaboration) and CE practices in a joint manner, thereby acknowledging the ecosystemic nature of CC. In this sense, the approach is innovative in that it links two subjects that have previously been addressed in isolation; furthermore, it seeks to elucidate their interconnections, interactions, and relationships by situating them within an ecosystem of actors and stakeholders at three levels: macro, meso, and micro. The field of research pertaining to circularity is experiencing a period of rapid expansion, while the notion of circular ecosystems is only beginning to emerge. This research aims to provide a basis for understanding CC ecosystems. The proposed CC ecosystems encompass a range of characteristics emerging from the CC project, which is composed of layers and situated within a broader network of stakeholders, who are linked by relationships, commitments, and business models. These stakeholders are driven by circular strategies and supported by tools and work/assessment methods throughout the project life cycle. Therefore, this article makes two contributions: firstly, it opens a new pathway for studying CC through an ecosystemic approach. Secondly, it proposes a formalization of CC ecosystems in the form of a scalable (micro, meso, macro) and adaptable map (different stages of the project life cycle).

2. Theoretical Framework

2.1. Cognitive Synchronization: Circular Construction and Value

Despite the growing interest in a CE in AECO, a semantic blur has long persisted in this field. This is sometimes attributed to the uniqueness of non-standardized buildings and to the multidisciplinary nature of the actors involved throughout the building life cycle, which differs significantly from that of manufacturing industries [3,8,16]. The plethora of definitions is relevant at different stages of the life cycle of construction assets and reflects the diversity of approaches and the multiplicity of interpretations [8]. The lack of standardization in the definition of a CE risks hindering exchanges and implementation [13]. Based on a systematic literature review, ref. [8] proposed a definition of CC that integrates sustainability concerns at the three scales. This definition also includes environmental impacts such as climate change, biodiversity loss, and pollution, based on [20] and adapted for the AECO sector. The CC is defined as "(. . .) a **multidimensional**

and dynamic economic system for construction based on the application of CE principles. It aims to achieve buildings and infrastructure designs considering different **systemic levels (micro, meso, and macro)** to achieve a built environment that targets zero waste and pollution. It allows construction materials and products to remain in use, retaining their maximum value by following biological or technical looping strategies through and within the whole life cycle of construction projects. This approach operates in a sustainable, clean, and renewable way, allowing for the regeneration of natural systems. It is enabled by a context defined by technology, management systems, government policies and regulations, business models, and social and stakeholder behavior that enable construction needs to be met sustainably" [8], pp. 14–15.

Understanding CC highlights the importance of maintaining the elements' value as long as possible by offering them different life cycles [26]. However, the notion of status cannot be reduced to a binary opposition: **resource/product or waste** in the specific socio-economic and cultural contexts considered. These two types of status are subject to specific regulations. The current lack of clarity in the legislative framework governing the end-of-waste status has been identified as a significant challenge in the context of reuse [27]. However, the European Commission has initiated efforts to develop a set of rules on this matter for specific priority waste streams, marking a promising step forward [28,29]. Cultural perceptions need to be considered in addition to legal and regulatory issues. Several researchers have examined the **continuum between waste and resources,** focusing on wear and tear [30,31]. Boniver et al. [32] highlighted the inherent complexity, if not the impossibility, of categorizing types of wear and tear. This is due to the unique context and interactions associated with wear and tear, as well as the necessity for collective negotiation—involving cleaning teams, maintenance managers, and infrastructure managers—to assess the acceptability of wear and tear. From a sociological and environmental perspective, further study is warranted on the creation of value through the relationships between stakeholders and the deepening of the attributes that make them up.

In the literature, value is predominantly studied from an **economic or technical perspective**, through R strategies [23], which propose to remedy this wear (from R3 to R9) and to quantify it through methods and tools (e.g., inventories). This research bias may be linked to the difficulty of quantifying value, particularly when it is affective (e.g., family) or cultural (e.g., heritage). Such an approach tends to neglect sociological aspects, which are of paramount importance in multidisciplinary approaches [3,12]; furthermore, it enables the validation and optimization of products and services through the incorporation of feedback from producers, suppliers, customers, and users. Moreover, value must be addressed with policymakers to overcome economic barriers, which are often tied to regulatory constraints. Consequently, multidisciplinary approaches facilitate the formulation of viable business models that are aligned with market supply and demand across the four key stages of business models, as defined in [18]: value proposition, value creation, value delivery, and value capture.

Therefore, the process of identifying and attributing value (economic, affective, heritage, etc.) to elements is one of creating and sharing a common frame of reference. These exchanges and sharing enable stakeholders to gain an understanding of one another's perceptions and to align themselves based on common values. This process is referred to as **cognitive synchronization** (co. sync). Vikstedt and Rajala [33] identified twelve **consolidation mechanisms, from perfect alignment to total misalignment,** in terms of the values, goals, and practices that stakeholders espouse. Firstly, **cognitive alignment** describes the concordance of values, beliefs, and perceptions between stakeholders, who are often far apart at the inception of a project but gradually become aligned as they pool, share, and consolidate. Secondly, **goal alignment** refers to the coherence and agreement of objectives between stakeholders. Thirdly, **practice alignment** provides a foundation for the harmonious integration of value-creating practices, which may be either compatible or mutually synergistic. It should be noted that, on the one hand, a partial alignment or misalignment is more realistic; on the other hand, aligning practices does not necessarily create positive value, nor does misalignment inevitably lead to negative results: the latter can be beneficial in CE contexts where several institutional logics co-exist. Finally, addressing the four business model dimensions iteratively, while taking into account the CE challenges, is a way to bridge the gaps between conceptualization (cognitive synchronization) and implementation (operative synchronization) [20].

2.2. Operative Synchronization: Implementation and Circular Strategies

The CE concepts have sometimes been presented as a way of operationalizing the implementation of sustainable development for businesses within the AECO sector [3]. Charef et al. [16] identified 18 circular design approaches in their literature review, mainly "design for" Reduce–Reuse–Recycle/Adaptive Reuse/EC/Closed Loops/Deconstruction, Disassembly/Industrialized Buildings—Flexible—Disassemble/Manufacturing and Assembly/Prefabrication/Reverse Logistics/Sustainable Building/Transformable Building. Based on the Lansink scale, these approaches are either in alignment with or have their foundations in **the R strategies.** According to the R strategies' authors [23], the transition from a linear economy (LE) to a CE is proposed to occur in three stages: first, to use and manufacture smarter products through innovations in core technologies and product design by refusing (R0), rethinking (R1), and reducing (R2) the use of natural resources and new products. Next, to extend the lifespan of products through new innovative revenue models and sociological and institutional changes: the strategies of reuse (R3), repair (R4), refurbish (R5), remanufacture (R6), and repurpose (R7) allow products and their components to remain in circulation and avoid becoming waste. Finally, the principles of recycling (R8) and recovery (R9) fit more within an LE. Recovery, often defined as incineration, "encourages material wastefulness [and] requires cheap and abundant waste to ensure the return of investment of its facilities, which means that it competes for resources with other R strategies" [14]. It should be noted that, within the same project, several strategies may be used for different components: a structure may be maintained (i.e., refuse its demolition (R0)), its spaces rethought (R1), certain materials reused on site (R3) or recycled (R8), windows or doors repaired (R4), and certain technical elements refurbished (R5) or remanufactured (R6). In this way, each building component can be assigned a specific strategy. The building can then be examined and split into either functional layers (shearing layers based on [34]) or external/structural/internal layers [35,36].

The reuse strategy (R3) advances sustainable development by extending the lifespan of building components, reducing waste production, and substituting new materials, thereby minimizing the environmental impact associated with manufacturing [37–39]. In considering the entire life cycle of a building, a distinction can already be made between **current and future reuse**. *Current reuse* aims to identify the reuse the potential of elements destined for dismantling or demolition and to extract the reusable elements (reuse potential); on the other hand, it also aims to integrate those elements that have already been used for the first time into a new cycle (effective reuse) [36,40]. The second reuse is more a question of the elements and components' design, through the choice of reversible materials, elements, and assembly techniques to facilitate and allow their *future reuse* [41,42]. The temporal aspect represents the initial point of differentiation. It should be noted that the term *circular construction* (CC), as used in the following text, encompasses both new builds and current and future renovation work.

Furthermore, the reuse strategy has the potential to bring about a significant transformation in economic models and supply chains by shifting the focus from the temporality of products to a more ownership-based model. This can be achieved through various mechanisms, including rental, shared use, donation, and resale. However, to ensure the effective implementation of such strategies, the integration of additional "R" strategies is essential [14]. For example, reuse (R3) is facilitated when refuse (R0), rethink (R1), and reduce (R2) strategies are considered upstream of the project brief. In the downstream phase, the reuse of materials allows for the postponement of recycling (R8) and recovery (R9). Thus, these strategies are interconnected, and they require greater collaboration between stakeholders via operative synchronization (ope. sync.) and alignment in a project (micro), in the industry (meso), and in politics (macro) [3,14].

Figure 1 provides a synthesis of the concepts presented here; it depicts the influence of R strategies at the three scales (macro, meso, and micro) throughout the life cycle of a built property, integrating the renovation of the present and future, and decomposed into layers.

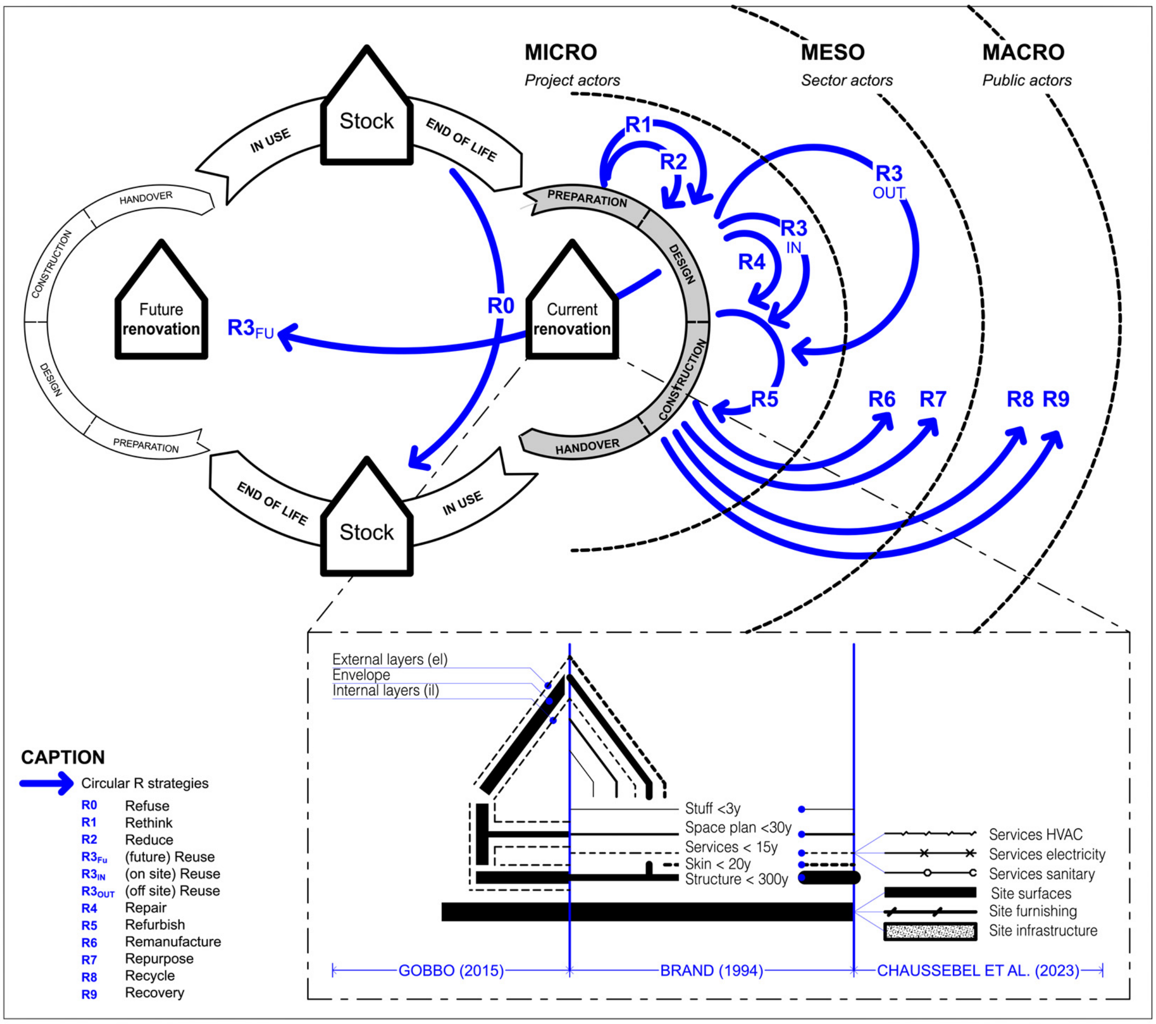


Figure 1. Synthesis of the impacts of R strategies on stakeholders during the life cycle of a built asset (current and future renovation), and their applicability (layers), based on [34–36].

2.3. Collaboration and Collective Work

Although collaboration requires additional time and resources, it is widely recognized as a critical element in the circular transition and throughout the circular construction cycle. Collaboration enables more effective outcomes, reduces errors, and harnesses collective intelligence, thereby supporting a holistic and high-quality approach to the project [14,43–45].

Collaborative and participatory approaches are also gaining ground in terms of democracy and governance [8]. However, the concept of collaboration is now widely employed in the AECO sector, particularly since the advent of multidisciplinary teams engaged in architectural design processes [21]. This has led to a situation where collaboration is perceived as overused. The emergence and growing interest in building information modeling and management (BIM) has played a significant role in this.

Collective work is defined as a system in which stakeholders are aware that they are working as a group with the aim of achieving a common contribution (project), influenced by several factors including the media, the stakeholders' roles within companies, the relations they share with other actors, the feeling of belonging to the group, and the structure of the work. Collective work is carried out based on three principal notions: objective, which defines the intended achievement; action, which outlines the steps required for objective fulfilment; and operational tasks, which represent the tangible results of the collective work. In this process, the work is divided between individual and collective work, which can be collaboration or cooperation. In collaborative work, the task is carried out collectively by multiple stakeholders, whereas cooperation involves the sharing of tasks between the stakeholders [46,47]. Each solution proposed by one actor is satisfactory in isolation, but inconsistent if combined with the others. The process of reaching a satisfactory solution involves two forms of synchronization: **mutualization and consolidation.** These occur in iterative loops until a solution is reached. Mutualization, which typically occurs at the outset of the process, involves stakeholders pooling their knowledge, constraints, and solutions to expand potential options. Consolidation occurs later in the process, as stakeholders converge towards a final solution after multiple alignment attempts. The domain of knowledge of each stakeholder is enlarged in proportion to the number of actors [21].

The **media, including tools and artefacts,** influence the collective work. However, the term *tool* is polysemous and overused: it can refer to the spoken word, pencil, computer, software, planning, or books. The study of the uses of tools in the execution of collective actions provides insight into the operational procedures and collective endeavors [47]. In the context of sustainable practices, ref. [21] identifies three typologies of eco-design support tools: firstly, **intellectual tools** that express the underlying philosophy of the project and support co-construction of references through investigation into aesthetic, structural, technical, and functional aspects. Secondly, **cognitive tools** form the set of knowledge tools (e.g., books, guides, platforms, technical sheets). Thirdly, **technical tools** refer to the practice, including a variety of tools, both physical (e.g., paper plans, sketches) and digital (e.g., modeling/simulation). All of these tools may be employed at various stages of the CC process and for a variety of uses, such as teams' coordination (restricted or extended), communication (formal or informal), production of solutions (intermediate or final), synchronization of time (planning) and space (exchange), and storage (temporarily, permanently). These concepts are summarized in Figure 2, adapted from [21]: collective work within a business model includes synchronization (pooling and consolidation) and activities between the various stakeholders at different stages. The tools are used to perform the operative tasks (i.e., what is understood to be performed), in order to achieve the defined goal.

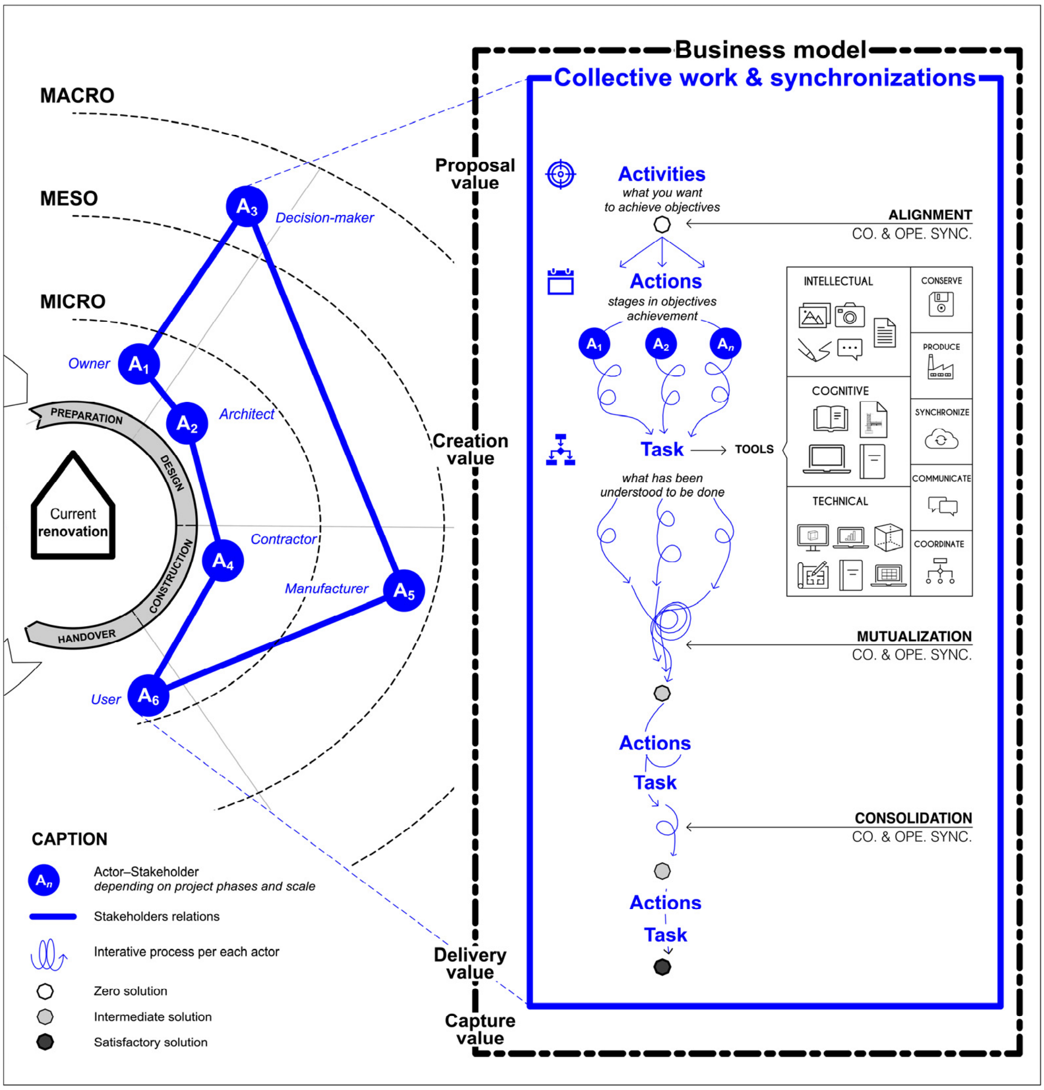


Figure 2. Synthesis of notions of collective work within a business model: activities, actions, tasks, tool uses, and cognitive and operative synchronizations, based on [22].

2.4. Research Gaps

The application of circular strategies in AECO has been the subject of several studies. These have revealed that, to date, a great deal of emphasis has been placed on technical and technological approaches—based, for example, on materiality, construction systems, and tools. The organizational challenges inherent to circular networks and systems are increasingly being explored in academic research. Recent studies have identified the collective action—such as cooperative and collaborative work—in value chains as an essential element in achieving circular goals [48]. However, research, including EU policies, focuses more on "end-of-pipe solutions" and less on the socio-ecological issues involved in a CE [16]. Moreover, few studies have explored CC through the interconnections of collective actions and the relationships between stakeholders within circular ecosystems.

Therefore, the first objective of this research is to present the characteristics of collective activities within CC ecosystems, as commonly discussed in the literature. Secondly, this research aims to identify their interconnections and relationships. To this end, the figures presented in the preceding section are refined with findings from the literature review within a map, as detailed in Section 5 (Discussion). To achieve this, a literature review is carried out to answer the following questions:

QR1. What are the impacts of circularity on stakeholders, and on their activities and relationships?

QR2. What is the impact of circularity on construction systems at the three scales? How is this reflected?

This article is structured as follows: Section 3 outlines the research methodology, Section 4 presents the results of the literature review, and Section 5 discusses the results. In light of the above considerations, Section 5 begins with a discussion of the results of the literature review, highlighting shortcomings and making recommendations for future research. Next, the proposed CC ecosystem map is presented and discussed in detail. Section 6 concludes with a summary and analysis of the limitations of this research.

3. Methodology

The primary objective of this research is to identify the defining characteristics of collective activities (i.e., cooperation, collaboration) among stakeholders engaged in CC projects (micro), within the sector (meso), and at the governmental scale (macro) across CC ecosystems. Secondly, the characteristics identified here are used to develop a mapping of the characteristics of CC ecosystems. This mapping is evaluated and tested against the findings of future research conducted in the field. To achieve the first objective, an intensive literature review is conducted, with the objective of exploring new notions and concepts related to collaboration and circular construction. The adoption of CE practices, particularly in the AECO sector, is still in its early stages. This experimental phase explains why much of the existing research focuses on identifying barriers and challenges through field-based methods such as stakeholder interviews, analyses of pilot projects, and case studies. The mass adoption of circular practices has not yet been achieved, and most existing studies reflect this exploratory and fragmented nature. Since the literature review highlights the challenges faced by the sector, this article employs a literature review as its primary research method, grounding its analysis in the realities of the field while expanding the scope of inquiry through an ecosystemic approach. In the second phase of the research, the findings of this study are subsequently compared with practices in the field through analyses of concrete case studies and interviews with stakeholders involved in CC ecosystems.

This review was conducted using the SCOPUS database, which is regarded as the largest repository of scientific abstracts and citations of peer-reviewed literature [49]. The choice of keywords for the search was designed to open up the field of research as much as possible. The following search string was used: [collaboration] AND [circularity] AND [construction] OR [architecture]. The term [collaboration] was selected over [cooperation] or [collective work] because it is a more general term that is less specific and, therefore, less likely to exclude studies that are relevant to our research. The search was carried out in several stages, as shown in Figure 3. The keyword search identified 25 articles that were selected based on their relevance to the topic under investigation. The following exclusion criteria were applied to ensure the quality and relevance of the selected articles: [field], [publication stage], [language], and [open access]. The research fields selected were as follows: engineering, environmental sciences, social sciences, business management and accounting, economics, econometrics, and finance, decision sciences, materials science, and multidisciplinary. The fields of energy, computer science, Earth and planetary sciences, and mathematics were excluded from further consideration. Of the 25 articles selected, 5 were excluded in accordance with the inclusion and exclusion criteria. Two articles were excluded on the grounds of their field of application, [textiles] [50,51], and three were excluded for lack of relevance to this research: one examining the design of emergency facilities [52], a second exploring the adoption of building information modeling (BIM) in public works procurement [53], and the last employing a technical approach to investigate the viability of recycled materials in three-dimensional printing [54]. In total, 20 papers addressed the issues of CC and collective activity across different ecosystems (Table 1).

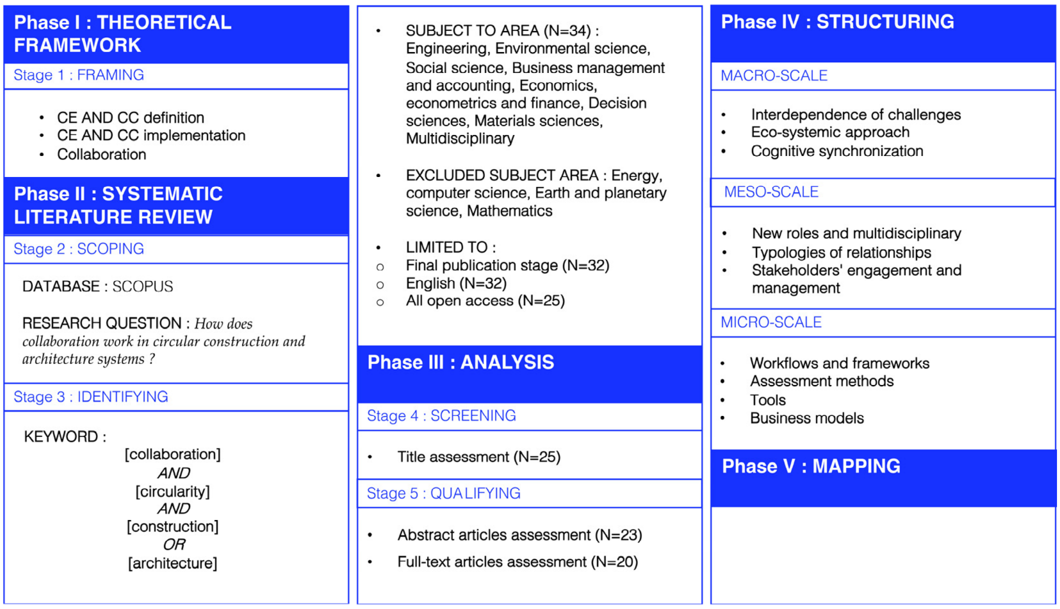


Figure 3. Diagram of the methodological stages.

This review demonstrates a considerable range of methodological approaches, with a diversity of outcomes. These findings reinforce the necessity of linking them in an ecosystemic map. For purposes of greater clarity, the results are presented and structured according to scales—macro, meso, and micro. The boundaries between each of these scales are permeable. The structure of the results demonstrates the pressures, relationships, influences, impacts, and interconnections that emerge and evolve throughout the life cycle of CC. The first section is global and deals with CE references in relation to social and environmental issues, emphasizing the cognitive synchronization that is required at the macroscopic scale. The second part of the review focuses on the sectoral and industrial scales (meso), concentrating on the influence of the CC on collective activity in the construction sector and on the ways in which changes in roles (expansion, creation, hybridization, multidisciplinarity), relationships (typologies, engagement), and stakeholder management are presented. In the third part, the analysis concludes with an examination of the micro scale of the CC, with a focus on the collective implementation of circular principles through methods (processes, assessment), tools, and business models.

4. Results

The literature review identified several research approaches that have been employed in the study of CE and CC. It should be noted that only one paper references the term "collaboration" in its title, and none of them references it as a keyword. Several studies concentrate on material flows, including aluminum [55] and glass [56]. Other research examines concepts associated with the CE, including modular CC projects [57]. Some authors have conducted research on R strategies as a whole [58,59], while others adopt a systemic approach, examining issues such as value capture and the traceability of elements throughout the life cycle, including applications and actors [59,60]. Most studies pursue the same objective: waste reduction. The research methods employed are varied, including interviews [44,55,56,60–64], pilot projects [61,65], case studies [55,61,63,66,67], literature reviews [67–71], and surveys [57].

4.1. Macro—CC Ecosystems: Interdependencies and Evolution of CE Concepts

4.1.1. Interdependence of Challenges

This literature review identified six categories of reasons—similar to those in [72]—for the slow circular transition of AECO compared to other sectors Zabek, Wirth, and Hildebrand 2020), despite its identified potential [55,65,72]. The initial category pertains to **environmental impediments** associated with safety and the potential hazards linked to the utilization of secondary materials. These encompass health risks, such as the possibility of contamination and the toxicity of reused materials. Secondly, **economic disincentives** are reflected in the potential additional costs associated with initial investment and the absence of a market. As posited in [63], these obstacles are intertwined with cultural issues. The objective is to transition from linear remuneration models (e.g., lump sums, pro rata construction costs) to models that capture value at all stages of the product life cycle, extending beyond the delivery of products and acceptance of assets. Remuneration is contingent upon evolution (wear and tear) and is based on performance. Thirdly, **social and cultural obstacles** are linked to the lack of knowledge, interest, and confidence in the CE [63]. These impediments occasionally originate from commonly accepted ideas about aesthetics and wear and tear. For instance, there is a tendency to favor materials that are perceived as more durable, such as steel, over those that are considered to deteriorate over time, such as wood. Similarly, there is a preference for materials that are perceived as more aesthetically pleasing, which can result in the neglect of reused materials [63]. The absence of robust quality assurance and the paucity of available data reflect **the technical and regulatory challenges** that constitute the fourth category of obstacles. The fragility of the market is, to some extent, attributable to deficiencies in information management, monitoring, product traceability, and techniques specific to an LE. These deficiencies result in an increase in construction and demolition waste throughout the supply chain. The lack of tools and methods to assess the circular potential of projects contributes to the acknowledged fragmentation of the sector, which is characterized by silo working [57,59,60,72,73]. The fifth obstacle is the presence of **policy barriers**, which can be classified into two sub-categories: the first comprises the absence of standards, legislation, and policy incentives that facilitate circular practices, including reuse. The second sub-category encompasses standards that impede the implementation of circular practices, including reuse [63]. In addition, **organizational impediments** emerge from the intrinsic complexity and fragmentation of the sector, where stakeholders engage in collaborations on a singular, long-term product, primarily focusing on budgetary, planning, and quality concerns that refer rather to an approach characterized by short-term vision [59,60,72]. Figure 4 illustrates the life cycle of a building in a circular vision (as presented in Figure 1), focusing on a specific point in time, which represents an intermediate renovation stage in the life cycle of a building. This intermediate renovation stage is employed to illustrate the interrelationships between the challenges and constraints that are commonly experienced by the stakeholders. Around a stakeholder (An), an octagonal shape develops, representing the satisfactory solution to the project, which is initially specific to each stakeholder. At the vertex of this octagon, the six categories of challenges are represented by a letter and a circle, comprising sub-categories of constraints that form ramifications [21,74]. The links are represented by blue lines. This representation of interconnections is schematic and is valid at time T of the CC process.

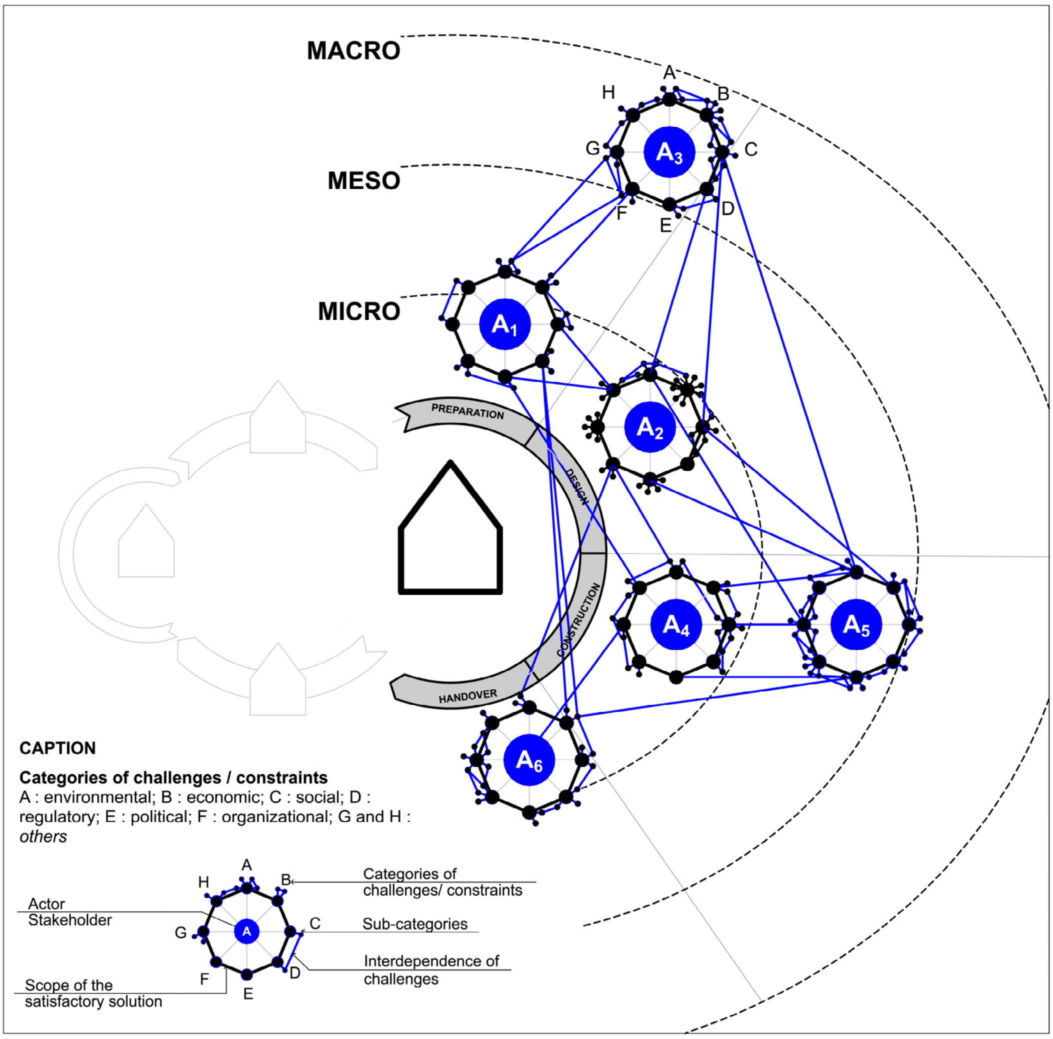


Figure 4. Diagram of the interdependencies between the categories of challenges and constraints faced by stakeholders at the different stages of CC (current renovation).

4.1.2. Ecosystemic Approach

The challenges of CE in AECO are numerous, intricate, and interrelated, and they are too extensive and complex to be addressed individually [44,61,63–65]. An increasing number of academics are adopting an ecosystem approach, which involves studying the stakeholders and their interrelationships at each stage in the life cycle of products and built assets [44,58,63]. **The ecosystem approach** is defined by [66] as "(...) a stream of management research that considers that companies should be managed in evolving multi-actor systems, borrows the idea of biological ecosystems to examine the interdependencies and interactions of stakeholders towards a system-level goal in socio-technical contexts, highlighting the co-evolutionary dynamics between stakeholders" [65] (p. 194). The **concept of circular ecosystems** is gaining traction, but it is still in its infancy globally [75] and probably even more so in the AECO sector. **Circular ecosystems** are defined as "a community of heterogeneous, hierarchically dependent but interdependent actors who collectively generate a sustainable outcome for the ecosystem" (in [61]).

The interdependencies between climate change and the AECO sector should be considered across the entirety of the life-cycle phases as a complete system [65,67,68,72]. The CE is regarded as a pivotal mitigation strategy, affording sector actors a pivotal role in adaptation to climate change [72]. Consequently, it is vital to comprehend their role in this relationship in order to facilitate circularity; the transition from an LE to a CE requires abandoning the hierarchical, centralized systems that are typical of resource-wasting industries, in favor of flexible and decentralized models [68].

4.1.3. Evolution of CE Concepts and Implementation

The literature review revealed a **plethora of references and concepts** that have been developed under the CE over time, which give rise to **a persistent semantic vagueness** [63]. At present, there are over 100 definitions of CE [64]. Indeed, although the discourse around circularity has focused for several years on the theory of the R principles, the CE has been formalized through various concepts, as [69] points out, tracing the key milestones from the 1960s to the present day. On the one hand, concepts such as the spaceman economy, cradle-to-cradle, and blue economy have facilitated the establishment of a shared frame of reference and an understanding of what a CE is [69,70]. Conversely, other concepts have concentrated on the implementation of a CE, such as industrial ecology, the Ellen MacArthur Foundation's RESOLVE framework, and the R strategies (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover, renew, refill, replant, replace, restore, regift, respect, rot, redesign, reclear, remove, risks, returns, rewards) [58,59,61,68]. In order to adopt novel solutions, it is necessary to undergo a change in our frame of reference and perceptions. In the context of the reuse strategy, for example, a stakeholder's perception of the value of a reused element can influence the perceptions of other stakeholders, leading them to consider the element to have no value [61]. The influence of the regulatory framework is considerable. Furthermore, it is evident that regulatory, normative, and cultural–cognitive elements—the "three pillars" of institutional theory [73]—play a pivotal role in the implementation of novel circular concepts and practices.

4.2. Meso—Influences of Circularity on Roles, Relationships, Management, and Engagement of Stakeholders in the AECO Sector

The literature demonstrates an evident absence of studies examining the interrelationships and stakeholder engagement within the context of circular processes within the company, between companies, and within the sector and society [61,65,66,72]. Understanding the interrelationships within circular ecosystems is challenging due to their inherent unpredictability and the lack of suitable analytical methods and tools [65]. Three changes are required to rethink and reorganize ecosystems, both industrial and sectoral, within a global circular vision [61]: (i) a **change in roles**—either the expansion of existing roles or the emergence of new roles; (ii) **a change in new, more collaborative relationships** and interactions; and (iii) a **change in perceptions** (frame of reference), allowing new attributions of value to resources and new ways of conceiving (e.g., design thinking). Such changes give rise to systemic modifications that yield benefits for companies (micro level), industries (meso level), and society (macro level).

4.2.1. New Roles and Multidisciplinarity

In this way, the CE impacts, influences, and modifies the roles of the actors, with increased collaboration within the ecosystem necessitating **the acquisition of novel skills, knowledge, and expertise**, which will impact every role within the stakeholder ecosystem, including the most junior. For example, those currently engaged in waste management may eventually assume the role of material sources. In contrast to an LE, which tends to compartmentalize the roles and tasks of actors, a CE favors hybrid and multitasking roles, whereby responsibilities are redefined and shared in order to achieve a common circular objective. The advent of these novel (hybrid) roles alters the dynamics between ecosystem stakeholders. They are predicated on a foundation of trust, collaboration, and more transparent communication, fostering positive attitudes that engender greater stakeholder commitment to the CE and facilitate the establishment of a new frame of reference. In this context, each stakeholder assumes the role of an advocate (plaidoyer) [44]. The hybridization of the roles and relationships of stakeholders exerts a mutual influence, resulting in a repositioning of the role "importance cursor". For example, sub-contractors, regarded as the less engaged actors in CC [69], are now involved at **an earlier stage of the decision-making process** as part of the circular team [19]. This early involvement has a positive impact on their commitment to circularity, with the potential for enhanced problem-solving capabilities [65]. Furthermore, the concept of expertise is evolving. Pilot case studies illustrate this shift, demonstrating that circular expertise is more multidisciplinary in nature (e.g., knowledge of materials, linked to ecology and human resources), whereas an LE compartmentalizes expertise by discipline (architecture, engineering, management, etc.) [61]. The CE and CC encompass **a multitude of forms of knowledge**, which collectively address the intricate complexities of environmental and social issues across a spectrum of scales [63]. Despite this reassessment, certain roles—such as architects, engineers, and designers—remain important, but with the acquisition of new knowledge (e.g., constructive, organizational, sociological).

The collective work between these **new roles** represents a significant challenge in terms of extensive management and coordination of **multidisciplinary and intensive collaborations**, which could be assumed by designers and architects, according to [63]. These managerial and coordinative roles are not those of (passive) facilitators [44], instilling circular ambitions in customers; they are characterized by a high level of commitment to the implementation of the circular objectives that have been jointly defined. Nevertheless, should the transition in roles be gradual, or if the stakeholders are unable to accept the changes required, other profiles should be considered to meet the requisite needs. In addition, multidisciplinary collaborations—based on knowledge sharing—enable actors to differentiate themselves in the market by developing new business models.

However, the implementation of multidisciplinary collaboration at an early stage may potentially **increase the overall complexity of the processes**, which may already be experiencing difficulties due to the adoption of circular practices. Circular practices and multidisciplinary collaborations give rise to a greater number of iterations and feedback loops within the network of stakeholders, comprising individuals with diverse profiles, skills, and knowledge. Consequently, further studies and meetings are necessary [63]. This extension can have repercussions on the smooth running and motivation of the teams: the time pressure linked to the lack of time for studies and validations can lead to frustration among the project stakeholders [62]. Therefore, the time and financial constraints inherent to linear processes, which are predicated on profitability within narrow timeframes and constrained budgets, can impede experimentation and the seamless functioning of CC. In some instances, the advantages of multidisciplinary collaboration are insufficient to offset these pressures, both intrinsic and extrinsic to the project [61,62]. Open-mindedness, transparency, and accurate, predictive communication within multidisciplinary teams would make it possible to minimize the uncertainties of CC (supply/demand, market conditions, material flows, etc.) and to counter the acknowledged fragmentation of the sector [61,68].

4.2.2. Typologies of Relationships Within Circular Ecosystems

A number of studies have examined the concepts of commitment, involvement, management, and the specific types of relationships that arise in particular contexts, with a view to understanding collective work and collaboration. Blomberg et al. [44] identified **four typologies of relationships between stakeholders within circular processes:**

1. **Competitive relationships** are characterized by a competitive pursuit of either service or work contracts or material, financial, or human resources. In order to maintain a competitive advantage, stakeholders must continually renew their activities and reinvent themselves in order to differentiate themselves from their competitors.
2. **Directive relationships** are characterized by an unequal distribution of power between stakeholders, with one group holding the power and the other group dependent on it. Directive relationships encompass both steering relationships, which entail intricate processes of influence and negotiation, and regulatory relationships, which are characterized by concise, institutionalized interactions guided by formal requirements and procedures.
3. **Mediative relationships** encompass one or more individuals who facilitate connections between organizations, industries, and contexts. While their role is pivotal in the formation and maintenance of networks, these actors assume the role of either coordinators (with a high level of involvement) or facilitators (with an informal, neutral role).
4. **Collaborative relationships** are typified by mutual dependence, close links, and equality between actors, with bidirectional or multidirectional communication flows. They can be classified into three categories: (a) plaidoyer relationships raise awareness about the CE and promote product design practices. These relationships are characterized by low mutual dependency and involvement, and they serve to align the perspectives of stakeholders by influencing attitudes, practices, and operational methods through data collection, discourse, negotiation, and information dissemination, thereby establishing a shared frame of reference. (b) Partnership relationships necessitate a considerable degree of involvement, commitment, and dependency to achieve the common objective. These relationships are based on trust, transparency, and the mutual sharing of resources, fostering co-creation, innovation, and problem solving through a collaborative approach that encourages negotiation and role sharing. (c) Knowledge-sharing relationships are established over an extended period and are predicated on mutual trust. In some cases, stakeholders may assume the role of consultants or experts. The sharing of knowledge serves to circumvent potential conflicts and facilitate the project delivery process.

To make systems circular, all four types of relationship are needed, despite the prevalence of certain types at specific levels (e.g., directive/macro, competitive/meso). The conjunction of directive and mediative relationships engenders propitious circumstances for the flourishing of collaborative and competitive relationships. Moreover, the framework for a CE is provided through the directive relations, which influence roles in environmental policies. Ultimately, the transition from linear models to the integration of these novel roles and relationships must be undertaken collectively to ensure the realization of shared benefits. A single stakeholder who adheres to a linear approach may potentially undermine the circular objectives of the entire system [55,56,62,69,70].

4.2.3. Stakeholder Engagement and Management

The term **engagement** has been employed throughout the literature to describe a range of relationships, including those pertaining to collective work, collaboration, and the sharing of information. The definition proposed by [66] embraces the notions of mutual alignment and understanding among an organization's stakeholders in pursuit of common interests and goals [67]. However, there is a paucity of studies that address the processes within circular ecosystems that favor technical or technological solutions, which might be described as a "technological fix", in order to meet the challenges [63]. Engagement, collaboration, and information sharing are critical to circularity from the outset of CC, but they need to be considered together. Effective information management alone is not enough; stakeholder management is required, with attention to the interrelationships shaped by the specific context, situation, and issues involved [44,57,58,66].

The involvement of actors in circular ecosystems is approached in a variety of ways. For example, ref. [69] focused on stakeholder involvement in CC: direct engagement, which is promoted by central roles (e.g., project team, suppliers), or indirect engagement, where actors do not play a central role but have an influence on the implementation of the project (e.g., public administrations, governments). Other researchers have proposed that commitment should be studied through the lens of the organizational structure of project teams and the alignment of values. The authors of [66] identified **four archetypal forms of engagement within circular ecosystems,** illustrating the manner in which stakeholders' interactions are initiated, coordinated, and managed. The first two archetypes are characterized as self-centered and are differentiated according to the alignment of stakeholder values: (i) **the attracting magnets archetype** is characterized by the alignment of two groups, which attract one another and are coordinated by a central entity that oversees the existing circular ecosystem and attracts new participants. (ii) **The sieve archetype** is constituted by a single actor who selects and engages others, whether or not they are aligned with the circular objective. (iii) **The chain reaction** and (iv) **rush hour archetypes** are both characterized by a lack of central coordination. On the one hand, the stakeholders are aligned with the circular objective, which naturally attracts new players; on the other hand, the ecosystem is self-organized, and its interests are misaligned.

Figure 5 provides a schematic diagram of the broadening of the spectrum of stakeholders' knowledge and skills, represented by a radar diagram. The archetypal engagements between specific actors are represented by thick pink arrows, while the relationships are illustrated by thin pink lines. It should be noted that the representation is symbolic and, therefore, should be compared with the results of practical research.

4.3. Micro—Implementation of Circularity Principles: Workflow, Framework, Assessment, Tools, and Business Models

Despite the growing interest in CC, the implementation of circularity remains unclear, incomplete, and in its infancy, with a predominant focus on waste reduction and recycling [64,70]. Furthermore, while collective activity and collaboration are identified as essential by many, the relationships within ecosystems remain challenging to understand, apprehend, and qualify. This difficulty is linked to the inherent complexity and unpredictability of CC ecosystems, coupled with a lack of suitable tools for their visualization [65]. The ecosystem approach necessitates enhanced, precise, and prospective communication, facilitated by information and stakeholder management tools that facilitate the identification, coordination, and evaluation of collaborations in circular approaches. The benefits of predictive and proactive coordination and open collaborations are numerous, including the reduction in uncertainties associated with climate change [59,60,63,64].

In the course of the literature review, three distinct categories of CC implementation were identified: (i) working methods, including collective processes, workflows, and frameworks; (ii) circularity assessment methods; and (iii) the tools. Of the 20 articles, more than half proposed one or more implementations of CC, as shown in Table 1. The following sections detail each of the three implementation categories.

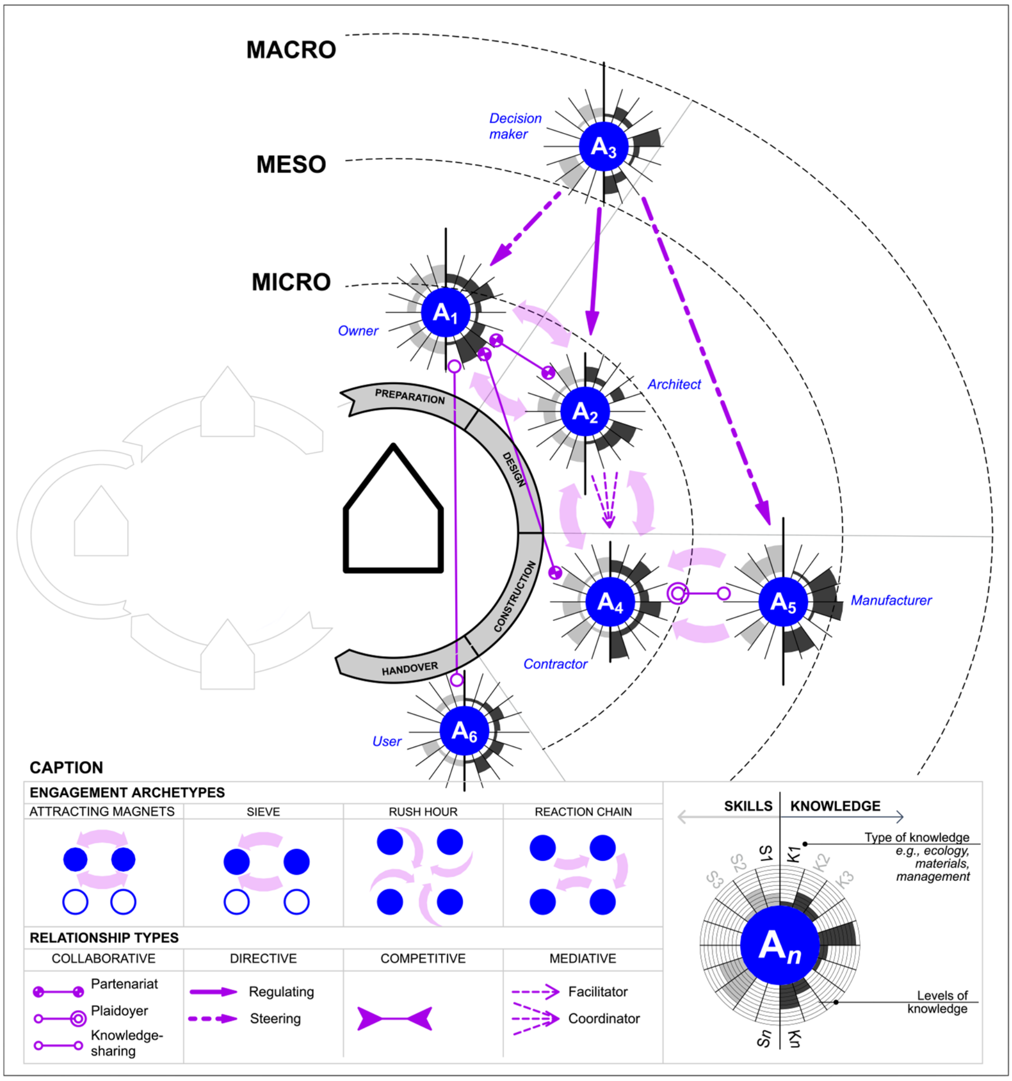


Figure 5. Diagram of the archetypes of engagement, relationships, and the skills and knowledge of the players at the different stages of CC (current renovation).

Table 1. Implementation of circularity: workflows, frameworks, assessment methods, and tools.

Ref.	Article Title	Implementation Type		
		Workflow Framework	Assessment Method	Tools
[60]	Circularity information platform for the built environment	X	/	X
[66]	How to engage stakeholders in circular economy ecosystems: The process	/	/	/
[44]	Multi-Stakeholder Networks in a Circular Economy Transition: A Typology of Stakeholder Relationships	/	/	/
[59]	A Traceability Framework to Enable Circularity in the Built Environment	X	/	X
[72]	Circularity as a Climate Change Mitigation Strategy in the Building Sector: The Stakeholder's Involvement in the Interconnected Life Cycle Phases	/	/	/

Table 1. *Cont.*

Ref.	Article Title	Implementation Type		
		Workflow Framework	**Assessment Method**	**Tools**
[58]	Development of a Circular Building Lifecycle Framework: Inception to Circulation	X	/	/
[61]	Industrial ecosystem renewal towards circularity to achieve the benefits of reuse—Learning from circular construction	/	/	/
[56]	Make or break the loop: a cross-practitioners review of glass circularity	+/−	/	/
[67]	Circular Material Systems: anticipating whole-system design in architecture and construction	/	/	/
[55]	A cross-disciplinary, cross-organizational approach to sustainable design and product innovation in the aluminum industry	+/−		
[68]	Evolving Relations of Landscape, Infrastructure and Urbanization Toward Circularity: Flanders and Vietnam	/	/	/
[57]	Developing critical success factors for integrating circular economy into modular construction projects in Hong Kong	/	/	X
[62]	The Circular Retrofit Lab: A multi-disciplinary development of a building envelope according to circular design qualities	+/−	/	/
[63]	How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy	/	/	/
[69]	Promoting stakeholder collaboration in adopting circular economy principles for sustainable construction	/	/	/
[65]	Evaluating Regional Strategies towards a Circular Economy in the Built Environment	/	/	/
[73]	Data- and stakeholder management framework for the implementation of BIM-based Material Passports	X	/	X
[64]	New circularity indicator for decision making in the stockpile management of construction and demolition waste: perspectives of Australian practionners	/	X	/
[70]	Circularity economy in construction: the digital transformation perspective	/	/	X
[71]	Digital technologies and material passports for circularity in buildings: an in-depth analysis of current practices and emerging trends	/	/	X

Caption: X: the implementation is clearly discussed; +/− the implementation is partially discussed and/or not very detailed; /: the implementation is not discussed.

4.3.1. Circular Workflows and Frameworks

A total of seven methods and workflows were identified through the literature review, with various terminology employed by the authors, e.g., model [60], framework [55,58,73], map [56]. The authors of [62] did not use a specific term; they modeled an ideal collaborative process in four stages. The methods and workflows are presented in detail below:

- The authors of [60] developed and experimented with a circular information platform (CIP) based on a master model composed of four process models, with a view to web instantiation. The proposed methodology was inspired by the smart cities data management framework and focuses on data collection, standardization, and storage. The four models focus on (i) actors and activities, (ii) practices, services, and applications in the life cycle, (iii) digital technologies, and (iv) data and equipment for the IT infrastructure. The links between the models are unidirectional.

- The authors of [59] proposed a traceability framework to facilitate circularity within the built assets industry and across the circular ecosystem. This framework is structured around five key questions that explore the importance of traceability for decision making (why?), the categories of data required (what?), the temporality to traceability (when?), the importance of collaboration between stakeholders (who?), and the use of technological tools to link information across project components (how?)
- The author of [58] proposed a framework for the circular life cycle of buildings that is flexible, interdisciplinary, and focused on maintaining the value of materials in circulation. At each of the seven stages, a key actor (influencer) leads one or more of the fourteen identified R strategies. This framework does not link its components (i.e., project phases, building phases, life-cycle phases, key influencers, R strategies).
- The authors of [56] modeled a value network map of the main actors in the glass sector. These actors are connected by material flows (i.e., glass) and immaterial flows (i.e., instructions, guarantees, advice, knowledge, warranty).
- The authors of [62] modeled the influence of early multidisciplinary collaboration in CC through the work process, focused on the early stages of the design phase, with an extension of the phases for informed and joint decision making.
- The authors of [73] proposed a framework for managing the data and stakeholders articulated around the material passport (MP). This framework is intended for three groups of stakeholders: AECO organizations, regulations, and industry, which are linked together. These links, in the form of unidirectional or bidirectional arrows, are not very detailed or explicit; they concern data, regulations, implementations, and opportunities. A diagram of the life cycle of a building completes the proposed framework by identifying four stages conducive to the use of the MP.
- The authors of [55] proposed a framework for sustainable design and product innovation that is articulated around the three pillars of sustainability (environment, social, economic): emphasizing interdisciplinary collaboration, environmental awareness, human-centered problem solving, and the creation of solutions through ideation and prototyping to promote the circular transition of the sector. There is no formal link between the pillars.

Despite the differences found, some similarities emerge. Raising stakeholder awareness is a formalized element in two of the seven frameworks studied: on the one hand, the authors of [73] see using the MP as helping the regulator (key stakeholder) to raise awareness in society; on the other hand, [55] proposed cultivating, sharing, and co-creating this environmental and circular awareness in a multidisciplinary way. In addition, three studies in the literature review identify specific actors—*key influencers*—of circular practices: for [58] they are different for each stage of the project. According to [56], the actors identified depend on the knowledge required for each type of material. Finally, for [73], the influencers are those who have knowledge about the tools used. Overall, although all representations talk about workflow, processes, or frameworks, not all of the key elements of collective work processes [76] are present simultaneously, including the actors, the tasks and activities, the flows and relationships, the decision moments, and the artefacts or objects. Table 2 presents a synthesis of the seven proposed frameworks, emphasizing the key elements of process modeling for each selected research project. The most frequently occurring elements are those pertaining to the life cycle and the actors involved. The authors of [62] and [55] failed to account for the entirety of the process life cycle, limiting representation to a single phase. Additionally, the inclusion of actors in the process representation is lacking. The authors of [56] failed to address temporality in their process formalization. In the case of [55,56,58,62,73], there is a notable absence of any consideration of interrelationships. Only two of the selected frameworks, [59,60], address interrelationships, albeit in a limited manner. The interrelationships depicted in the former are unidirectional, while those in the latter are presented in a schematic form. The table also shows that none of the frameworks includes decision moments (alignment, mutualization, consolidation). Finally, the workflows' process formalizations are varied: they are interesting to consider in the development of our mapping proposed in the remainder of this article (Table 2, right-hand column).

Table 2. Analysis of the circular processes resulting from the literature review with regard to the key elements required for the processes.

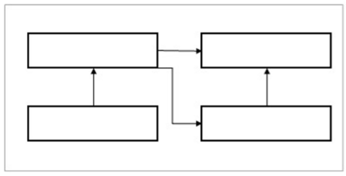
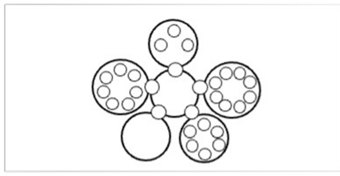
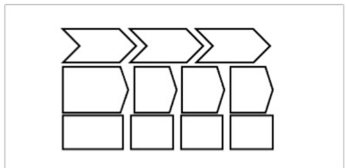
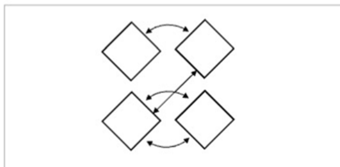
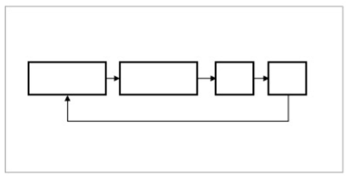
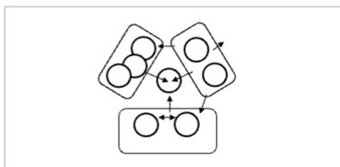
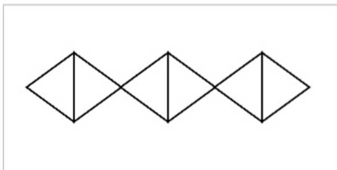
Ref.	Key Elements of Collective Work Processes								Formalization
	Stkh.	T.&A.	Int-Rel.	Dec.	Lfc.	Ele.	Objectives	Tools	
[60]	v	x	+/−	x	v	x	x	v	
[59]	v	v	+/−	x	v	v	v	v	
[58]	v	x	x	x	v	x	v	x	
[56]	v	v	x	x	x	v	x	x	
[62]	x	x	x	x	+/−	x	x	x	
[73]	v	x	x	x	v	v	x	v	

Table 2. *Cont.*

Ref.	**Key Elements of Collective Work Processes**								**Formalization**
	Stkh.	**T.&A.**	**Int-Rel.**	**Dec.**	**Lfc.**	**Ele.**	**Objectives**	**Tools**	
[55]	x	x	x	x	+/−	x	x	x	

Caption: v: the key element is represented in the model; +/−: it is represented in part in the model; x: it is absent from the model.

4.3.2. Circular Assessment Method

Several studies address the topic of evaluation in the context of CC and CE. These studies cover a range of aspects, including collaboration and engagement between stakeholders [60,69], the quality and performance of secondary materials [60,71], and predictive evolution and long-term effects [60]. Furthermore, the studies address the predictive evolution and long-term effects [60], traceability [59], and risks [64,71]. Others propose the assessment of circular design [58,60,63], recycling [71,73], material flow flow [70,71], and potential reuse and recovery of materials. The most frequently cited methods are life-cycle assessment (LCA) and environmental impact calculations [60,63,64,70,71,73]. Nevertheless, despite the plethora of recommendations to evaluate the CE and CC, the methods are rarely (if ever) delineated in sufficient detail within the articles themselves. One article [64] merits particular mention for proposing an evaluation method: an indicator based on circularity indices proposed by the Ellen MacArthur Foundation, which focuses on the management, stockage, and storage of construction and demolition waste in relation to thirteen categories of environmental, social, and economic risks, according to severity scores.

4.3.3. Tools for CC: Typology and Uses

In addition to the framework, workflow, and assessment methods, tools represent the final means of implementing circularity. Table 3 presents a classification of the tools discussed in the literature review, delineating **their typology and uses**, which are **primarily digital technologies:** building information modeling (BIM), Internet of Things (IoT), radio frequency identification (RFID), artificial intelligence (AI), robot learning, digital twins (DTws), augmented reality (AR), virtual reality (VR), laser scanning, and blockchain (Bkc). Two tools are specific to CC: materials passport (MP) and life-cycle assessment (LCA). Two research projects examined the relationship between BIM and circular design, as well as the integration of design for deconstruction (DfD) and flow analyses in material banks (MBks). One study developed a proprietary tool, the circular information platform (CIP), for use by contractors, manufacturers, and governments [60]. Most of the digital tools are employed throughout the life cycle of CC [71].

As illustrated in Table 3, the intellectual tools that would enable the co-construction of common reference are absent from this review. Cognitive tools are employed for the purposes of alignment (synchronization), i.e., to facilitate the comprehension, standardization, and dissemination of component data and to ensure their long-term storage. BIM and MP assume a pivotal role in these applications. The CIP, as outlined by [60], is the sole cognitive tool that is capable of facilitating coordination through the visualization of market orders. Furthermore, the CIP functions as a technical instrument for this purpose. This review identified the technical tools, which pertain to practice, as the most frequently discussed. These tools are primarily employed for the purposes of synchronization, production, and storage. Technologies such as IoT, RFID, AI, robot learning, blockchain, and digital twins are employed to enable the synchronous control of buildings, the updating of maintenance plans, and the planning of end-of-life scenarios.

Table 3. Types of tools and their uses from literature review.

Uses	Tools	Intellectuals	Cognitive	Technical
Coordinate	**Small team**			
	Extended team		CPI (platform) = visualize supply chain (orders/demand) [60]	CPI = provide an overview of supply and demand orders [60]
Communicate	**Formally**			CPI = communicate on circular design, feedback to evaluate policies [60]
	Informally			
Synchronize	**Time (planning)**			BIM + IOT/RFID = control and monitor synchronously [60]
				IA/robot learning = control synchronously and proactive maintenance of buildings [71]
				Digital Twin + BIM = plan maintenance and end of life [71]
				Blockchain = track components in the supply chain [71]
				PM + AR/VR = facilitate model and data updates by users [70]
				PM + BIM = share information on the asset's life cycle across PM [59]
	Space (aligning)		BIM + LCA = standardize data [70]	BIM = ensure exchanges between different types of data using IFC as the Web Ontology Language [60]
			PM + BIM = understand components using databases [73]	BIM + LCA = help with decision-making [70]
			PM + AR/VR = share data with users [70]	PM + BIM = support the engagement of stakeholders [63]
				Blockchain = ensure secure, decentralized data exchange [71]
				PM + BIM = understand components using databases [73]

Table 3. *Cont.*

Uses	Tools	Intellectuals	Cognitive	Technical
Produce	Intermediate solution			BIM + LCA = run simulations for circular decision-making [70]
				BIM = design CC [60,71]
				Digital Twin + BIM = carrying out pre-demolition audits [71]
				Laser scanning = model and rebuild in 3D [71]
				IA/Robot learning = carry out inventories and pre-demolition audits [71]
				PM + BIM = carry out CC simulations, analyze recyclability potential, carry out reuse inventories [59,63,73]
	Final solution			PM + BIM = produce a CC design [59,60,71,73]
				BIM DfD = Design for Deconstruction (DfD) [70]
				IA/Robot learning/conception parametric = generate circular solutions [70]
				Digital Twin + PM BIM = produce unique component identifications [71]
Conserve	Temporally			
	Permanently		BIM + Material banks = understand material flows [70]	PM + BIM = document and trace materials (process, composition, etc.) [59,60,63,70]
				PM + BIM = store data (database as support) [73]
			PM + BIM = centralize materials data in databases (process, composition, etc.) [59]	IOT/RFID = trace components [60,70]

Laser scanning is employed at the outset of projects to reconstruct buildings in 3D. AI and robot learning represent technological tools to produce inventories, pre-demolition audits, or the generation of parametric designs for circular solutions. Furthermore, the traceability of components can be guaranteed through the utilization of IoT and RFID technologies. BIM, MP, and LCA tools are primarily employed to align stakeholders: they serve as decision aids, facilitating engagement and ensuring the comprehension and exchange of data regarding the components of constructed assets (synchronizing in space). BIM is a topic of considerable discussion in the context of its potential as a means of producing intermediate or final solutions. However, it is frequently employed in conjunction with other tools:

- BIM and LCA tools facilitate the execution of CC simulations. The integration of BIM and DTws allows for the implementation of pre-demolition audits (intermediate solution) and the generation of unique component identifications (final solution).
- BIM and MP are employed for the purpose of conducting simulations and inventories of potential reuse, analyzing the recyclability of materials, and producing designs that facilitate a circular approach to construction. The integration of BIM into MP facilitates the storage, documentation, and tracing of materials data, thereby ensuring their conservation.
- BIM with a DfD methodology enables the foreknowledge of the end-of-life and deconstruction processes associated with the CC.

4.3.4. Circular Business Models

Modifications to business models at the organizational level and across the value chain facilitate the integration of alternative processes, enabling the creation, delivery, and capture of value without the waste of materials and depletion of resources. In this sense, designers assume the role of agents of change, assisting customers, clients, and users in adopting a systemic circular approach to thinking that is less object-, product-, or building-oriented [57]. Pilot projects are actively contributing to changes in practices and mindsets within agencies and companies. To rethink the business models of architecture and design agencies, client–designer partnerships must extend beyond the handover phase to encompass the end of the building's life cycle. Conversely, the advent of these novel business models would necessitate a shift in remuneration structures for project managers. Rather than relying on traditional linear models such as hourly fees or lump sums based on construction costs, a new paradigm would emerge, wherein project managers are remunerated on a long-term basis, based on the performance of the building. This mixed-blessing concept [69] represents a significant departure from the conventional fee structures that are currently the norm in the industry. The early engagement of all stakeholders would ensure transparency and visibility of the value chain. While for [63], a simple way to ensure stakeholder engagement is to focus on reusable materials, for [64], linear logic blurs financial estimates and undermines stakeholder engagement. It should be noted that circular solutions can involve additional costs, since they require more time for research, innovation, manpower, and risk taking. The circularity indicators, such as SCI [64], can facilitate the assessment of circular issues in a comprehensive manner, encompassing environmental, social, and economic risks and accounting for the spatial and temporal scales of CC.

5. Discussions and a Proposed Ecosystem Map for CC Ecosystems

This article aims to enhance the comprehension of the interconnections and collective activities (e.g., processes, assessment methods, tools, business models) between actors in CC ecosystems at the macro, meso, and micro levels. To achieve this, a literature review was conducted to answer two questions: QR1. What are the impacts of circularity on stakeholders and on their activities and relationships? QR2. What is the impact of circularity on construction systems at the three scales? How is this reflected? Firstly, the findings were used to identify the characteristics of stakeholders' collective activities at the three levels. Secondly, these characteristics were then linked together in a map of CC ecosystems.

5.1. Five Significant Impacts on CC Ecosystems

From the **perspective of stakeholders**, the concept of circularity necessitates a degree of engagement from the various actors. The level of commitment required is contingent upon the structure of the ecosystem in question, whether it is centered or self-organized [64], the nature of the relationships that are shared [44], and the extent to which there is an influential role played by "key players" [58]. An understanding of these interconnections enables the anticipation of discouragement, abandonment, exhaustion, and feelings of failure, as observed in [62]. Furthermore, as ecosystems become more intricate, the roles of stakeholders become more multifaceted, necessitating a broader range of skills and knowledge. This encompasses a spectrum of expertise, from macro-level considerations to project-specific knowledge (micro), such as uses of technological tools, data management, and an in-depth knowledge of materiality.

From an **ecosystem perspective**, a circular approach necessitates an examination of the interdependencies and interrelationships between stakeholders and challenges at the ecosystemic level [75], such as between cultural and environmental issues (e.g., concern about potential health risks associated with secondary materials). Similarly, the cultural perception of wear and tear impacts the economic value of the market. The results indicate the necessity for a significant transformation in business models, which should no longer be centered on the provision of value but, rather, on the preservation of circular value throughout the preparation and end-of-life phases of CC. It is thus evident that the model must be constructed on the basis of performance and lifespan, as opposed to mere delivery. The organization of CC ecosystems is impacted by their structures and their collective activities, as well as the relationships and roles of stakeholders and their exchanges (knowledge, information, etc.). Several studies have demonstrated the extent to which the various scales of ecosystems are interconnected and intertwined. It has been demonstrated that the challenges of CE and CC can, on occasion, extend beyond the boundaries of the project, thereby constraining the scope for action of project stakeholders. Perceived as intangible, they have the potential to elicit negative sentiments among stakeholders, as evidenced by [62] in their Circular Retrofit Lab pilot project, where financial and temporal constraints and pressures underscored the necessity of "establishing a valuable network in circular building" [62] (p. 7) through early multidisciplinary collaboration. Nevertheless, this early collaboration between actors at the micro, meso, and macro scales increases the complexity of the projects, but it also presents opportunities for learning and skill development. In this manner, the stakeholders are mutually interdependent and evolve in conjunction with the transitions. The ecosystem approach allows benefits to be distributed across the three levels of circular economy ecosystems [61].

From the perspective of **the business model**, the concept of circularity has an impact on the project value chain at the micro level. This entails a reorganization of project phases in order to align them with the requirements for circular knowledge and skills, such as contractors and (de)construction sub-contractors, who are involved in the decision-making and design processes. Such collective activities result in a transformation of the manner in which contracts are awarded, initially at the project level and subsequently at the sectoral level. Consequently, a circular transition necessitates a collective shift in the value perception, encompassing both the concept of wear and tear and that of ownership. These findings are consistent with those of other researchers [75]. A collective change in these two perceptions, at the macro, meso, and micro levels, will have a significant impact on business models by integrating a fifth key dimension [18]: maintaining circular value throughout the whole life cycle.

From the **perspective of CC projects**, circularity affects the advancement and scheduling of projects due to the involvement of new stakeholders in the process, as previously discussed, as well as the introduction of points of cognitive and operative synchronization. From the outset, common values and references are discussed, shared, and aligned. This alignment enables the definition of precise objectives, which can then be implemented (operative synchronization) by targeting the objectives, determining the actions to be taken and the deliverables to be produced. These moments serve to clarify the manner in which collective work, collaboration, and the implementation of circularity should be conducted [75], facilitating the optimal utilization of ecosystem benefits [25]. These moments of synchronization are added to the stages of linear work processes; they cannot be assimilated into the traditional stages of project progress. The synchronization of all stages of the process results in a prolongation of the timeframe for CC project phases in comparison to LE projects.

From the perspective of CC practice and the resulting collective activities, the concept of circularity raises questions about **the tools employed and their uses**. Circularity necessitates the use of intellectual tools for the co-construction of new references and for a variety of uses, including coordination, communication, synchronization, production, and conservation. However, the literature review does not consider intellectual tools. These gaps highlight the necessity for further research on the role of intellectual tools within CC ecosystems. This should include an investigation into their formalization, interoperability, and level destination. Moreover, the tools identified in the literature review are predominantly digital and technological. This can be explained by their capacity to process large quantities of data and perform complex simulations. The articles examined in this review do not address the use of low-tech tools. The role of technological tools within CC ecosystems must be considered in the context of the sector's specific needs, uses, and long-term sustainability: Are technological tools accessible to all stakeholders, in terms of accessibility and cost? What is the short- and long-term environmental impact of technological tools? These questions provide a foundation for further research.

It is notable that few of the tools discussed address stakeholder management and coordination at any level (macro, meso, or micro). While this category of tool may be examined in other areas of research, it would be appropriate for them to be studied alongside practical tools that are specific to the AECO sector. Indeed, an integrated approach is required for the study of ecosystems, encompassing both stakeholder management tools and those related to the design, production, and management of CC (intellectual, cognitive, technical).

5.2. An Ecosystem Map for CC Ecosystems

The results highlight the complexity of CC ecosystems, in accordance with the results of other recent research [75,77]. Acting in isolation on one part or one element of the ecosystems can lead to the exhaustion of actors, a slowing down of the circular transition, and even its failure. Understanding ecosystems is challenging: on the one hand, because they are difficult to define exhaustively and, like biological ecosystems, are constantly evolving. Conversely, CC ecosystems lack common representations and visualizations—a limitation that has been identified by other studies, and which contributes to reduced clarity and limited perspectives for research [75]. Faced with this challenge, this article proposes a representation of this multidimensional network in the form of a map as a tool for better understanding. Representations are indispensable instruments in the AECO sector, facilitating effective communication among stakeholders, including architects, engineers, contractors, and manufacturers, through the use of plans, drawings, and models, both physical and digital. These representations are flexible in scale and adaptable in content, depending on the subject, audience, and objectives pursued [47,74]. These may be descriptive, exploratory, or optimization-driven [78]. In the context of the CE, the development of representations that serve as ideation tools represents a growing area of research, particularly in addressing the complexity of circular ecosystems. Approaches that emphasize relationships and interactions are especially promising [79]; they offer valuable insights into sustainability and circular transitions. The proposed CC ecosystem map combines these descriptive and exploratory dimensions, aiming to understand the interconnections among stakeholders and the circular strategies employed. The design of the proposed map is based on the research projects of the respective authors, which combine the application of circular strategies within circular renovations and constructions throughout their life cycle cycle [35] and the processes of multidisciplinary and collaborative eco-design [21]. The map is intended to support intellectual, cognitive, and technical tools. The results of the literature review are then incorporated.

The map, schematized in Figure 6 and detailed in Figure 6a,b, reflects the impacts, links, and relationships from the literature review. The term map has been deliberately chosen to facilitate navigation between the three levels of scale. This map is neither exhaustive nor fixed: it is flexible, adaptable, and evolving for future research. The map is designed as a tool that emphasizes cognitive synchronization as a key moment of communication, alignment, and exchange between actors on three scales. For macro-scale actors such as governments, the map offers a global view of the impacts and influences that regulatory and socio-economic frameworks have on actors at the meso and micro scales. For stakeholders in the AECO sector and industry (meso), the map can be employed to delineate the implications of an innovation and to simulate research and development scenarios (e.g., a machine for cleaning reused bricks on a building site). Ultimately, the stakeholders in a CC project can use the map as a singular tool to identify the influences of a regulatory framework, the relationships and constraints shared by the stakeholders, and the knowledge and skills required at each stage of the CC project. The map will ultimately need to be further developed to reflect the specific context in which it is applied, taking into account relevant norms and regulations, industry-specific practices and innovations, the nature of the CC projects (public or private), the targeted or imposed socio-environmental objectives, and the circular strategies to be implemented.

The color blue emphasizes the impact and influence of circularity on "traditional" processes. Figure 6 guides the reading by identifying the process highlights, divided into two parts: influence on the temporality of CC processes and the value chain (Figure 6a), and influence on cognitive and operational synchronizations at a stage (Figure 6b). Figure 6a illustrates a timeline, parallel to the value chain, comprising six phases on the x-axis (preparation, design, construction, acceptance, use, and end of life), each comprising stages and sub-stages, as detailed in Figure 6b. The preparation phase encompasses the inception and programming/planning stages, which are further divided into synchronizations (cognitive and operational) and actions and tasks. The y-axis illustrates the characteristics of the CC ecosystem, from the global to local levels. Initially, it depicts the stakeholders and their evolving roles, the tools and assessments identified in the literature review for each stage, and the implementation of R strategies for CC. Several deliverables are produced in one stage (Figure 6a, flag). Relationships between players—directive, mediative, collaborative, and competitive—are represented by purple lines; they are theoretical and not exhaustive. The Figure 6a,b show three of the abovementioned CC impacts (blue):

- Given that circular construction is firmly embedded in the local material context, the selection of materials and components for the project cannot be postponed until the design phase. This is why a "call for tenders" stage is incorporated into the preparation phase. This stage is designed to engage with (de)construction companies, materials suppliers, and waste managers in order to ascertain the availability and movement of materials.
- Circularity's influence on the value chain is illustrated by the maintenance of value from the preparation phase to the use and end of life of the project.
- As discussed previously, synchronization requires new tools to align values and references (co. sync.) and to manage and coordinate stakeholders (ope. sync.). The

second part of the map (Figure 6b) focuses on this through a typical phase: the detailed process can be applied to the design and construction phases.

Cognitive synchronizations, which are of greater significance at the outset of the process, are employed to align values, circular objectives, and practices between the stakeholders: What value is placed on the existing building? Which R strategies are targeted? The cognitive synchronization begins with a pooling of knowledge, the skills required, and the challenges associated with CC: the requirements pertaining to project knowledge and stakeholder competencies are elucidated, deliberated upon, and delineated during the sub-steps. As identified in the literature review, circularity broadens the scope of knowledge, which is diverse and multidisciplinary (Figure 6b, top left); for example, it concerns materiality, (de)constructive systems, ecology, and sociological notions. The same applies to skills that go beyond the professional framework or the role of the actors in the process. By pooling knowledge, cognitive synchronization makes it possible to identify the knowledge and skills that are needed and those that are lacking to carry out CC. Similarly, these moments make it possible to identify and understand the constraints (economic, environmental, regulatory, technical, organizational, and cultural) of the actors (Figure 6b, bottom left). Based on these requirements, the stakeholders will engage in the next phase according to one of the engagement archetypes. On the one hand, pooling highlights the interdependent challenges and constraints of a single actor; for example, market availability influences architectural design. On the other hand, constraints are shared and interlinked for several actors, e.g., the DfD constraints imposed by an architect influence the labor costs of construction companies. The cognitive synchronization culminates in the alignment of the stakeholders on values, practices, and circular objectives (Figure 6b, center); for example, at the pre-design stage, the on-site reuse (R3 IN; circular objective) of the skin layer (target) is shared and known by all stakeholders. As identified by [58], each stage makes it possible to address one or more R strategies led by a key influencer. For example, during the preparation, the client has the responsibility to refuse renovation (R0) and to rethink the building (R1).

During **operative synchronizations**, the steps to be taken to achieve the circular objective are defined. The tasks to be performed are identified, whether they are individual, cooperative, or collaborative. It is also at this stage that the choice of working methods (e.g., BIM) and tools (e.g., digital) is defined in terms of their use (preservation, communication, production, synchronization, and coordination) (Figure 6b, right) [58]. Both synchronizations need to be tooled up, from the preparation of the CC project to its end of life (Figure 6a): intellectual tools to imagine new reference systems, cognitive tools to retrieve the state of knowledge on CC, and technical tools to describe the circular objectives, commitment contracts, etc. (Figure 6b).

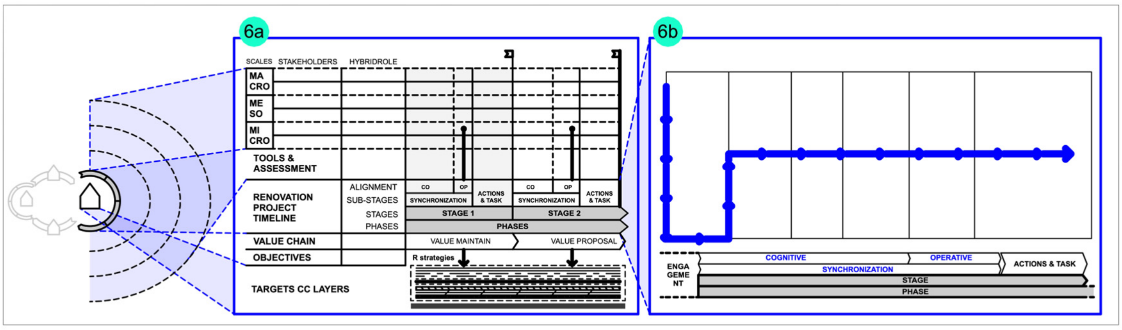


Figure 6. *Cont.*

6a

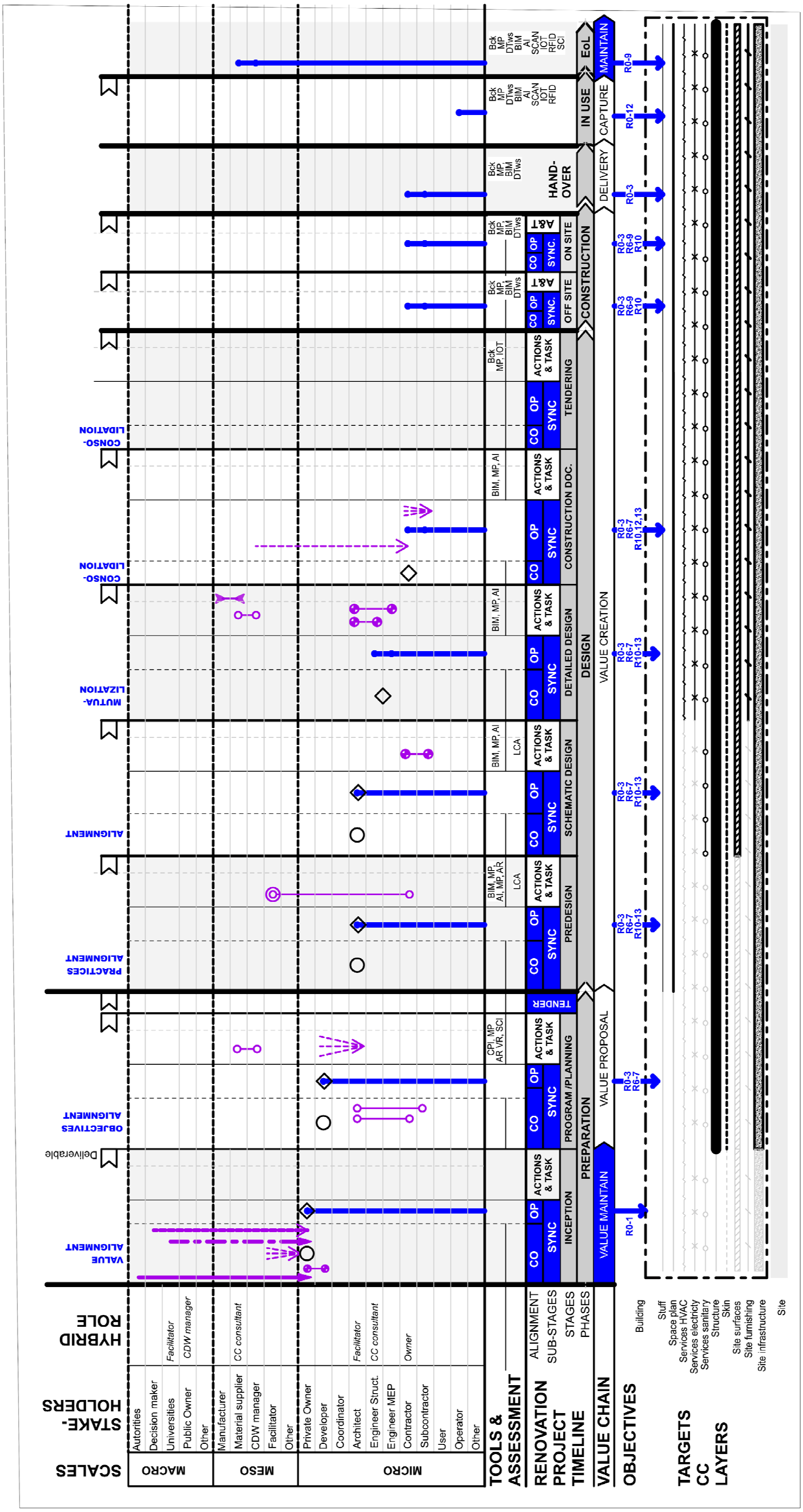


Figure 6. *Cont.*

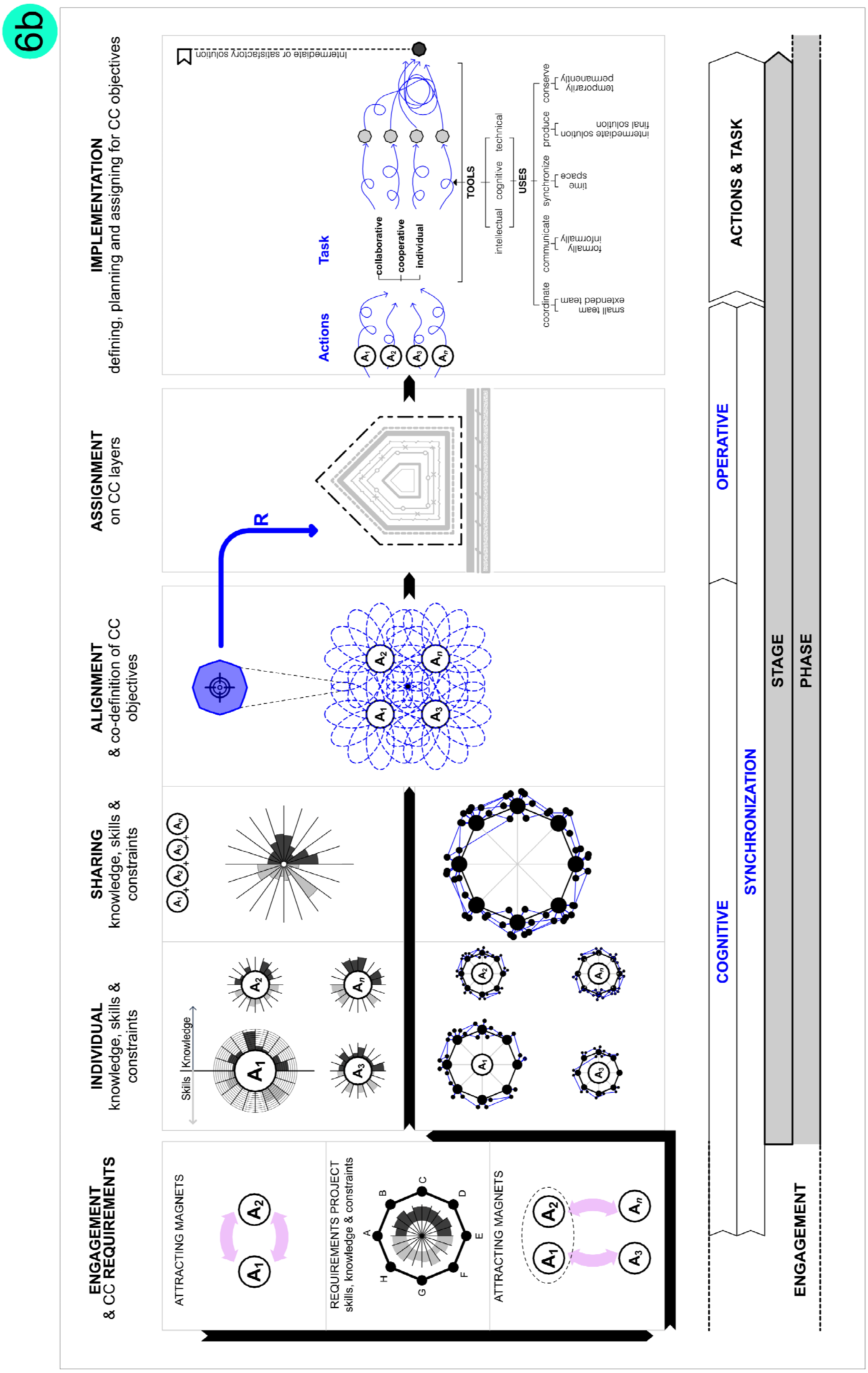


Figure 6. Map of CC ecosystem: interconnections within the collective activities of stakeholders, focusing on the two parts (**a**,**b**). (**a**): multidisciplinary CC processes through timeline on the value chain regarding to global to local characteristics of the CC ecosystem (stakeholders, roles, relations, deliverables, tools, assessments, circular strategies, layers) (**b**): detailed process of cognitive and operational synchronizations at a generic stage.

6. Conclusions, Limitations, and Future Research

6.1. Conclusions

This article examines the collective activities of actors within circular construction (CC) ecosystems, analyzing their impacts at the macro (regional, national), meso (industrial, sectoral), and micro (project) levels. The contribution identifies key circular strategies aligned with the Reduce–Reuse–Recycle framework as essential for transitioning from a linear economy (LE) to a circular economy (CE). This emphasizes the need for stakeholder collaboration and illustrates how cognitive alignment and operative synchronizations can enhance collective sustainability efforts. Through a comprehensive literature review, two primary questions are addressed: (QR1) How does adopting a circular approach affect stakeholders? (QR2) What are the implications of circularity for construction systems across these three levels?

At the macro level, this review identified a range of research approaches, but we observed that the issue of collaboration is rarely addressed. Most studies concentrate on material flows and modular circular construction projects, with the principal objective of reducing waste. The analysis reveals a set of interdependent challenges, encompassing environmental, economic, social, technical, policy, and organizational factors, which impede the transition to a circular model within the architecture, engineering, construction, and operations (AECO) sector. It is recommended that an ecosystemic approach be adopted to emphasize the interconnectedness and collaboration of stakeholders, framing the transition as a move towards decentralized, flexible systems while addressing the semantic ambiguities within the CE framework. In this regard, the recommendations presented in this article align with the recently published ISO standards concerning the circular economy, in particular through the principles of interdependence, a systemic vision, maintenance, and the creation of circular value. These align with the specific standards concerning definitions, business models, evaluation, information, and traceability.

At the meso level, this literature review examines the impact of CE principles on stakeholder roles and relationships. Despite the growing importance of circular processes, there is a significant gap in the understanding of the interactions and engagement strategies of the relevant stakeholders. A holistic approach is essential for addressing the complexities of circular systems, which necessitates transformative changes such as evolving roles, fostering collaboration, and shifting perceptions of resource value. The advent of multidisciplinary roles serves to enhance collaboration and trust, thereby facilitating effective problem solving. This study identified four types of stakeholder relationships (competitive, directive, mediating, and collaborative), as well as four types of engagement (magnet, sieve, chain reaction, and rush hour).

At the micro level, this review indicates that the practical applications of CE principles remain underdeveloped, with a tendency to focus narrowly on waste reduction. The intricate relationships inherent to circular ecosystems underscore the necessity for enhanced information management and coordination tools. Three principal categories of CC implementation were identified: working methods, assessment methods, and tools. Despite the existence of a variety of proposed methods, many lack comprehensive descriptions of the collaborative processes involved. The utilization of digital tools, including building information modeling (BIM) and artificial intelligence (AI), is of paramount importance for the facilitation of stakeholder alignment. Furthermore, the discussion emphasizes the necessity for a shift in business models to integrate CC principles, advocating a transition from traditional remuneration structures to performance-based models. This positions designers as agents of change, promoting systemic circular thinking while underscoring the need for robust frameworks to effectively implement circularity in construction.

This study revealed five significant impacts on CC ecosystems, emphasizing the necessity for stakeholder engagement, which vary depending on the ecosystem's structure and key actors. As circular ecosystems become increasingly complex, it is imperative that stakeholders develop a broader skillset that encompasses both macro-level concepts and the specific requirements of individual projects. Furthermore, critical interdependencies among stakeholders were identified, which require a shift in business models from a focus on value provision to the preservation of circular value throughout the entire product life cycle.

Finally, the findings indicate a notable research gap concerning the socio-ecological dynamics within circular ecosystems and their implications for stakeholders. In order to address this gap, the development of an ecosystemic map is proposed, which would serve to visualize the intricate relationships and collective activities of stakeholders, thereby illustrating the flow of impacts and synchronizations throughout the CC process. This map could serve as a flexible tool for understanding and navigating the complexities of CC ecosystems, highlighting the importance of cognitive and operational synchronizations among stakeholders. Ultimately, this research underscores the need for a collaborative approach to stakeholder management, incorporating both technological and intellectual tools to facilitate effective communication, coordination, and alignment of objectives in the transition toward circularity in the construction sector.

6.2. Limitations and Perspectives

Several limitations constrain this research. Firstly, the rapidly evolving field of CC and the CE presents a challenge to maintaining the literature review in a fully up-to-date state, as evidenced by the recent CE standards [80], which may result in some outdated or context-specific findings. Secondly, although this study encompasses the macro, meso, and micro scales, it may oversimplify the inherent complexities within and between them, thereby creating gaps in understanding how challenges at one level affect another. Although it is intended to be a comprehensive tool, the inherent complexity of CC ecosystems necessitates the completion of other research from all disciplines to the greatest extent possible. In light of these considerations, a number of potential avenues for further inquiry can be identified. Furthermore, this study may not fully account for the impact of contractual agreements (public and private) on stakeholder collaboration, and its emphasis on stakeholder engagement might not capture the full diversity of perspectives within circular ecosystems. This may introduce bias and fail to account for key interdependencies that influence the success of circular practices. Finally, while the proposed CC ecosystem map is useful, it remains generic and would need to be tested in real-world settings for validation. The reliance on theoretical frameworks rather than extensive empirical evidence raises questions about the practical applicability of the proposed strategies.

From this perspective, future research could focus on empirically validating the circular ecosystem map proposed in this study by applying it to concrete construction projects. This bottom-up approach would initiate analysis at the micro scale and establish links with the meso and macro scales. Such an investigation would allow researchers to assess the effectiveness and adaptability of the map in real-world settings, thereby challenging its assumptions and refining its framework. In addition, an important area for further research is to understand how contractual relationships and agreements between stakeholders affect collaborative processes within CC ecosystems. This research could explore the specific mechanisms through which contractual frameworks facilitate or hinder stakeholder collaboration and could provide insights into best practices for fostering effective partnerships in CC initiatives. This article represents the initial phase of a research project examining collective activities within the context of the CE and CC. The influence of contractual agreements between actors will be partially addressed during the second stage of this research through interviews with actors involved in private and public CC projects that have already been carried out. Given the growing body of research on CC ecosystems, a comparative analysis of different approaches on a European or global scale would also be valuable. Such a cross-referencing study could identify differences in stakeholder engagement strategies, regulatory frameworks, and implementation practices in different contexts, contributing to a more comprehensive understanding of how CE principles are operationalized in different regions.

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