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Detecting and Understanding Barriers and Drivers to Advance Systematic Implementation of Resource Circularity in Constructions

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Abstract: As the construction sector is one of the most carbon-intensive and resource-intensive industries, the necessity for a transition from a linear to a circular economy is widely acknowledged. Aimed at facilitating the transition, several policy frameworks, operational tools and assessment instruments have been developed in recent decades. Nevertheless, the integration of circularity in the construction sector remains constrained and haphazard, frequently focusing solely on the production phase and neglecting the comprehensive impacts within the overall process. The detected gap between theoretical framework and practical implementation is reflected by the limited coordination between policies and tools, which creates a significant obstacle to the adoption of consistent and effective practices. A dual analysis is conducted, comprising two parallel domains: an investigation of a circular policy theoretical framework in urban environments through a literature review, and an analysis of practice-oriented tools through resilience assessment and green building rating systems. As a result, common ground and shared targets are identified between the two scopes, as well as contrasts and inconsistencies that require further attention. These are classified according to their role as barriers or drivers of change, and recommendations for synergistic improvement between policies and tools are provided.

Keywords: barriers to circular systems; building construction; circular economy; circular-oriented policies; green building rating systems

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1. Introduction

Among the key challenges connected to the achievement of sustainable development globally, the shift from a linear to a circular economy probably represents one of the most relevant and complex issue to address, not only for the multiple scales involved but also for the articulation of production streams and related financial implications [1,2]. Constructions play a key role in this pathway, as they are largely responsible for both climate-altering emissions and finite resource withdrawal [3]. Buildings generate more than one-third of carbon emissions globally, consume over 40% of final energy, 12% of freshwater, 30% of raw materials, and generate about 20% of global wastewater and up to 40% of solid waste sent to landfill [4]. The projections for future scenarios show a growing trend for all these figures unless major changes are made soon. As an example, raw materials extracted and processed for this sector—especially mining materials and metals—are expected to double by 2060 [5].

In this context, many international agendas have recently focused their attention on coupling energy efficiency with the increasing need to reduce the embodied impact of all the construction-related processes to fully address the transition towards the concept of a climate-neutral city [6–9]. Circularity of resources is a pivotal strategy to this end; reusing materials is the first step from a linear to a circular economy, as it reduces the consumption of raw materials, which perfectly aligns with the mainstream need to consider the whole life cycle of a building, rather than focusing on the sole use stage [10,11]. Despite being well acknowledged at the policy level, where the European Renovation Wave clearly demonstrates the urgency to transform the built environment by reducing the energy demand of inefficient assets, the focus on the construction-related environmental impact still requires more effort to concretely support the adoption of resource circularity approaches [12].

Indeed, a deep shift towards circularity remains challenging even in Europe, which was a frontrunner in the circular economy (CE) from the very beginning, with large performance variation detected across Member States [13]. Although Europe and the UK are leaders in research in this field, with several studies addressing the shift from a linear to circular economy in the construction sector [14], CE is poorly implemented in the real construction market, especially at the building scale where a systemic application is lacking as well as the adoption of a whole life cycle approach [15]. On the one hand, theoretical principles and policy trajectories to move towards a circular economy are generally advanced and acknowledged worldwide, and increasingly targeted in the construction sector. On the other hand, the uptake of such wide and forward-looking principles remains a distant prospect for the real market, with 70% of recycled construction material utilized only for backfilling or as a road base, which means that most of these resources are 'downcycled' [16,17]. Furthermore, there is little reuse of building components like bricks, floors, and walls. Only 10,6% of the almost six tons per capita used by the sector annually in the EU is of recycled and reused materials [18].

Overall, it can be observed that even in CE-oriented countries and EU member states, a lack of coordination at the policy level is hampering the real uptake of circular practices in the building sector, not to mention that a lack of a harmonized set of indicators to measure progress in the circularity of resources represents a significant barrier to systemic, constant and effective monitoring of the trends, as clearly emerges within the current state of the art [19]. There is indeed a growing number of tools and assessment frameworks to encourage the spread of resource circularity in the construction sector, but their efficacy in fostering circular-oriented practices is still to be demonstrated. The gap between the targeted circular systems is grounded in quite a robust theoretical framework, and the concrete application in the real market is still underexplored, with studies more focused on product and component production processes rather than the whole construction stream, not yet sufficiently supporting a systemic perspective on the transition progress [20–23].

Some Member States, such as Italy, have therefore invested a part of the exceptional measures of the EU Recovery Fund comprehensively addressed to support the achievement of sustainable development goals, for funding specific actions aimed to introduce mandatory metrics and impact assessment tools in regulations regarding the construction sector. Within this context, the Italian Ministry for University and Research supported, under the umbrella of the competitive national PRIN 2022 programme, the project "BETTER POLICY Building Environmental Tools to Empower Responsive Policies Outreaching LifeCYcle. Guidelines and protocols to enable Public Administration-driven processes in the Italian construction sector", with the overall aim of facilitating the introduction of life cycle assessment tools in public projects. A specific task force has been dedicated to life cycle-oriented circular economy practices and tools within the project.

The investigation was originated by the very slow implementation rate of circular-oriented processes in public-driven construction initiatives, which are instead supposed to be the pilot of a massive adoption at the national level [24]. Despite the national obligations introduced to comply with the EU vision, the actual adoption of CAM (Minimum Environmental Criteria)—which are supposed to set the conditions to meet adequate design and construction solutions and enable low-impact and circular-based systems—is largely fulfilled more as an administrative step rather than a real mindset shift opportunity.

Accordingly, the core research question is to identify and understand which barriers and gaps still need to be addressed, and what good practices and drivers could stimulate the change, considering tools and policies at the same time. The study examines the gap between the progress in the theoretical framework and the limitations in the real market application, where sustainability assessment tools seem to represent the main (voluntary) way to monitor both the quality and performance resulting in the building process.

Therefore, the scope of the research project is to understand why circularity of resources in the construction sector has failed to be systematically implemented so far, with particular reference to the Italian national context.

A methodology to correlate the two ends of the topic is developed. On the one hand, the scientific literature about CE policies is reviewed; on the other, a systematic analysis of the most diffused building sustainability assessment tools is carried out. Thereafter, a critical discussion of the outcomes is performed to search matches and uneven topics (Sections 2 and 3). This cross-search method aims at identifying the mutual connections between measures and targets established by the policies and the performances assessed by the tools, so mapping potential integrations to build consistent decision sequences among the two investigated fields. This should couple the advancing knowledge and practice in the field of circular construction, overcoming the lack of complementarity that is argued to exist between the two domains. Findings are systematized to discuss challenges at the policy level to better support the adoption of circular economy principles, practices, and measures in buildings (Section 4).

2. Materials and Methods

The study consists of a dual methodology to investigate barriers and drivers for implementing CE in the construction sector on a regular and large basis. On the one hand, a systematic review of the literature is conducted to find relevant studies, policies, tools, strategies, and practices for an effective uptake of CE principles along the whole life cycle of a building (from material production to building dismantling and beyond). On the other hand, privately and publicly driven sustainability assessment tools for buildings are screened to detect possible good practices to be moved into policy frameworks, as well as potential room for improvement in the tools themselves. This combination of search methods was intentionally chosen with the purpose of unveiling the detachment of policy and practical levels, which represents one of the major issues hampering the effective shift of the sector towards circularity. Therefore, commonalities and, even more importantly, potential contrasts between the two were searched. The results focus on which relevant CE aspects identified in the literature are not yet assessed by tools and, conversely, which CE practices are currently considered by tools but are not assumed as relevant by policymakers. As a consequence, a knowledge base for advancement in the field is given, preparing the ground for recommendations for both policy improvement and tool refinement. Figure 1 shows the workflow diagram of the entire methodology.

2.1. Method A: Literature Review of Circular Economy in Life Cycle-Based Policies and Studies

A literature review was performed searching for circularity in life cycle-driven urban policies, with the first term standing for WHAT and the second for WHERE. The complete search string was Circular* AND (LCA OR (life AND cycle) OR LCC) AND (urban AND (policies OR environment OR studies)). The two most reliable and complete databases were selected: Web of Science (WoS) and Scopus. These two databases are widely regarded as mainstream bibliometrics tools, offering comprehensive coverage of subject areas, and being regularly maintained and updated by professional organizations. As a result, they are recognized as high-impact and trustworthy search engines [25,26].

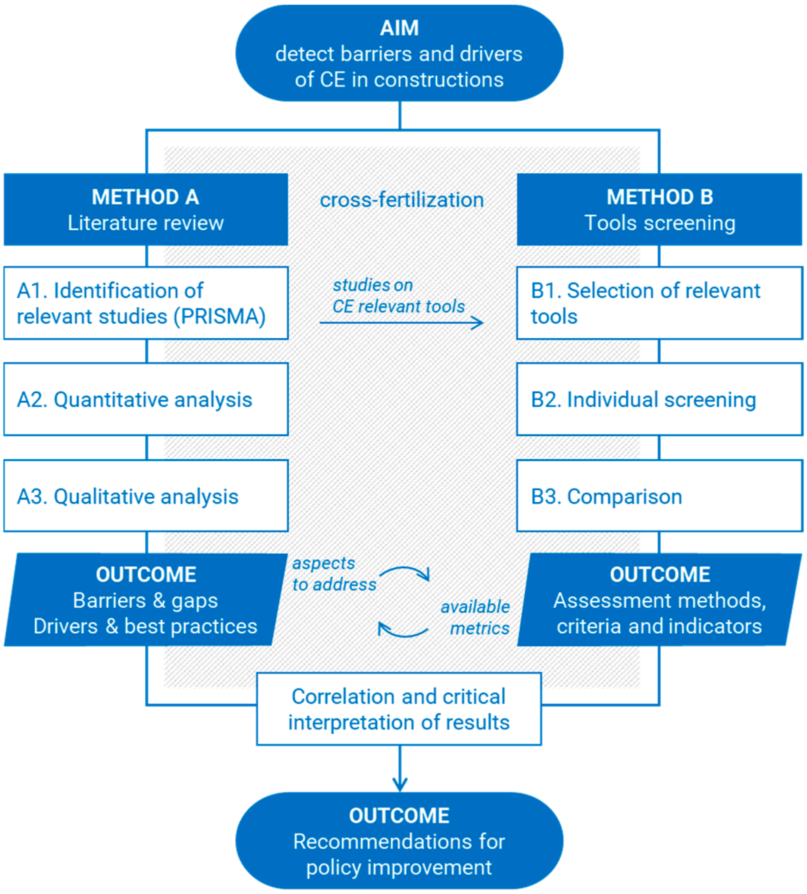

Figure 1. Workflow diagram of the whole methodology.

The string was searched in the database by topic (title, keywords, and abstract) with the following filters applied:

- Time: From 2014 to 2024 (10 years), as it represents the timeframe in which the topic has emerged and rapidly diffused in policies.
- Language: English.
- Type of document: Research articles and review articles.
- Types of work: Articles, review articles, and book chapters.
- Research area/subject: Environmental science; energy; engineering; social sciences; business, management and accounting; materials science.

The search was performed between January and February 2024; records published after 28 February were not included. The search was reported through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), as shown in Figure 2, which was assumed as a structured and well-established procedure for phase A1. The scope of this study was not to perform a systematic literature review, but rather to conduct a systemic screening of current studies to map the main barriers and drivers cited in field positioning and then linking these with results from Method B (tools). Therefore, it is important to clarify that PRISMA guidelines have been adopted only as a reporting scheme for record selection and not for following its whole structure for reviewing purposes.

According to the PRISMA diagram above, a total of 189 documents were retrieved from WoS and Scopus, including 36 duplicate documents. So, a total of 154 records were included in the first stage of the literature. A first round of result visualization was launched through VOSViewer version 1.6.20, an open-access and easy-to-use software that helps identify and visualize trends, patterns, and clusters of recurrent topics in bibliometric networks [27]. The totality of papers was entered into the software by selecting the analysis on word co-occurrence with keywords; fractional counting was then selected, and five was the minimum number of term co-occurrence to be shown on the map. A cleaning phase was also performed, checking the totality of considered words and adding a thesaurus file, which forced the system to exclude terms that were not relevant to avoid duplications (i.e., singular and plural words), double-counting (i.e., with abbreviations), and synonyms and near synonyms (i.e., life cycle assessment and life cycle assessment). Optimizations were also performed in the scale of visualization to obtain the best possible results. The weights were performed with the total link strength.

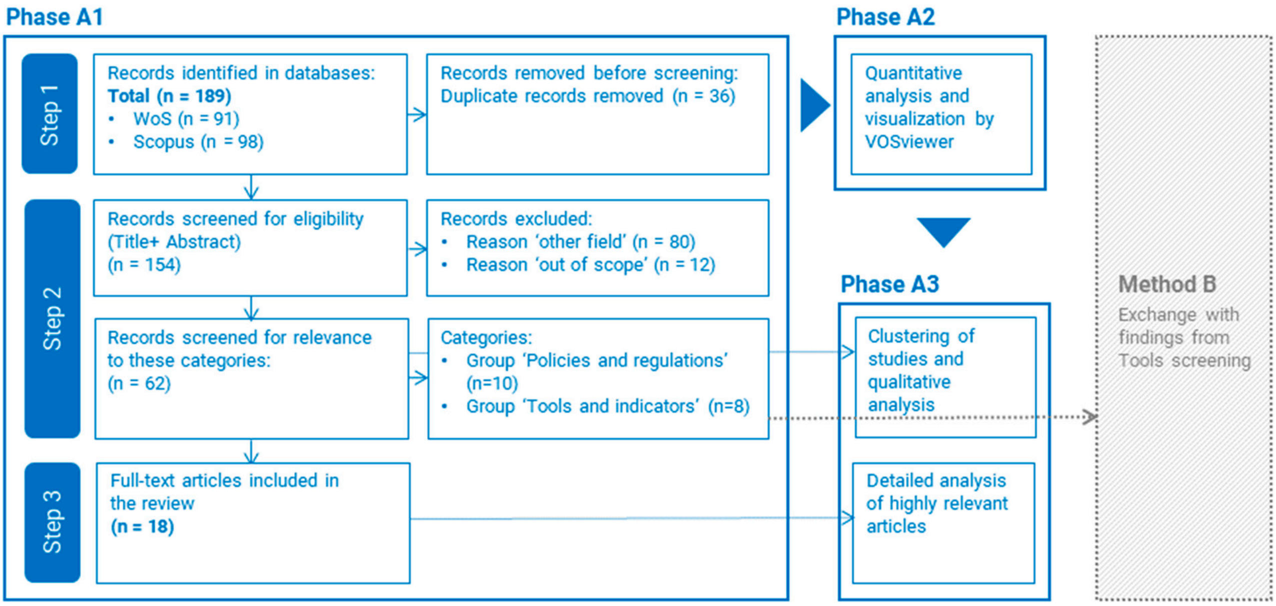

Figure 2. PRISMA diagram of the literature review (Method A).

Afterwards, titles and abstracts of these records were screened and 92 were excluded: 80 because they pertained to other research fields (i.e., not built environment-related: ecology (10), agriculture or urban agriculture (16), rainwater harvesting and wastewater (3), sanitation (2), agro-industry (2), chemical industry (1), just to name a few); 12 because they were out of scope. From the remaining 62 records, recurrent topics and/or relevant ones are clustered—per common topics and scale of application—to feed a first qualitative analysis of results.

As third step, records highly relevant to the scope of the literature were selected and grouped as follows:

- Group CE in LC-driven policies or regulations (10);
- Group Integration of CE in design indicators, tools, metrics (8).

These 18 records were read in greater detail and findings about gaps, barriers, and drivers of CE in constructions drawn to be critically combined with findings from the tool screening (parallel search phase).

2.2. Method B: Review of Circular Economy in Life Cycle-Based Tools

At the same time, a review of private or public tools to encourage and assess sustainability of constructions has been performed. These indeed are current tools used in the construction sector to assess a variety of building impacts within a harmonized scoring system [28–30]. To this end, the most diffused Green Building Rating Systems (GBRSs) from all over the world were selected [31,32], namely LEED (USA), BREEAM (UK), and DGNB (DE). Similarly, two relevant Resilience Assessment tools were identified: RELi and REDI. Additionally, Level(s) EU was selected as the sustainability assessment framework promoted by the European Commission. Besides these international tools, two Italian tools were selected, with the specific goal of understanding if and how Italy as a member state had already introduced CE principles in its operative frameworks, namely UNI/PdR

13/2019 (which derives from Protocollo Itaca, the national version of SBTool) and CAM (Minimum Environmental Criteria, which are a set of prescriptive criteria to encourage sustainable design and construction in public interventions).

After selecting the tools and the most recent or relevant version, an individual screening of each was performed. In particular, the checklist of each selected rating was screened per keywords such as "circular*", "reuse", "recycl*", "lifecycle" which were searched in credit titles and/or brief descriptions. Results were reported into an Ms Excel spreadsheet structured as shown in Table 1, and relevant indicators and metrics were reported where available in the tool's user manual.

Table 1. Template used for the individual screening of CE-related tools.

Name of the Tool—Rating System's Version				
Evaluation Category	**Mandatory Credit**	**Credit Code**	**Credit Name**	**Description, Indicators and Metrics**
Category 1	Yes/No	Code 1	Credit 1	Description 1
Category 2	Yes/No	Code 2	Credit 2	Description 2
Category n	Yes/No	Code n	Credit n	Description n

As last step, a quantitative comparison of weights assigned to circularity in each tool was made, based on assigned points, as well as good approaches, and possible implementation barriers, either in common or specific to one tool, were retrieved to be discussed further in the following phase of the study (i.e., critical interpretation).

2.3. Critical Interpretation of Results from the Investigated Sources

The last phase consists in analyzing results from the two search methodologies to provide cross-fertilization and advance recommendations for policies and CE-related tools. Results from the two methods are systematized considering the mutual relationships and contrasts. A correlation matrix between tools and policies is built to this end: the eight main assessment topics are considered for the first, while recurrent and noteworthy drivers of change from the literature are listed for the second (these are presented in detail in the following paragraphs). The connection is derived by searching the 18 full-text co-occurrence of terms, concepts and synonyms of both drivers and assessment topics. The number of co-occurrences suggests the strength of the link. On this basis, a radar chart for each driver is derived to help understand what driver–topic nexus must be developed further, and, on the other hand, what areas still need to be investigated to connect theory and practice of CE in constructions. The overall process is additionally informed by general findings from the other records included in the review.

General findings are then discussed per barriers and drivers according to the following Thematic Families (TFs): TF1 policies and guidelines, TF2 tools and means, and TF3 practices and implementation. Albeit focused on a specific level of CE implementation, recommendations to improve these families are given considering the whole picture.

3. Results

3.1. Literature Review

Quantitative analysis of the first stage of the record screening was carried out. Thus, the following figures are derived from the 154 records (duplicates excluded).

Figure 3 illustrates the time distribution of records in the selected decade, with 2020 emerging as a turning point in the amount of research about CE, probably due to the introduction of such a topic within the overall sustainable development strategy of Europe and other countries globally.

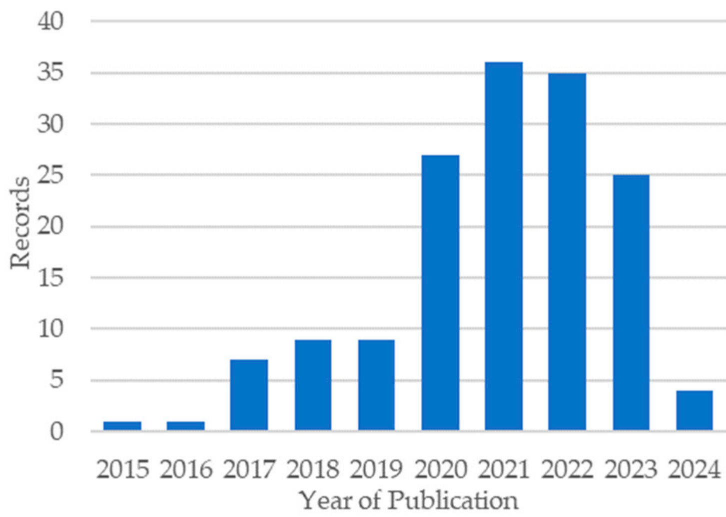

Figure 3. Time distribution of records.

According to the geographic distribution of the selected studies (Figure 4), Europe ranks first, reasonably due to the strong support that the Commission is giving to circularity. This indeed reflects the interest that some member states are giving to CE, at least from a theoretical standpoint. However, China is also positioned well, and shortly after comes Brazil.

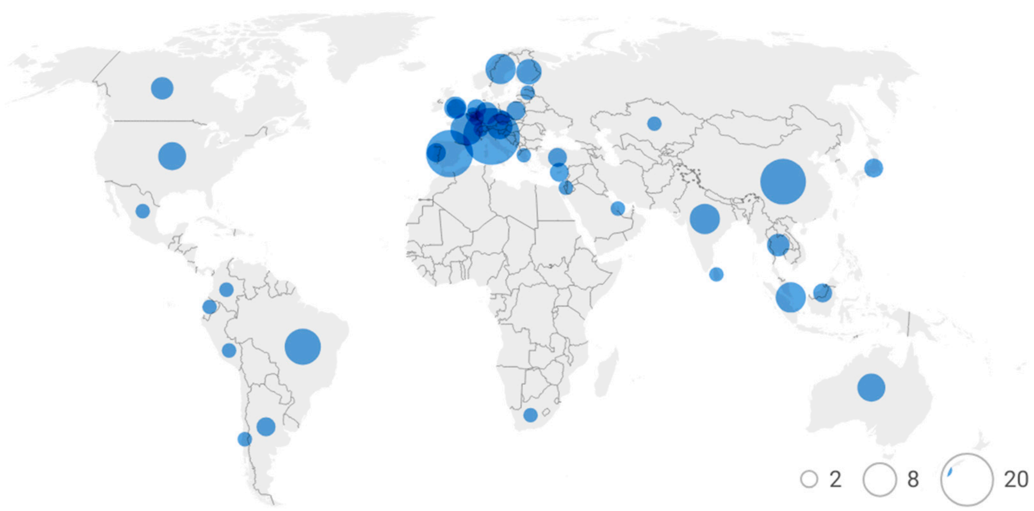

Figure 4. Distribution per geographic area of corresponding authors (elaborated through Datawrapper).

Afterward, the 154 records were analyzed by topic through the VOSviewer tool. Figure 5 shows two main thematic clusters: one focused on the circular economy (green) and one on LCA and other environmental impacts (red). Although smaller, the graph also depicts a yellow cluster focused on waste and a blue cluster focused on ecology and environmental sciences.

From the remaining 62 records, titles and abstracts were screened and recurrent or notable topics from the selected studies were derived, as shown in Figure 6, and thematized more in detail in Table 2. Table 3 reports most relevant papers to the study divided in policies' and tools' groups.

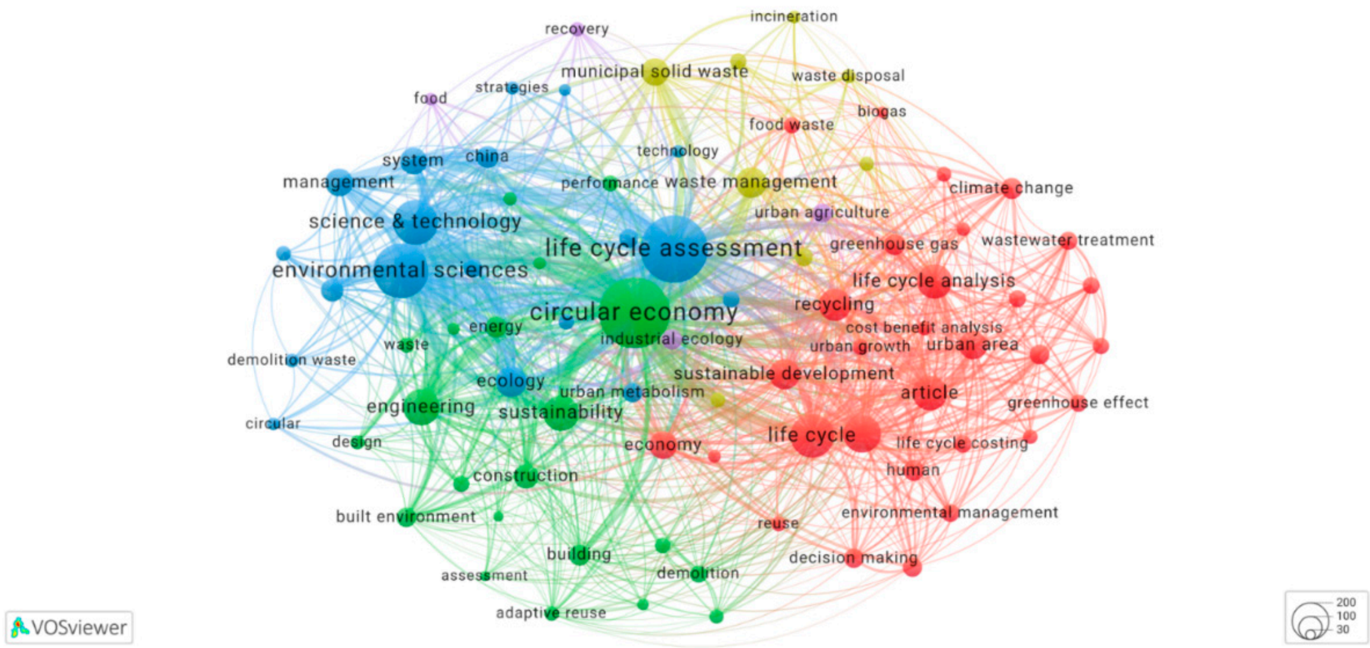

Figure 5. Visualization of links between recurrent keywords.

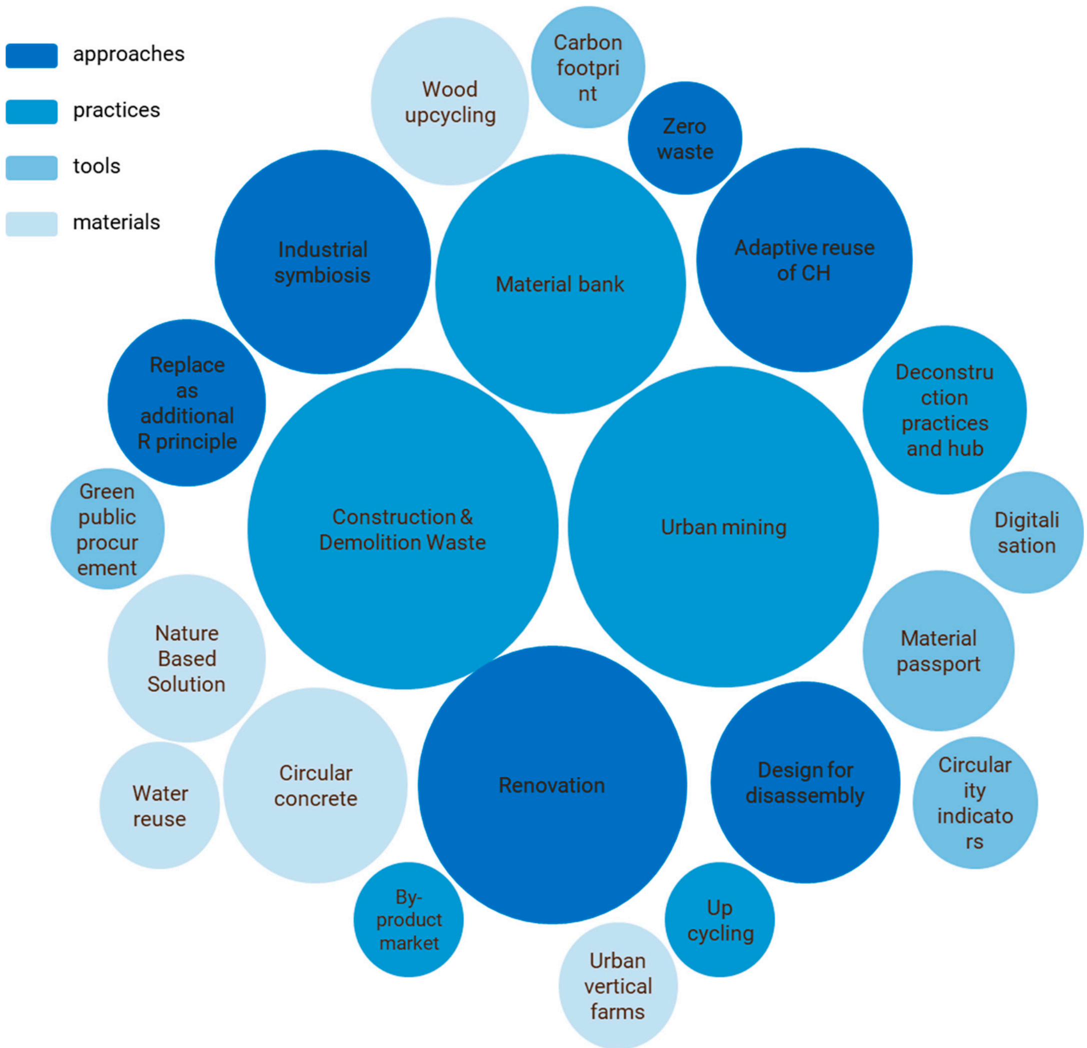

Figure 6. Notable topics from the included records (elaborated by the authors through RAWgraphs).

Table 2. Cluster of records per homogeneous classes.

Approaches	Refs.
Industrial symbiosis: Several studies mention multiple co-benefits of Industrial Symbiosis (IS) approach for CE	[33–36]
Renovation: CE is deemed relevant for renovation projects to reduce constructions' environmental impact	[37–42]
Adaptive reuse of cultural heritage: Concept that has diversified applicability for CE	[40,43–45]
Replace as an additional R principle: Additional mainstream approach in CE principles	[46]
Design for disassembly: Environmental benefits from the design of components designed for disassembly to facilitate better applicability of life cycle assessment	[37,40,47]
Zero waste: Educational practices designed to promote changes in user behavior to support CE	[48]
Practices	
Construction and Demolition waste: CE applied to CDW represents an important strategy with social and economic benefits	[41,49–55]
Urban mining: As powerful means to help CE in constructions	[51,56–63]
Upcycling: As novel and positive way to reach a high-quality reuse in buildings	[63]
Material bank: Key to facilitate CE spread	[64]
By-products/secondary materials market: Useful practice to integrate the policy on the efficiency of materials during production and consumption	[40,52,59,63,65]
Deconstruction practices and hub: A key optimization in CE to limit the resource demand and structural waste	[66,67]
Tools	
Green Public Procurement: GPP as strategic tool to achieve CE objectives	[11]
Material passport: (MP) as a useful tool for CE	[59,68]
Digitalization (including BIM, GIS): Digitalization as a support to CE; including BIM or GIS with info about building component lifespan and recycling potential	[50,65,69–71]
Carbon footprint: Carbon footprint indicator among the most recurrent metric for CE	[34]
Material circularity indicator: Among the most used indicators in the circular economy, complementary to LCA	[72]
Materials	
Water reuse in constructions: Towards a circular model in the water sector, the configuration of future water infrastructure changes through the integration of grey and green infrastructure	[73]
Nature-based solutions: Nature-based solutions for CE to contrast the negative urbanization impact	[73,74]
Wood up-cycling: Need to improve the applicability of life cycle assessment in a normative context	[75]
Circular concrete: Circular concrete is mainstream	[50,76,77]
Urban vertical farms: Urban vertical farms and CE benefits for dwellings	[78]

Table 3. Selection of highly relevant papers to the scope of the study.

Group	Refs.
Papers highly relevant to CE policies	[11,34,46,51,61,66,69,79–81]
Papers highly relevant to CE tools and indicators	[39,49,59,72,82–85]

3.2. Tool Review

For each of the selected tools, tables such as Table 4 have been filled, showing CE-relevant criteria and the adopted metrics and targets.

Table 4. CE credits in LEED rating system.

LEED New Construction V4 [86]				
Category	**Prereq.**	**Credit**	**Metrics**	
Sustainable Sites		Rainwater Management	Percentile of Rainfall Events	80th/90th Percentile
Water Efficiency	yes	Outdoor Water Use Reduction	Reduced irrigation	Reduce the project's landscape water requirement by at least 30% from the calculated baseline for the site's peak watering month.
	yes	Indoor Water Use Reduction	Building Water Use	Reduce aggregate water consumption by 20% from the baseline
Materials and Resources	yes	Storage and Collection of Recyclables	Provide dedicated areas accessible to waste haulers and building occupants for the collection and storage of recyclable materials for the entire building. Collection and storage areas may be separate locations. Recyclable materials must include mixed paper, corrugated cardboard, glass, plastics, and metals. Act appropriately for the safe collection, storage, and disposal of two of the following: batteries, mercury-containing lamps, and electronic waste.	
		Building Life Cycle Impact Reduction	Percent of existing walls, floors and roof reuse by project area	15–30–45–60–75%
			Maintain Interior Nonstructural Elements (1 point)	Use existing interior nonstructural elements for at least 30% of the entire completed building, including additions.
			Whole-Building Life Cycle Assessment	Conduct a life cycle assessment of the project's structure and enclosure that demonstrates a minimum of 5–20% reduction, compared with a baseline building in at least three of the six impact categories.
		Building Product Disclosure and Optimization—Sourcing of Raw Materials	Responsible Sourcing of Raw Materials	Use products sourced from at least three different manufacturers that meet at least one of the responsible sourcing and extraction criteria below for at least 15/30%, by cost, of the total value of permanently installed building products in the project (1 or 2 points).
	yes	Construction and Demolition Waste Management	Diversion	Divert at least 50% of the total C&D materials from landfills and incineration facilities.
			Waste Prevention	Salvage or recycle at least 50% of renovation and demolition debris and utilize waste minimizing design strategies and construction techniques for new construction elements. Divert at least 50% of all renovation and demolition waste, if any.

Thereafter, critically analyzing the protocols, eight major common themes (Table 5) are identified with reference to resource circularity, as follows:

- Recycled materials, including credits that award the reuse of existing materials or the use of high levels of recycled content. This can be accomplished mainly during the design and construction stages, but also includes waste collection during the in-use stage.
- Life cycle impact, which strongly encourages the assessment of design and construction impact through LCA tools.
- Water management and reuse, which typically refers to strategies to reduce landscape watering needs or indoor freshwater use by means of flush reduction technology or reuse strategies.
- Waste management addresses CDW flows and destinations, encouraging selective demolition or at least waste differentiations.
- Flexibility and adaptability support the adoption of design practices and choices that are adaptable to future changes and requirements.
- Disassembly, which includes credits related to construction strategies and technologies easy to disassemble in the future, particularly using precast components and dry systems.
- Excavation soil reuse encourages the reuse of excavated soil on site for other functions, such as backfilling, among others.

- Land use, with a preference for brownfield redevelopment rather than using new uncontaminated soil.

Table 5. CE-relevant categories in the analyzed rating systems.

Criteria	LEED	BREEAM	DGNB	ITACA	Level(s)	CAM	RELi	REDi
Recycled materials	•	•	•	•	•	•	•	
Life cycle impact	•	•	•		•	•	•	•
Water management/reuse	•	•		•		•	•	•
Waste management	•	•	•		•	•	•	
Flexibility and adaptability		•	•	•	•			
Disassembly		•		•	•	•		
Excavation soil reuse				•		•		
Land use			•					

Notably, the DGNB protocol, compared to the others, contains a list of criteria to which circular economy bonuses can be attributed, encouraging their use.

Despite their presence in each protocol, the number and weight of CE-related credits per category may vary significantly. Figure 7 illustrates briefly how different evaluation categories related to CE are weighted in the diverse ratings (i.e., the wider the line, the higher the relative weight assigned, or the number of credits related). Life cycle impact and recycled material categories clearly stand out per the given importance.

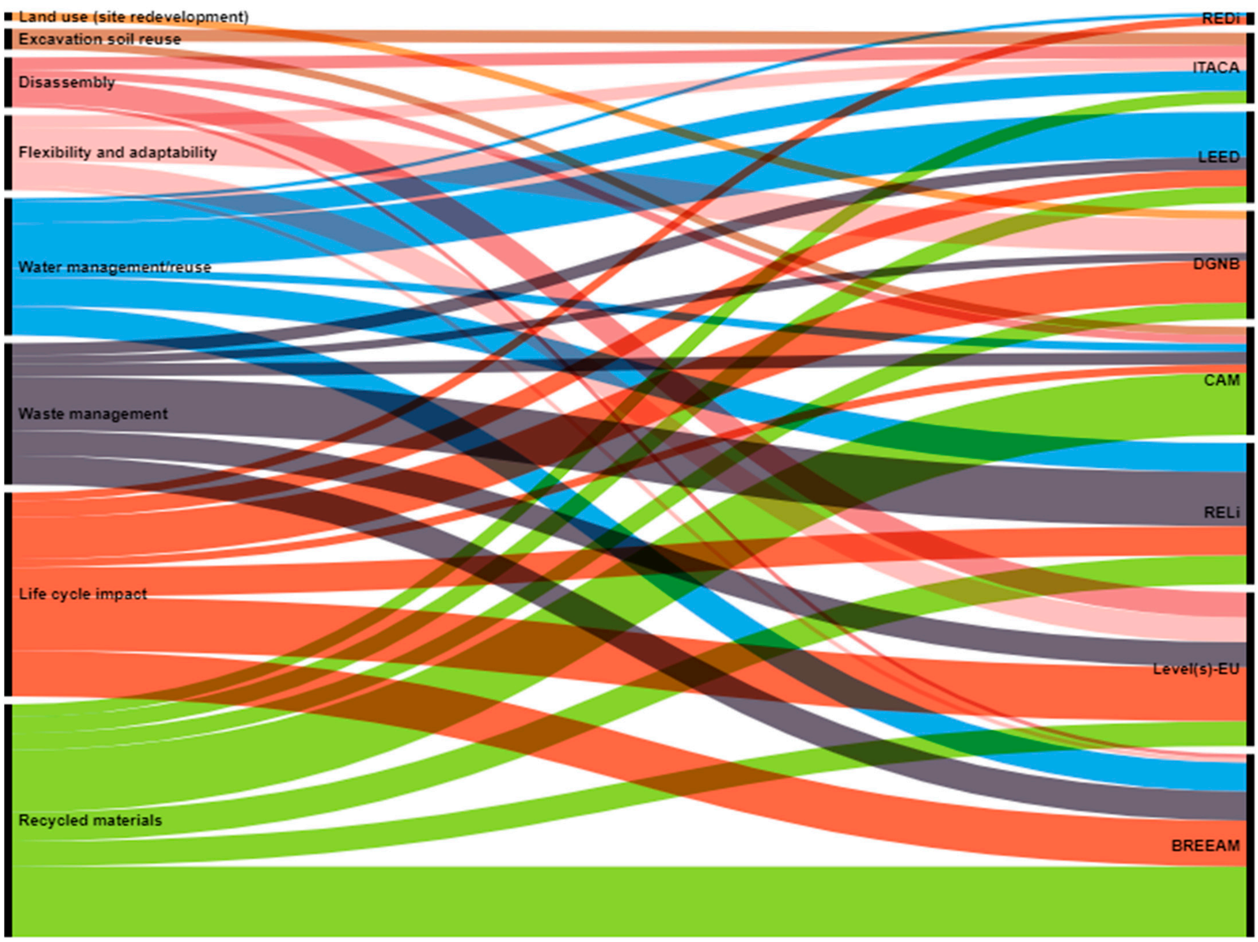

Figure 7. CE-related topic relevance for each protocol.

3.3. Critical Interpretation: Joint Analysis and Correlation

The correlation matrix (Figure 8) reports the number of co-occurrences of terms in the full texts included in the literature, and can be divided between connections, which are mentioned as being already established, and those which are identified as being in need of further development.

	CE-related topics in tools*	CE drivers from the literature										
		D1 inter-/cross-disciplinary approach	D2 multi-scale approach	D3 public communication of CE benefits	D4 support to industrial symbiosis	D5 GPP and other pilot actions by PA	D6 financial incentives to CE products	D7 buildings knowledge and material cadaster	D8 urban mining, material banks and markets	D9 digitalization (GIS, BIM, etc.)	D10 as-a-service business model, Ext. Prod. Resp.	D11 green or selective demolition
already established	Recycled materials (MAT)	0	1	1	1	2	2	2	3	1	2	5
	Life cycle impact (LCI)	0	1	0	0	0	0	3	1	1	0	0
	Water management and reuse (WA	0	0	0	0	0	1	3	0	1	0	1
	Waste management (WAS)	0	1	1	1	0	1	1	4	5	1	3
	Flexibility and adaptability (FLE)	0	0	0	0	0	0	1	0	0	0	0
	Design for disassembly (D4D)	0	1	0	0	0	0	2	1	0	1	1
	Excavation soil reuse (SOI)	0	0	0	0	0	0	0	0	0	0	0
	Land use (LAN)	1	0	0	0	0	1	3	0	0	0	0
need to advance	Recycled materials (MAT)	2	1	2	1	1	0	0	4	0	2	2
	Life cycle impact (LCI)	4	4	2	1	0	0	1	1	3	1	2
	Water management and reuse (WA	0	0	0	0	0	0	0	0	0	0	0
	Waste management (WAS)	2	3	5	1	1	0	1	7	1	3	3
	Flexibility and adaptability (FLE)	0	0	1	0	0	0	0	0	0	1	0
	Design for disassembly (D4D)	0	1	0	0	0	0	0	2	0	3	1
	Excavation soil reuse (SOI)	0	0	0	0	0	0	0	0	0	0	0
	Land use (LAN)	0	0	0	0	0	0	0	0	0	0	0

Figure 8. Correlation matrix between assessment topics and drivers. Items are placed in descending order (by average in the screened tools, from the one weighing the most to the least). The darker the blue, the more frequent the co-occurrence.

Overall, the assessment areas to which tools assign more value are also the ones with higher co-occurrences in the established section, while those which are assigned less points and attention can be divided between those with little or no connection in the matrix and those which are identified for development.

Waste management related to D8 (urban mining, material banks, database and markets) emerges as the most recurrent co-occurrence mentioned as being in need of further development. Also, D3 (public communication of CE benefits) is highly cited regarding waste management, as an area that needs to be improved. On the contrary, waste management and D9 (digitalization) seems already well established in the literature, as well as recycled materials and D11 (green or selective demolition).

Radar charts are then produced for the eleven drivers found so far, the most significant to the discussion being represented in Figure 9a–d.

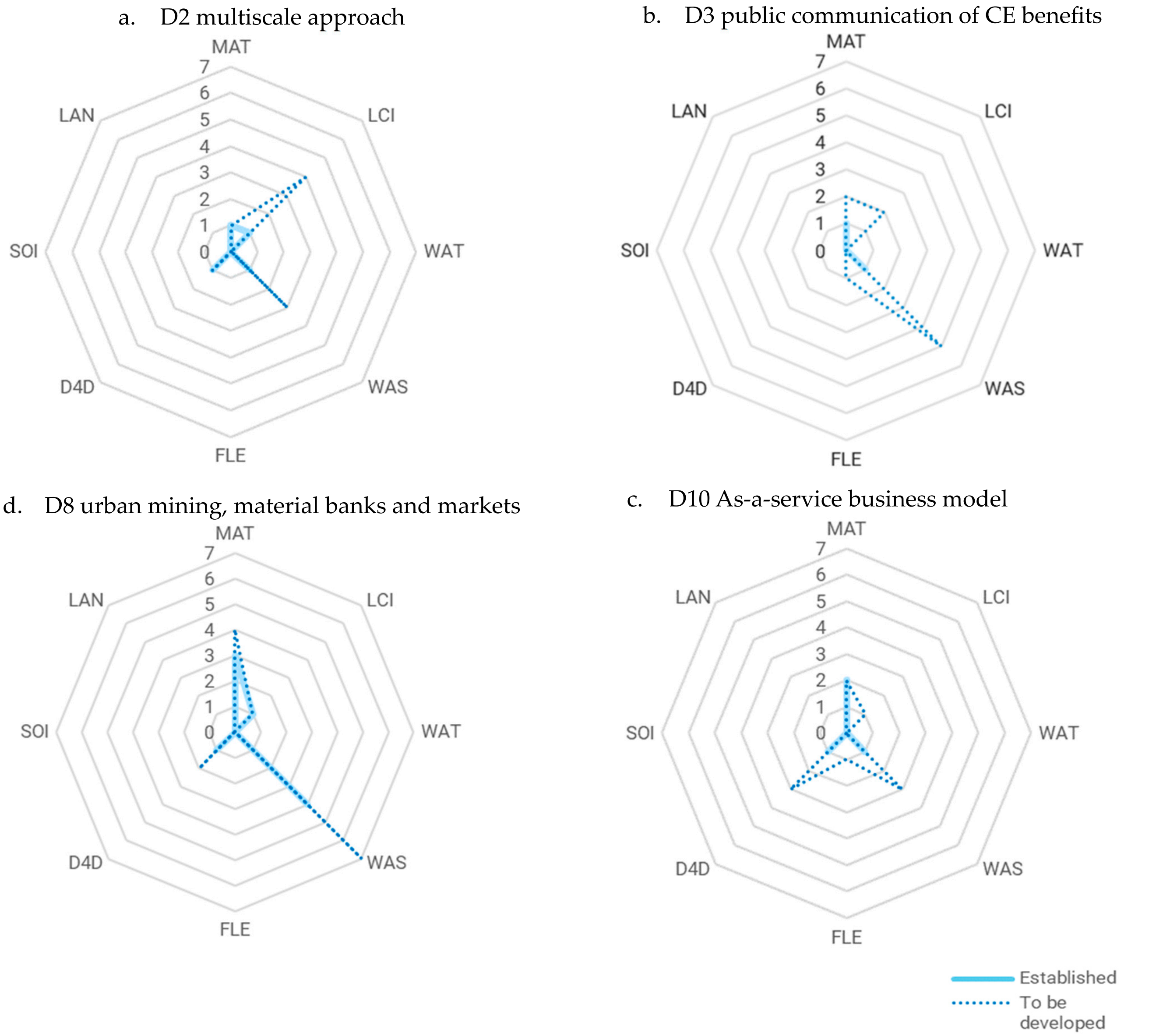

Figure 9. Radar charts for relevant drivers: clockwise (**a–d**). Light blue represents established areas, while the blue dotted line represents drivers yet to be developed.

4. Discussion

Results from the literature review (method A) prove that the topic is considerably investigated from a theoretical perspective. Similarly, results from tool screening (method B) confirm that designers and contractors have several possibilities to assess the circularity performances of their projects. Nevertheless, it is confirmed what was initially stated, that there is a lack of coordination between policies and tools, which hampers the systematic implementation of CE in constructions. Indeed, few connections among the findings from each method have been found, and a wide room for improvement is detected in both, as well as high advancement potentialities due to the two ends' mutual exchange.

Looking at the correlation matrix, it emerges that recycled materials—the assessment topic to which rating systems assign on average more weight—are quite well correlated to the main drivers. The issue is mentioned as already established, especially with respect to green demolition (D11), but would highly benefit from further development in the field of urban mining and material bank databases (D8). As for life cycle impact, room for improvement is mentioned especially with regard to methodological issues (D1, D2 and D9), suggesting that a broader, multi-scale and cross-disciplinary approach would help the assessment along with digitalization. Water management and reuse is not deemed as relevant to the topic from the driver's standpoint.

Waste management emerges as pivotal in this correlation, both for established connections and areas in need of improvement, where it particularly stands out that urban mining and the development of material banks, platforms and markets (D8) will be crucial. On the other hand, it can be generally observed that certain assessment areas have little or no connection with the detected drivers, as in the case of Adaptability and Flexibility. Design for Disassembly, instead, is very little established in practice, but mentioned as an area to be developed further, especially to develop as-a-service business models and Extended the Producer Responsibility (EPR) beyond selling, which is something the European Commission is particularly emphasizing.

Grounded in these overall observations, a specific discussion regarding barriers and drivers as a knowledge basis for further research steps follows; this is graphically synthesized in Figure 10, considering the journey that policies and tools should jointly undertake to advance systematic implementation of circularity in the construction sector.

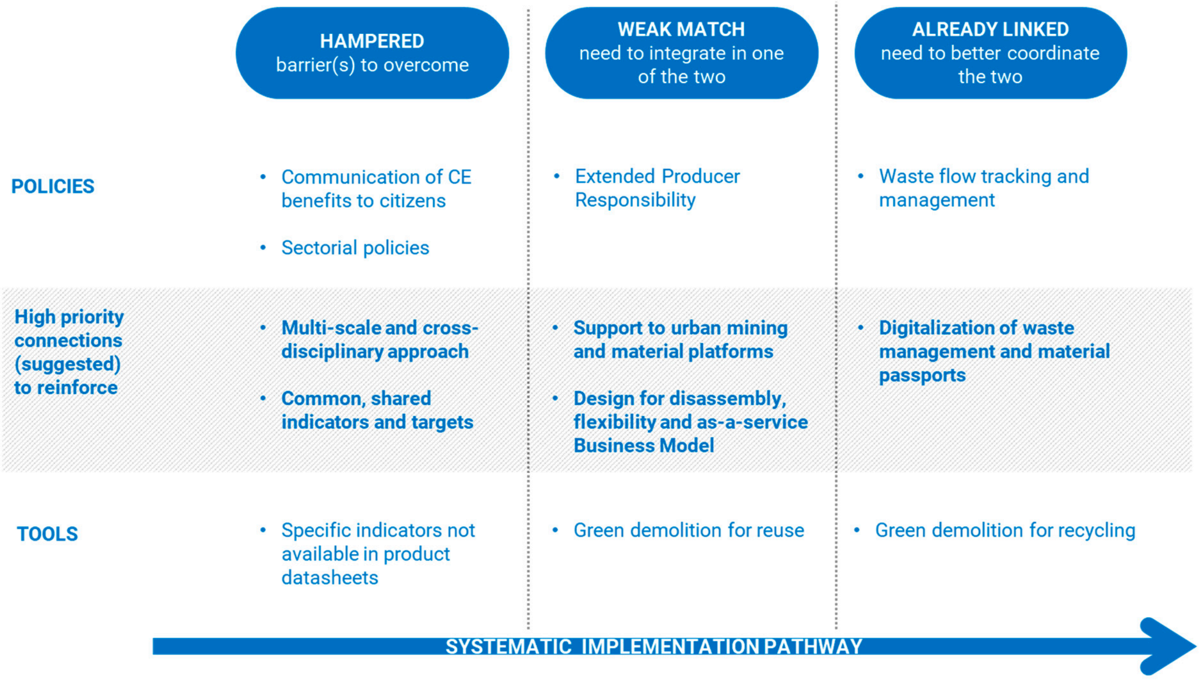

Figure 10. Graphical synthesis of main barriers and drivers within the systematic implementation pathway of CE in construction.

4.1. Barriers, Bottlenecks and Gaps to Overcome

Despite available policies, frameworks, tools, and best practices in the field, the building sector still has serious gaps, bottlenecks and barriers hampering the uptake of circular design and construction. Overall, the literature about circularity in construction remains at an early stage [46].

4.1.1. TF1 Tools and Means

Regarding tools to evaluate and implement circular design in construction, the relative weight of circular economy-related credits within the screened rating systems ranges from 3 to 39% of the whole. The most recurrent CE items in credits include life cycle impact, recycled material, waste management, and water reuse/management. Conversely, design for disassembly, flexibility and adaptability, and land reuse are less prevalent compared to others. This in fact reflects findings from the literature, where it is largely argued that most of the attention of policies and tools target only recycled materials or saving actions, rather than flexibility, dismantlability, and other "novel" design concepts related to CE.

This observation is particularly valid for the Italian CAM, where most of the credits are focused on recycled content of materials and components used in the project, and little reference is made to disassembly potential, with no mention of flexible design.

The reason why many tools (and players in the construction sector) focus mostly on 3R principles is probably related to cost and ease of implementation. In fact, compared to the others, design for disassembly might be more difficult to design and implement, and also may be more expensive in the short-term perspective. For example, "design for disassembly" is deemed an excellent way to reuse and recover the same structure or components of a building and to reduce waste after the end of life of buildings, but procedural cost still represents a major problem, as also the low level of knowledge of designers and construction companies on this topic. In this regard, green or selective demolition is still a niche of the construction market, and significant social and economic limitations still exist [66]. A hint for how to support deconstruction—which is more expensive than traditional demolition—is to promote the net financial and material benefits that can be retrieved at the end of the process [66].

Besides GBRSs and Resilience Assessment tools, it emerges from the literature that LC-based approaches, practices, and tools are difficult to implement, as it is hard to collect reliable input data and details about existing buildings, which represents a significant barrier affecting tools' effectiveness. In particular, it is still challenging to measure embodied energy in existing buildings [44], as well as the residual value of materials and components already in place. Albeit the discourse about life cycle impact assessment tools has been focusing on the accuracy of software and results, this analysis highlights that more attention should rather be paid to the accuracy and availability of input data, which are often difficult to retrieve and unstable across the time. A harmonized database at the national or even international level could help raise transparency and availability on information for impact assessment.

4.1.2. TF2 Policies and Guidelines

In terms of policies, serious flaws in both their structure and content are detected. Firstly, there is a big misalignment between policymakers and stakeholders from the construction sector; one of the principal barriers in the circular economy field is that public organizations recognize the need to move towards circularity in constructions, while private owners, practitioners and workers from the sector hardly know the practices that can be implemented, their benefits in the long run and the corresponding know-how, which is why a more stakeholder-centered approach in policies is called for [87].

Additionally, a scale issue and a general lack of interdisciplinarity are pointed out; too often, research and policies consider CE at a macro-scale or micro-scale, whilst the meso-scale (built environment) is frequently neglected despite being just as relevant [82]. Similarly, most policies target the production stage, while the distribution and use stages are frequently neglected. Even when the end-of-life stage is considered, this is done only in principle, as the actual reintroduction of the "reusable/recyclable" products into the market is often not considered [11].

At the same time, most studies and policy frameworks act on a "case-by-case or sector-by-sector approach", thus failing to consider the systemic interdependencies of CE that, by its own nature, go beyond a specific object or field [11].

4.1.3. TF3 Practices and Implementation

Despite their value and benefits being largely acknowledged both in tools and policies, many relevant CE practices require additional effort and research to enable feasible implementation pathways, as in the case of urban mining and material banks, which still have serious gaps in terms of "project timelines, salvage time, skills and costs" [57].

At the connection point between the two investigated domains, a frequently mentioned problem is the lack of a systemic approach, as discussed by Saadè at al. [72], who advise that CE targets be integrated with another sustainability-related issue rather than each sector acting on its own. Indeed, many studies and dedicated frameworks tend to introduce new indicators and metrics, which unfortunately are not well integrated with already used tools. Somehow, the screened ratings accomplish that already, as they tend to be comprehensive by definition, which is a positive fact, but as they are mostly third-party-driven and voluntary, they are not referenced in public policies.

Moreover, poor communication with citizens and clients is indicated as a serious barrier to CE uptake, either by tools or policies; Joensuu et al. [88] claim that LCA still has shortcomings in revealing clearly and understandably the benefits derived from reuse, recycling and reduction practices.

4.2. Drivers, Positive Trends, and Best Practices

4.2.1. TF1 Tools and Means

An interesting approach is that implemented by the German system DGNB, which spreads CE all over the evaluation categories in addition to certain dedicated credits; in other words, it incentivizes the adoption of specific CE approaches within several credits not specifically targeted by assigning a bonus, usually up to 10 points, if the project includes some aspects concerning CE. This approach goes right in the direction that several authors encourage to assume CE as a cross-sectoral design and evaluation theme.

4.2.2. TF2 Policies and Guidelines

The adoption of the same multi-/inter-disciplinary approach is strongly encouraged at policy and regional levels, where, for example, Joensuu et al. [88] envisage the potentialities of providing municipalities with an updated database of cross-sectoral best practices for CE implementation. Additionally, strong work on the communication of benefits and revenues generated especially through industrial symbiosis networks is deemed as key to the shift to circularity [35].

Therefore, Green Public Procurement (GPP) and pilot actions by municipalities are deemed a good way to spread circular practices among citizens. In this context, Stahel [89] illustrates a set of principles to overcome this general lack, among which financial incentives (e.g., tax rebates for circular products) and technical loop adjustments are proposed in order to make them continuous.

4.2.3. TF3 Practices & Implementation

Overall, filling the knowledge gap is among the most mentioned drivers of CE uptake in the building sector, acting on policies, practices, and tools. Stephan et al. [63], for instance, argue that better knowledge of building stock as embodied environmental impact may help city councils better manage renovation programs. On the same wavelength, more effort should be put into improving material bank databases and cadasters, which is a key prerequisite for the implementation of a paradigm shift towards a circular construction industry [59]. At a higher level, it is crucial to strengthen secondary resource markets. In this context, novel concepts emerge to help waste (component or material) management across the entire life cycle; it is the case of the "product-as-a-service" business model, which gives the manufacturer the responsibility for the product from production to the end-of-life stage and beyond (EPR—Extended Product Responsibility), paving the way to the "sharing economy" [11,46].

Regarding means, digitalization is largely considered a powerful driver to shift towards the circular economy, mainly providing info about resources to be reused/recycled [69] and optimization methods for upcoming waste and recycling masses [70]. Urban mining platforms can also benefit from this, as well as green demolition by law, deconstruction practices, and hubs, which are also deemed key means for the circularity shift. Novel approaches in this field make use of BIM and GIS (respectively, at the building and urban scales) to provide detailed and interconnected information about material/component life span, embodied carbon, and reuse/recycling potential [61,69]. Similarly, material passports, as encouraged by the EC, can be extremely important to this end. It can be concluded that detailed LCA procedures are too technical and demanding to enable the application of CE on a large and systematic scale on the market, where there is a general lack of specialists and/or difficulties are faced in supporting the specialists' calculation of cost, which is not mandatory yet. Accurate LCA calculations are valuable to support research findings, but then, more agile procedures should be embedded in current tools to support sustainability assessment in ordinary interventions.

4.3. Limitations and Early Recommendations for Future Studies

The multisource nature of the proposed investigation poses some limitations for the chance to connect well-defined theoretical concepts and systems with less-developed indicators regarding the assessment tools in real market practice. This is not related to the availability of indicators but rather to the data to which these indicators refer, which are usually derived from technical sheets or documentation held by manufacturers or building companies without a standardized process; such a compulsory process should be adopted as a common shared protocol. This generally affects the comparability of information sets coming from the market side and makes more difficult the evaluation of the solutions within the range of indicators typically embedded in rating systems (which usually assign a scoring depending on the assessor's capacity to find and interpret the information). Thus, the main risk managed during the investigation was to match well-defined but general concepts, targets, and indicators from the theoretical side with more specific but often project-driven information from the practical tools. To reduce this risk and keep the investigation and matching process as rigorous as possible, the consolidated PRISMA approach was adopted to conduct a systematic analysis and record collection. The quality of the original data used to fill the documentation for scoring purposes in the rating system might represent a bias and a structural limitation, which reflect the limited level of maturity from the market perspective in considering the circular transition an opportunity rather than a mere administrative obligation. At least at the national level, this represents a relevant bottleneck in fostering CE adoption.

As arguable in Table 3, "Papers highly relevant to CE tools and indicators" might be influenced by specific project aim and objectives while the group referred to "Papers highly relevant to CE policies" presents a very limited risk in this direction, being largely retrieved from review papers or policy reviews where sources come from wider and more reliable datasets. The aim of the study presented in this article was to lay the groundwork for the CE Task Force within the BETTERPOLICY project to report on the barriers and drivers for the uptake of circularity in construction, and then to formulate, in line with the overall project findings, a set of recommendations to stimulate the integration of life cycle-oriented tools and strategies into national policies. So far, the findings have confirmed the initial assumptions that there is a gap between policy frameworks and operational tools, and initial suggestions have been discussed as to what directions should be taken to overcome such a gap. However, insights on how to advance the systematic implementation of circularity in the construction sector can already be mentioned.

In particular, there is a promising area, dealing with digitalization, which is under urgent development at the national level. According to the findings discussed so far, digitalization of waste management appears already advanced in terms of implementation, as well as green demolition workflow, but there is still the need to connect (waste) material workflow to an effective matchmaking platform. This would be extremely useful to ease the selection of the most appropriate materials, products, and solutions for meeting the CAM obligation according to a truly sustainable (circular) design and construction approaches. Disparity in CE uptake in different regions proves the need for a more coordinated effort at the national level to provide, for instance, a common platform on materials which, working as an inventory, would speed up and facilitate the selection of the management process, while offering a clear and transparent understanding of what products come from reuse, as well as their potential for future reuse.

The upgrade of digital processes and digital skills of practitioners represents essential components for a strategic national pathway to circular constructions.

Further insights can be gained from setting up roundtables and workshops with both policymakers and practitioners to verify whether the above drivers and barriers are also perceived by them and, if so, how easily they think they can be implemented or overcome.

5. Conclusions

Overall, it emerges that policies to support the circular shift in constructions still have serious gaps. Notably, voluntary tools for sustainability assessment are already more advanced to this end, but as long as they are not mandatory, their potential remains untapped. Nevertheless, room for improvement in this second investigated field is also detected as a result of a gap analysis in the literature; indeed, tools tend to support and assess CE areas which are still quite well established—such as recycled materials—but often fail to consider the whole life cycle of buildings and impacts beyond the project itself (e.g., actual recycling of materials). Thus, a series of interconnected recommendations is presented below.

Firstly, the sectoral approach that features most policies and measures must be replaced by a strongly systemic approach, with CE being cross-sectoral by definition. Accordingly, it is key to adopt an integrated policy mix instead of several policies working on their own.

Also, the targets of these policies should be refined; it is indeed no longer sufficient to focus on using recycled materials in buildings. Rather, more innovative and comprehensive strategies should be emphasized, from those pertaining to the early design stage (e.g., design for disassembly) to those related with the end of life of materials and components (e.g., selective demolition, material banks and urban mining hubs). Policies must also carefully address procedures and mechanisms related to the latter, in order to ensure that closed loops work effectively. Tools' weighting criteria should be refined accordingly to assign more relevance to these "new", albeit more complex, practices.

Moreover, policies should be more stakeholder-centered rather than resource-driven, as the engagement of construction players is fundamental to ensure that CE practices are implemented.

Concerning the tool side, some room for improvement is also detected in this domain, as current tools and procedures might be difficult to implement in "ordinary" projects; for this purpose, digitalization is considered a powerful means to support the adoption of circular practices in the built environment, but its impact has not been evaluated yet. Thus, it is important to carefully evaluate its benefits and success factors before integrating it within CE-related tools and practices. Otherwise, risks might occur, making it simply more demanding for stakeholders without bringing effective benefits.

Overall, pilot actions by the municipalities are encouraged to show potentialities and paybacks of CE constructions and cities, as well as to help fill the considerable knowledge gap in the field. In this regard, it is highly recommended that political frameworks and tools that are publicly driven assume best practices and "more comprehensive and systemic" tools such as GBRSs as references, rather than encouraging the assessment of CE in construction through a sectoral system.

Finally, a promising approach to promote the adoption of CE practices and approaches in building design and construction is seen in the spill-over of the above instruments from private to public standards. For example, it is worth following the DGNB reward mechanism, which gives bonus points to those projects that include CE practices in other assessment categories of the building. Accordingly, national standards, such as the Italian CAM analyzed here, could adopt the same cross-sectoral reward mechanism to steer circularity in the public sector, piloting best practices to showcase the potential and benefits of CE.

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