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A systemic framework to categorize Circular Economy interventions: An application to the construction and demolition sector

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ABSTRACT

The Circular Economy (CE) concept has recently gained momentum as a perspective to tackle global challenges such as resource scarcity and waste management. Multiple types of interventions have been proposed to support the transition towards a CE. This paper aims to (i) categorize CE interventions; (ii) analyze to what extent these intervention categories are considered when assessing CE interventions in a specific sector (Construction and Demolition; C&D); (iii) suggest indicators for the improvement of CE assessment tools in the context of a CE transition in the C&D sector. Through a literature review and expert interviews, we developed a systemic framework that categorizes CE interventions into four groups: Research and Realize, Implement, Support, and Enable, each considering the so-called 10R-strategies established in the CE field. To understand the relevance of these intervention categories in the C&D sector, we analyzed nine indicator sets (252 indicators) used for assessing circular interventions. The results show that the category of implementation of the R-strategies receives the greatest attention. However, though marginally, some assessments also consider those significant interventions that were categorized as Research and Realize, Enable, and Support. We argue that future assessments should incorporate these interventions, to encourage a systemic approach towards a CE transition. Independently from the sector analyzed, the framework can support actors involved in a CE transition, linking their contributions to the different categories of interventions and R-strategies, with a satisfactory balance of complexity and ease of application.

1. Introduction

1.1. The Circular Economy concept

In recent years, the Circular Economy (CE) concept has gained momentum as a perspective to tackle major global problems such as resource scarcity and waste management (Reike et al., 2018). It is seen as an alternative to the traditional linear economic model, contributing to environmental sustainability. CE is often conceptualized as an umbrella term (Blomsma and Brennan, 2017), encompassing both preventive strategies (e.g., functional replacement and dematerialization) and life extension of resources (e.g., reuse, recycling, repair). Most definitions of the CE are based upon the definition proposed by the Ellen MacArthur Foundation (EMF, 2013), according to which a CE is a system "*that is restorative or regenerative by intention and design*". In a CE system, "*products and services are traded in closed loops or 'cycles' and material flows are recirculated at high rates*" (Kraaijenhagen et al., 2016). One definition that has recently gained traction is from the work of Kirchherr et al. (2017), wherein "*a circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations*". Many iterations of the existing definitions will likely be further developed in the upcoming years, as we are now in a "*validity challenge period*" (Blomsma and Brennan, 2017 p.610), where "*theoretical or paradigmatic clarity regarding the CE concept has yet to emerge*".

In the beginning, CE focused on the implementation of only a few circular practices: the so-called 3R-strategies (*Reduce, Reuse, Recycle*; Schulz et al., 2019). Recently, multiple authors have stressed the importance of considering up to 10R-strategies (*R0 Refuse/Rethink, R1 Reduce, R2 Resell/reuse, R3 Repair, R4 Refurbish, R5 Remanufacture, R6 Repurpose, R7 Recycle, R8 Recover,* and *R9 Re-mine*; Reike et al., 2018).

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Building upon the Lansink's Ladder – a hierarchy for waste management (Lansink, 1979) – these strategies are ordered by priority depending on their level of circularity (*R0* being the highest circularity level). For example, smarter product manufacturing and use are typically preferred over the extension of the lifespan of products and their parts, which is preferred over recovery and recycling of materials.

To give structure to the different R-strategies and elicit their interconnectedness, several scholars have proposed frameworks to guide involved actors in their transition towards a CE, such as the well-known Circular Economy Butterfly diagram (EMF, 2013). Similar frameworks exist (Cheshire, 2016; Circulareconomylab, 2020; EC, 2018; EIT Raw-Materials, 2020; Elia et al., 2017; Guzzo et al., 2019; Potting and Hanemaaijer (eds), 2018, to cite a few). However, two main shortcomings can be identified in the current literature on CE frameworks[1].

- First, some of the CE frameworks fail to consider the plurality of circular strategies that can be implemented. In fact, the CE is most commonly represented as a combination of the 3Rs, and the use of the 10R-strategy scheme is far from being established (Bressanelli et al., 2020; Ghaffar et al., 2020), in a time where it should be highlighted that a CE requires a systemic shift (Kirchherr et al., 2017). Therefore, all the possible R-strategies should receive adequate attention, as the three most established R-strategies are just one part of the puzzle (Aceleanu et al., 2019).
- Second, to enable the implementation of the R-strategies, different interventions should be put in place, such as education, research, awareness campaigns, and financial support, to mention a few (Boons and Lüdeke-Freund, 2013; Ghaffar et al., 2020; Mendoza et al., 2019; Saidani et al., 2019). To date, these types of interventions are underrepresented in most of the frameworks focused on CE interventions. This lack of attention might hinder the transition process, as the efforts needed to support the implementation of the R-strategies are not holistically recognized, assessed, or tracked. Those efforts might come from stakeholders such as researchers, policymakers, and members of NGOs. Since their potential contribution (e.g., conducting research and development, enforcing laws, raising awareness among customers) does not find a place in the available frameworks, it might be challenging to identify and coordinate their roles.

As a consequence of the second shortcoming, criticisms have also been raised against the published circularity indicators, highlighting their failure in presenting the systemic and multidisciplinary nature of a CE (Saidani et al., 2017). Ideally, following the framework within which they have been conceived, circularity indicators should inform as to how well the CE principles are applied to a product, a service, or a system. However, the current indicators are deemed to have only a narrow focus on the measurement of how closed the material cycles are (Corona et al., 2019). Also, the considerable number of indicators used to assess circularity that are *"popping up across sectors and geographies has created an environment of competing and often conflicting indications of actual circularity progress achieved*" (WBCSD and Climate-KIC, 2018, p.2). A research gap exists in understanding to what degree these criticisms are valid, especially when several indicator sets are used to assess the same concept, such as circularity in a specific economic sector.

1.2. Aim and structure

The goals of this paper are (i) to develop a systemic framework that comprises and categorizes interventions that could be put into practice to achieve a CE; (ii) to apply the framework to a specific sector (Construction and Demolition; C&D sector), in order to understand the extent to which the intervention categories of the framework are considered when assessing interventions for a CE in the selected sector; (iii) to suggest indicators to have more comprehensive CE assessment tools in the selected sector, specifically considering underrepresented categories of interventions.

The remainder of this paper is organized as follows: Section 1.3 introduces in detail the concept of a CE in the selected (C&D) sector. Section 2 presents the conceptual approach, the data used, and methods applied. Section 3 summarizes the results. Section 4 discusses the results. Section 5 presents our conclusions, acknowledges the limitations of the research, and proposes ideas for further investigation.

1.3. A CE in the construction and demolition sector

Transitioning towards a CE requires a holistic and global vision (Palafox-Alcantar et al., 2020). Nevertheless, sectoral economic approaches are essential for initiating discussions and implementing real actions. In the European context, the European Commission (EC, 2015) developed a package in 2015 to support the European Union's transition to a CE by adopting an action plan to enhance global competitiveness, stimulate sustainable economic growth, and generate new jobs. In the updated plan (EC, 2020), the EC identified seven key product value chains as priorities for accelerating the transition towards a higher degree of circularity. These are: (i) electronics and Information and Communications Technologies (ICT), (ii) batteries and vehicles, (iii) packaging, (iv) plastics, (v) textiles, (vi) construction and buildings, (vii) food, water, and nutrients.

The C&D sector is crucial for consideration, as it produces the highest amount of waste compared with other economic activities worldwide. In fact, it accounts for approximately 35% of the total waste generated in the European Union (Eurostat, 2016). From a CE perspective, considerable potential exists within the C&D sector, as it is still characterized by a linear economic model, founded upon the "take, make, dispose" principle (EMF et al., 2015; Stephan and Athanassiadis, 2018). Upon demolition, the building products often cannot be disassembled, reused, or recycled. Once obsolete, they are discarded and mostly end up in landfills (Cheshire, 2016). Actions to make the C&D sector more circular include not just recycling, but also: (i) implementing strategies aimed at reducing greenhouse gas emissions, (ii) operationalizing processes that minimize resource depletion (Hodge et al., 2010; Orsini and Marrone, 2019; Sieffert et al., 2014), (iii) avoiding the use of toxic materials (Fatta et al., 2003), and (iv) diverting waste from landfilling, as landfill capacity is becoming limited (Duran et al., 2006).

Achieving a CE in the C&D sector is a complex challenge as several barriers must be considered. Mahpour (2018) identified 22 barriers that hinder the transformation from a linear economy to a CE in the C&D sector. These barriers include technical issues, but also inadequate policies and legal frameworks for the management of C&D waste, insufficient awareness, absence of a common and clear understanding of the CE in C&D waste management, and a lack of funding to implement the CE. Additionally, to overcome transition barriers in this sector, it would be necessary to design effective CE models, reinforce the control of the source of the materials, enhance supervision and management, adopt innovative technologies and market models, and offer economic incentives (Huang et al., 2018).

Based on an analysis of the scientific literature, it appears that a comprehensive evaluation considering multiple dimensions (e.g., design, environmental, social, economic, technological, policy dimension, etc.) is mostly absent (Hossain et al., 2020). Recent CE agendas focus predominantly on the supply chain of materials (Akinade and Oyedele, 2019) and the recovery of construction materials for direct reuse (Pan et al., 2015). Therefore, it appears clear that a holistic approach, conceptualized through a framework, is needed. This framework should target many interconnected aspects, including awareness, legal frameworks, and funding schemes, and should leverage an interdisciplinary approach (Pomponi and Moncaster, 2017). Academic contributions such as the present one are key to putting forward a research

[1] A broader discussion of CE frameworks is presented in section 3.1.

agenda that can support practitioners and society to establish shared goals and coordinate action towards a well-orchestrated CE transition.

2. Material and methods

2.1. Conceptual approach

The current scientific literature on CE stresses the importance of establishing a reference framework that enables the systemic assessment of a CE (Foster, 2020; Meherishi et al., 2019; Schulz et al., 2019). However, the way the term "framework" is used in the literature is often confusing, especially when the authors overlook the definition and interpretation of what a framework is. In our work, we refer to a framework as a conceptual scheme used to classify interventions that can stimulate the transition toward a CE.

In regard to interventions for a CE, we use a broad definition of the term "intervention" throughout our discussion, based on the Cambridge dictionary[2], where it refers to "involvement in a difficult situation in order to improve it or prevent it from getting worse". We refer to "interventions" as all types of activities that relate to the R-strategies, e.g., research on recycling, organizations of workshops on reuse, academic courses on remanufacturing, subsidies for recycling, and so on.

In order to operationalize a framework and move to the practical step of an assessment, indicators play a pivotal role (Alaerts et al., 2019; Geng et al., 2012; Su et al., 2013). As explained by Waas et al. (2014), an indicator is "*the operational representation of an attribute (quality, characteristic, property) of a given system, by a quantitative or qualitative variable (for example numbers, graphics, colors, symbols) (or function of variables), including its value, related to a reference value*". The reference value can be a goal, a target, a norm, a standard, or a benchmark (Gallopin, 1997). Several different objectives might be pursued when using indicators, ranging from decision-making and management support tools, advocacy and communication, participation and consensus building, to research and analysis (Morse, 2015; Parris and Kates, 2003).

In the related literature, indicators have mostly been used as "data carriers", disconnected from the context in which they were developed and the intention of the assessor. In this work, we align with current streams of research in which indicators play a role as "information" or "message carriers" (Lehtonen et al., 2016), communicating arguments, ideas, and expectations of the assessment tool developers (Merino-Saum et al., 2020). Even though the variety of indicators mentioned in section 1.1 may represent an issue when comparing circularity assessments, this diversity allows for informed insights on the different perspectives on a CE and its operationalization. We looked at the indicators as a proxy for the interventions that the developers of each indicator set were aiming to assess. Following this logic, developers' selection of specific indicators may indicate their interest in assessing particular CE interventions.

2.2. Research flow

We conducted our research in six main steps (Fig. 1). Throughout these steps, we adopted a mixed-method approach that derived insights from both qualitative and quantitative, primary and secondary data.

Step 1. We analyzed the strengths and weaknesses of how current frameworks categorize CE interventions. To do so, we performed a literature review of frameworks related to CE interventions. We searched for different combinations of keywords in the title and abstract using the Scopus database[3]. We restricted the results to the English language and peer-reviewed documents, obtaining 242 results. We shortlisted those documents proposing or discussing frameworks related to interventions for a CE (18 documents were retained). A review of the grey literature led to the addition of the ReSOLVE framework (EMF et al., 2015), as it is an intervention framework developed by the most cited institution in the CE field, which is the inspiration behind the majority of CE conceptualizations. The shortlisted nineteen documents are available in Table S.1 (Supplementary material).

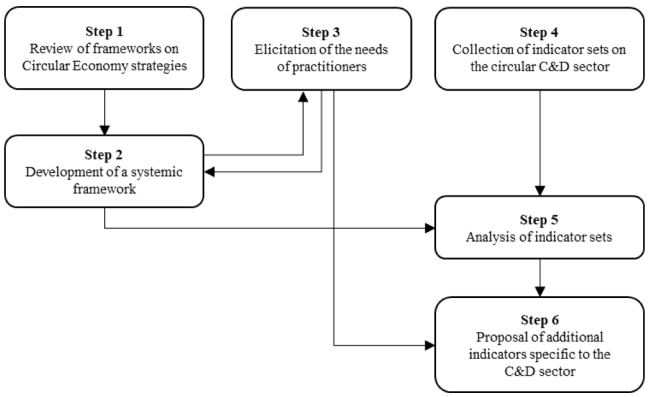

Fig. 1. Steps of the research project.

Step 2. Based on the literature review of frameworks performed in the first step, we developed a new systemic framework for categorizing CE interventions, applicable to any economic sector. The framework was developed by triangulating the information retrieved from the literature review and the insights provided by the experts interviewed (step 3). Similar examples of this process can be found in the literature, where gaps are first identified, and then new frameworks are developed (e.g. Dhir et al., 2020; Govindan et al., 2021; Millette et al., 2020). We grouped interventions into a parsimonious yet comprehensive number of clusters, challenging its consistency with the interviewed experts.

Step 3. We conducted six expert interviews pursuing three main objectives: (i) to gain insights on the challenges faced for the implementation of a CE, (ii) to iterate the systemic framework, and (iii) to propose additional indicators, specifically within the C&D sector, that have not yet been considered by indicator sets developers. The experts were selected because of their involvement in activities linked to the CE in Switzerland. Four of the experts worked specifically in the C&D sector, while the others worked on transversal projects encompassing multiple sectors. The experts were approached via the researchers' professional network. The interviews were conducted in-person or over the phone and lasted approximately one hour. Further details on the interviewees are provided in Table S.2 (Supplementary material). We transcribed the interviews and analyzed the content through an inductive approach, eliciting the different perspectives of the experts.

Step 4. Indicator sets assessing a CE in the C&D sector were identified through the research in the academic literature and the grey literature. These indicator sets represented the sample to perform our analysis aimed at: (i) testing the validity of the developed framework, i.e., if the categories of the framework were able to cover all the indicators used to assess a CE in a specific (C&D) sector; (ii) understanding the weight (in terms of the number of indicators) given to the different categories of the framework within the

[2] Available at: https://dictionary.cambridge.org/dictionary/english/intervention

[3] The search was performed and updated in October 2019. Keywords: "circular economy" AND ("framework" OR "taxonomy" OR "indicator*") AND ("strateg*" OR "action*" OR "intervention*")

Table 1
Indicator sets that form the sample of this study.

Indicator set identifier	Authors	Author typology	Year	# of indicators	Focus & authors' grouping of indicators
A	Núñez-Cacho et al.	Academia	2018a	15	Measuring circularity thinking in a construction company. 3 levels: Organizational, Process, Workgroup levels
B	Yi and Liu	Academia	2016	12	CE in construction enterprises. 3 categories: resources and benefits, resource recycling, and resource output
C	Nuñez-Cacho et al.	Academia	2018b	44	Measuring CE in the construction sector. 6 dimensions: transition to CE, material management, energy, water management, 3 Rs: Reduce-Reuse- Recycle, Emissions generated, Waste management
D	Gravagnuolo et al.	Academia	2019	17	Screening of circular economy actions in emerging circular cities. 10 categories
E	Potting and Hanemaaijer	Government	2018	41	Monitoring the progress of the CE in general, and also for the C&D sector. Effect indicators, Indicators for transition dynamics monitoring for circularity initiatives
F	Allen et al.	Government	2017	14	Applying CE principles to the built environment sector. Project phases
G	Circle Economy et al.	Organization	2018	64	General framework for circular building. 7 categories: Materials, Energy, Water, Biodiversity and ecosystems, human culture and society, health and wellbeing, multiple forms of value
H	Supply chain sustainability school	Organization	NA	18	Indicators for the construction industry in order to monitor and report on their progress towards the CE. Core sustainability indicators, metrics to calculate core sustainability indicators, supplementary indicators, commercial information
I	Madaster	Organization	2018	27	Improve circularity-oriented building design. 3 different phases: construction, use, End-of-Life; Other sustainability indicators are used, related to: energy, water, environmental footprint, carbon footprint, and other risks

different indicator sets. For academic contributions, indicator sets were obtained through a Scopus internet search. For inputs from practitioners, we used the search engine Google.com[4]. An overview of the indicator sets that formed our sample is depicted in Table 1. We obtained and analyzed the indicators from four academic papers, two governmental reports, and three organizational reports. Set A, B, C, D were developed by academics; set E and F by governmental organizations; sets G, H, I by other types of organizations. Since we were focusing on a CE in the C&D sector considering multiple levels of assessment (macro, meso, micro), the indicator sets retrieved referred to several levels at which a CE can be implemented in the C&D sector. The number of indicators per set varied from 12 to 64, with an average of 28 indicators per set (252 in total).

Step 5. Each indicator was linked to only one category of the framework (operationalization of the framework). This was a key step: we would have needed to reconsider the framework itself, if we could not link each indicator to one of the framework categories. Two researchers independently linked each indicator to one intervention category. Then we computed an inter-rater reliability score to check for the level of agreement between the two assessments made separately by the researchers. In case of disagreements, the indicators were discussed until agreed upon, following a similar strategy to the one implemented by other researchers dealing with the categorization of indicators (e.g., Ahvenniemi et al., 2017; Merino-Saum et al., 2018; Moraga et al., 2019; Saidani et al., 2019). We calculated the extent to which the nine indicator sets cover, on average, the categories of the framework. To obtain these values, we computed, for each category, the average coverage of the category based on the nine indicator sets. As a guideline on how the link between indicators and categories was made, we report in Table S.3 (Supplementary material) the allocation of categories for each indicator of the indicator set "E" as an example. We performed the Pearson's Chi-Square test of independence to test if there were significant differences in the coverage of each category of the framework across the sets. However, since the Chi-Square is an omnibus test, it shows a significant difference if at least one value significantly deviates from the expected value. In order to know precisely which sets covered which of the framework's categories in a significantly different way than the average, we performed a post-hoc Chi-Square test. To obtain a comparable overview of the weight given to each category of the framework by the indicator sets, we divided the number of indicators covering each category by the total number of indicators in that specific set. We then computed the average coverage of each category (across the nine indicator sets) to obtain an overall average coverage of the categories within our sample.

Step 6. We proposed additional indicators specifically for what concerns the C&D sector. These suggestions were based on the gaps that we identified in the literature review, and on the suggestions provided by the experts that we interviewed. The additional indicators suggested relate to the interventions that we found underrepresented in the indicator sets analyzed in step 5.

3. Results

3.1. Literature review of frameworks

The nineteen documents shortlisted through the literature review can be divided into two clusters. Most papers (twelve) focus on business models for a CE, while the seven remaining documents conceptualize the CE strategies more systematically. In these seven shortlisted papers the authors attempted to develop a conceptualization that categorizes the different kinds of interventions that can support the transition to a CE.

For example, Hopff et al. (2019) developed a framework to understand the various dimensions and scales of campus operations, and how to implement circular principles in campus development. Despite the narrow scope (the campus), the developed framework went beyond the sole analysis of the implementation of R-strategies. It gave space to the strategic level, which focuses on setting goals and policies, the tactical level (where processes are set up and the realization of goals is steered), and, finally, the operational level, where goals are achieved. Guzzo et al. (2019) identified practices (methods) for the operationalization of R-strategies; they expanded the discussion to the importance of considering different perspectives (conceptual, strategic, and practical) for bridging the conceptual and practical phases in circular innovation. Lieder and Rashid (2016) proposed a CE implementation strategy whose feasibility relates to legislation and policy, support infrastructure, social awareness, collaborative business models, product design, supply chain, and information and communication technology. Prendeville et al. (2018), who built on the ReSOLVE framework (EMF et al., 2015), developed a circular city policy intervention typology: a matrix connecting circular city principles (e.g., "regenerate", "share", "optimize") and different strategies (e.g., "knowledge development", "collaboration

[4] The search was performed in April 2019. Keywords: "indicator*" AND "circular" AND ("construction" OR "building")

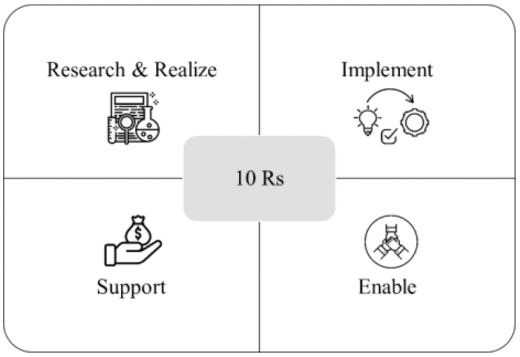

Fig. 2. The RISE framework.

platforms", "business support schemes").

Through our review, we also noted an emphasis on the importance of the role of different actors in a CE (e.g., government, start-up incubators, researchers), not just those directly producing, consuming or recycling products. For instance, Pinheiro et al. (2019) proposed an integrative framework and mentioned the role of different stakeholders (customers, government, and legislation) as key drivers for a CE. However, we found that the frameworks do not explicitly and sufficiently highlight that the CE (i) requires a systemic shift, (ii) needs to include the collaboration, partnership, and involvement of several stakeholders (academics, professionals, businesses, government bodies), and (iii) necessitates societal and behavior changes. While sporadically mentioned in the analyzed frameworks, these aspects are not explicitly outlined within any of the frameworks analyzed.

Among the contributions analyzed, we based the development of our framework mainly on the work of Prendeville et al. (2018), as we found it to be one of the most overarching and structured frameworks currently available. However, we found that the six circular city principles were not completely aligned with the 10R-strategies, and that no type of interventions was including the mere implementation of the strategies. As we will present in Section 3.3, the newly developed framework makes explicit all of the core categories of interventions.

3.2. Results of interviews

From the expert interviews, we derived three main insights that enriched the findings of the literature review.

- First, when asked about their opinion on some of the frameworks currently used for a CE (i.e., Cheshire, 2016; Potting and Hanemaaijer (eds), 2018), interviewees stressed the importance of considering additional strategies as opposed to settling on the most-cited 3R-strategies (*Reduce, Reuse, and Recycle*). While these latter strategies are relevant, all interviewees stressed the importance of a shift in mentality, starting with *Refuse*, which is required to rethink and enable the transition towards a CE. Also, *Recycling* should be seen as a short-term solution, possibly substituted by other strategies that could better maintain the value of the product/service. This mentality shift requires both a social aspect and awareness, which are primordial for behavioral change and, therefore, for the transition. However, these are often missing in the frameworks cited above, in which most emphasis is on *what* needs to be done to achieve a CE, rather than *how* this should be done. A more systemic view on the CE is therefore required.
- Second, the interviewees commented on specific aspects that the frameworks did not include. Economic factors, such as financial support, taxes, trade, and industry collaboration, should be included. The interviewees also shared that aspects such as regulation, research, and increased awareness of all actors on the CE were omitted, only implicitly stated, or taken for granted. In fact, the experts stressed the importance of legal aspects and requirements, government support, and public awareness for behavioral change for the transition towards a CE, which are missing in the available frameworks.
- Third, a key insight was the need for all actors to link their activities to a specific dimension of the CE, to find their place in the efforts made towards implementing a CE. The available frameworks do not make the role of these actors explicit, giving the impression that their contribution might only be marginal. A CE transition requires recognized and orchestrated efforts by all actors in a CE.

The triangulation of the literature review results with the insights from the interviews allowed us to develop and iterate a new framework, which we elaborate on in the following section.

3.3. The RISE framework

The RISE framework (Fig. 2) depicts four categories of interventions: (i) "Research and Realize", (ii) "Implement", (iii) "Support", and (iv) "Enable". All categories are in reference to the 10R-strategies. We extensively elaborate on issues related to the number and coverage of the four categories in the discussion Section 4.1.

The category "Research and Realize" aims at capturing the act of research by professionals and academics, who conceptualize a CE and guide its implementation. This act is often omitted from CE frameworks (Inigo and Blok, 2019). Researchers and professionals share and disseminate their knowledge of CE by publishing the outcome of their work. By organizing talks, discussions, and workshops, they encourage other stakeholders to undergo a CE transition. Research is incorporated into our framework since it is an engine for advancing technologies that can make our systems circular (Geng et al., 2012). Additionally, Lakatos et al. (2016) highlight how the roles and importance of non-economic actors, such as NGOs, in raising awareness among consumers and society at large are often neglected. Finally, educational development and reinforcement are essential components that need to be considered when conceptualizing relevant interventions for improving the circularity of our systems (Buil et al., 2017; Kirchherr and Piscicelli, 2019). We include all these concepts into the notion of "Research and Realize".

The category "Implement" covers the application of the R-strategies, i.e., applying, deploying, or executing CE strategies that specifically deal with the CE's technical, material and biological aspects. The implementation of the R-strategies is what the majority of the frameworks incorporate well. It is undoubtedly a key component of a framework envisioned to categorize all types of interventions that move society towards a CE. By definition, implementation refers to "*the act of starting to use a plan or system*" (Cambridge Dictionary[5]). The primary purpose of this effective execution is to achieve the sole aim of the R-strategy considered. For instance, installing a recycling machine in a factory relates to the execution of an action within a project associated with the *Recycle* strategy.

The category "Support" encompasses the actions of organizations and governmental, local, and regional authorities, whose role is pivotal in promoting and advancing the transition towards a CE (Alaerts et al., 2019). De Jesus and Mendonça (2018) explain how, in the scientific literature, "soft" institutional and regulatory drivers are often cited as factors facilitating a CE. Public policy measures (e.g., legal frameworks, taxes, incentives) addressing market failures are emphasized. These are typically national policy interventions aimed at creating fiscal incentives for a CE. Other kinds of "Support" include infrastructure and green or public procurement for a CE (Bag et al., 2020). The provision of subsidies, research grants, and funds to promote and implement circular projects is also considered a means of "Support". Jobs and employment,

[5] Available at: https://dictionary.cambridge.org/dictionary/english/implementation

Table 2
Interventions comprised in each category of the RISE framework.

Categories of the framework	Examples of interventions:
Research & Realize	Research and awareness, knowledge development and expansion, talks, discussions, workshops, education, community and social involvement
Implement	Assessment of materials and energy flows and their quantities, footprints (carbon, water, etc.), waste quantities and quality, structures, design, and the process or building model itself
Support	Financial incentives, funding, subsidies, taxes, quotas, public procurement, employment and human capital
Enable	Application of laws, directives and regulations – technologies, material passports, information sharing systems and tools, documentation practices, collaboration and partnerships among actors

human capital, trade flows, as well as the incorporation of CE principles in tenders, quotas, tariffs, and taxes are also acknowledged as means of "Support".

Finally, the category "Enable" aims at capturing initiatives and projects that enable the transition towards a CE and which were found to be relevant to include in a framework for assessing the different interventions leading to a CE (Patricio et al., 2018; Prendeville et al., 2018; Veleva and Bodkin, 2018). Enablers considered are bottom-up and social initiatives that organizations, businesses, or civil society could run. These could include collaboration platforms and networks, and entrepreneurial activities and projects, aimed at expanding knowledge and providing businesses or partners with the right tools to implement circularity. Other enabling interventions are start-up accelerators and CE incubators, social movements, CE business model advisory support schemes, the deployment of tools such as documentation and tracking schemes, and innovative technologies such as Building Information Modelling and Material Passports (if the C&D is considered). CE directives, regulations, and laws also contribute as enablers towards a CE (e.g., banning toxic materials or imposing the use of recycled ones).

To further explain the interventions that each category could cover, some examples are provided in Table 2.

3.4. Analysis of the indicators

Fig. 3 shows the extent to which the nine indicator sets cover, on average, the four categories of the RISE framework. The results show that, on average, 70% of the indicators reported in the indicator sets in our sample are used by the indicator sets' developers to assess interventions related to the "Implement" category. These indicators measure, for instance, how much waste is being recycled, reused, or avoided. Interestingly, these indicator sets are not limited to include only the topic of waste. Topics such as water usage, greenhouse gas emissions, and energy consumption are also included in the assessments. Also, the results show that other categories of interventions are assessed, which we have categorized as "Research and Realize", "Support", and "Enable".

Fig. 4 shows how each of the indicator sets of our sample covers the four RISE categories. Pearson's Chi-Square test of independence shows that the indicator sets are significantly different from each other[6]. The results of the post-hoc Chi-Square test[7] show that Set A covers the "Implement" and "Enable" categories in a significantly different way than the average percentage of coverage of each RISE category. While there is less focus on the "Implement" category, more focus is given to the "Enable" category. Set E is significantly different from the average values for the categories "Research & Realize", "Implement", and "Support". In this set, each of the four categories of the RISE framework exceptionally receives almost the same share of attention. Set G gives more attention to the "Enable" category. Finally, set I only focuses on the "Implement" category, even more predominantly than anticipated by its size (27 indicators).

Based on the literature review and the insights derived through the interviews of experts, we proposed potential indicators related to the RISE framework, and specifically for the C&D sector (Table 3). We focused on suggesting indicators that could assess the CE interventions that receive less attention by indicator set developers. We did not propose additional indicators covering the "Implement" category, as most indicators retrieved from literature and analyzed were already implicated in the assessment of this category. The proposed indicators relate to (i) "Research and Realize" (e.g., number of publications, patents, number of talks, discussions, exhibitions related to CE), (ii) "Support" (e.g., Taxes on landfilling), and "Enable" (e.g., Reverse logistics and take-back schemes set in place). These indicators do not represent a list to be used as an assessment framework, but rather serve as a suggestion for fine-tuning those frameworks demanding a more balanced assessment approach. As we will further discuss in Section 4.2, this list is a starting point for evaluating additional indicators that could be integrated into future measurement tools.

4. Discussion

The goals of the research were (i) to develop a systemic framework that comprises and categorizes possible interventions that could be put into practice to achieve a CE; (ii) to understand to what extent the intervention categories of the framework are taken into consideration when different indicator set developers assess interventions for a CE in the C&D sector; iii) to suggest indicators for the improvement of the CE assessment tools and to make recommendations for indicator set developers.

Our discussion focuses on (i) the contextualization of the results in relation to the current scientific literature, (ii) the proposal of potential applications of the framework, and (iii) the scientific and practical contribution of our work.

4.1. Contextualizing the results

We aligned our approach for developing the framework with the proposition of Prendeville et al. (2018), maintaining a specific separation between what we refer to as "Enable" and "Support" categories of interventions. In our framework, the "Enable" category includes the groups of "Collaborative platforms", "Regulatory frameworks", and "Bottom-up initiatives" reported by the *Circular city project map*. Moreover, our category "Support" covers the group of "Business support schemes" and "Procurement and infrastructure". Finally, the category "Research and realize" comprises the group "Knowledge development" of the *Circular city project map*. For this specific category, we clarify our focus on both knowledge production and dissemination, adding the word "Realize". Behavior change is undoubtedly needed for a CE transition (Parajuly et al., 2020). Nevertheless, awareness itself is an indispensable precondition: social awareness is crucial for a successful transition from a linear to a CE as customers are an integral part of a CE (Lieder and Rashid, 2016). However, customers are not the only

[6] The hypothesis that the sets similarly cover the four categories of the RISE framework is rejected (χ^2 (24, N=252) = 148.16, $p<0.05$).

[7] Adjusted p level of 0.05 for the post hoc test, therefore $p<0.0014$.

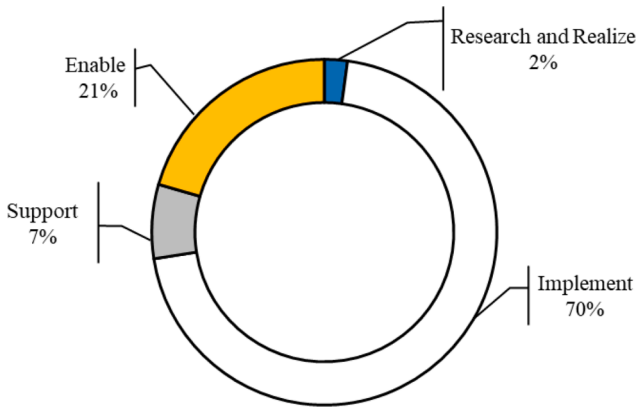

Fig. 3. Average coverage of the RISE categories.

concerned actors. In our work, we highlight the importance of awareness among all involved actors. Policymakers, for example, have the power to change laws and pave the way for a CE transition.

Our conceptual exercise showed the possibility of linking each of the indicators in our sample to one of the four RISE categories. This is in line with the recommendations of authors who have highlighted the importance of developing a clear and straightforward assessment framework, to ensure ease of applicability, both in the context of a CE assessment or a sustainability assessment in general (Sala et al., 2015). This relates to the benefits of offering tools developed in an academic context for the use of practitioners and of the general public. In fact, creating tools that are too theoretical, abstract, complex, or impossible to operationalize hinders the usefulness of the research efforts and contributes to the exacerbation of the science-practice gap (Bertuol-Garcia et al., 2018).

The application of the RISE framework in the C&D case showed that, on average, considering the sample of indicator sets analyzed, the greatest attention is given to "Implement" interventions. In some cases, indicator sets developers also use indicators to assess "Research and Realize", "Enable", and "Support" interventions. In addition, when comparing individual indicator sets of our sample, we found a significant difference in the coverage of the four RISE categories of interventions. No real patterns were identified that could explain the different coverage of the categories by the indicator sets (i.e., the type of developer - academics, governments, organizations – was insufficient to explain this variation). The difference could be motivated by a diverse conceptualization of a CE in the C&D sector depending on the developers of the indicator sets.

Overall, comprehensive studies which include a systemic approach, methodological issues, indicators, and frameworks are minimal, and they focus mostly on construction waste minimization and recycling (our "Implement" category) (Schraven et al., 2019). The results of our conceptual exercise (linking all the indicators to the four categories of the RISE framework) cannot be directly compared to any other published research as, to our knowledge, ours is the first attempt to operationalize such a framework. As the effective and systemic implementation of a CE in the C&D sector is just beginning (Adams et al., 2017; Leising et al., 2018), we contribute to the development of this more systemic transition by adding three categories other than "Implement" to the possible types of interventions.

4.2. Proposed applications

All actors who can have a role in the transition towards a CE (whether the transition occurs in general or in a specific industry) fall within the target of the RISE framework (e.g., policymakers, researchers, entrepreneurs, NGOs, project founders, start-up incubators). In our work, we specifically looked at which categories of interventions every actor could have agency on. Knowing that the transition to a CE involves a complex network of many actors (Hopff et al., 2019), we consider some actors not always recognized in the established literature (e.g., start-up incubators and networking organizations).

In Table S.4 (Supplementary material), we propose a matrix that allows concerned actors to better position themselves within the framework, by highlighting to which category of the RISE framework and R-strategy their roles and potential agencies might be linked. In doing so, the framework could aid in overcoming some of the existing barriers to the achievement of a CE. In fact, by allowing actors to map their potential contribution according to an established framework, it could serve as a shared communication tool and could foster interaction and partnerships among the actors involved. Overall, the framework could facilitate the discussion on the different roles and agencies of the parties involved in a CE transition, so that no efforts are marginalized but are instead recognized and championed.

Additionally, the framework could be used by policymakers to fulfill two main aims. First, policymakers could map the number and diversity of (local/national) CE actors based on their potential role, assess the currently available resources within the established geographical boundaries, and determine whether additional ones were needed. Second, policymakers could use the framework to categorize planned policy interventions and enhance their overarching coverage, potentially identifying policy elements that were missing for a systemic transition.

Furthermore, the framework could be key when opening calls for applications for CE research or applied projects. The framework and its extension provided in Table S.4 (Supplementary material) could be used as a guiding tool by project founders to categorize the required CE interventions and increase the level of detail of their project description. This clear project description could help the reviewer of the project applications to better understand how the involved applicants could systemically contribute to a CE transition. Furthermore, making agency explicit can support trust among stakeholders and foster collaboration and the transition (Binder et al., 2020). The project applicants could then use the framework and the matrix to show how all the parties involved in the project could take responsibility for specific categories of interventions in order to contribute to synergistically transitioning to a CE.

When developing an indicator set aimed at assessing the circularity of the C&D sector more systematically, the proposed indicators (Table 3) offer a valuable source of inspiration. As Turnheim et al. (2020, p.118) pointed out, "*policymakers may need new skills to deal with a variety of stakeholders (beyond large firms), manage and evaluate experiments (including acknowledging inevitable failures), and monitor progress on multiple dimensions (not just costs). This implies a major opportunity to develop new indicators, evaluation procedures, and assessment tools that can help in governing transitions*". For selecting which indicators to use, additional work is undoubtedly required to verify the feasibility and meaningfulness of collecting relevant data in a specific context (city,

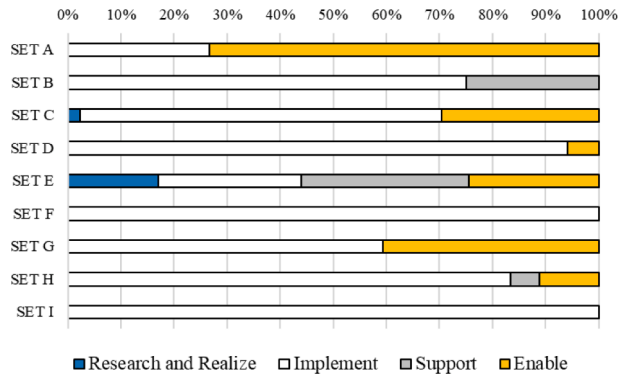

Fig. 4. Different coverage of the RISE categories across the nine indicator sets.

nation, etc.). The social and political characteristics of indicators, as much as their scientific qualities, should be thoroughly considered in terms of how they may support a CE transition, as well as a sustainability transition in general (McCool and Stankey, 2004). The proposed indicators have the twofold potential to challenge the current assessment frameworks and constructively offer ideas for their improvement.

4.3. Scientific and practical contribution

With the development of the RISE framework, we contribute to the mainstream of a holistic approach and to the overall discussion on how to transition towards a CE. We stress how the implementation of CE is tightly related to three ancillary categories of intervention ("Research and Realize", "Support", and "Enable"). We emphasize that each of the four categories ("Research and Realize", "Implement", "Support", and "Enable") can be linked to any of the 10R-strategies, and that strategies of high-circularity level should be prioritized. In fact, the analysis of the interviews highlighted how important strategies such as *Refuse* and *Rethink* are for a successful CE transition.

By analyzing how the circularity of the C&D is assessed through the use of indicators, we offer evidence of the ease of applicability of the RISE framework, which may be used to assess CEinterventions in any economic sector. We put forward an approach that, within a relatively small sample (nine indicator sets), allows for highlighting substantial differences in the way CE is assessed. In this regard, the potential of the developed framework is that it effectively elicits these differences in conceptualizations, highlighting the shortcomings and barriers of current CE frameworks Section 3.

Methodologically, our work contributes to the development of a research approach that uses indicators as units of analysis and assessment, going beyond their role as "data carriers". We identify them instead as "information carriers". We emphasize the value that indicators can have in research, as they mirror different perspectives, conceptualizations, and aims of indicator set developers. With our work, we contribute to this incipient line of research (e.g., Ahvenniemi et al., 2017, Merino-Saum et al., 2020), supporting the refinement of approaches that use indicators as units of analysis.

5. Conclusions

The concept of a CE has rapidly gained momentum and is used by multiple actors to align their plans towards a more sustainable society. However, what a CE exactly entails remains unclear, and actors involved in a CE transition set different priorities based on their capabilities and agendas. A transition towards a CE requires a more holistic approach and a concerted effort from all parties. By developing a systemic framework that comprehensively encompasses the possible interventions that can be put in place to transition towards a CE, this study improves our understanding of a CE in general, and in the C&D sector more specifically.

The RISE framework links interventions related to the "Research and Realize", "Implement", "Support", and "Enable" categories to all the 10R-strategies established in the CE field. The analysis of the interventions assessed in the C&D sector validate the general trend that the "Implement" category is the most assessed category, while indicator sets only partially consider the remaining three categories. We recommend that future indicator set developers conceive more comprehensive indicator sets. The focus of the assessment shall not solely be directed towards the implementation of strategies of low circularity level, but also consider the transition of our economic sectors from a systemic perspective.

We acknowledge some limitations of the research performed. First, the search terms used for the literature review of the frameworks might have reduced the number of results that we could retrieve. Adding terms

Table 3
Indicator suggestions and description, preferred trend, and RISE category of reference.

Indicator suggestions and description	Preferred increase (+) or decrease (-)	RISE categories
Number of Academic Laboratories involved with research on CE (or sustainability in regard to CE) in the C&D sector (e.g., research in buildings design for CE, research on innovative building materials)	+	Research and Realize
Number of academic platforms and panels (i.e., students and researchers sharing the outcome of their work and ideas regarding CE and discussing CE)	+	Research and Realize
Number of exhibitions or projects held concretely demonstrating CE strategies in the built environment (e.g., reuse in building construction, architecture/design with reused elements)	+	Research and Realize
Number of investors/real estate project owners or investments in circular buildings or circular real estate projects	+	Support
Number of philanthropic organizations or foundations funding or donating money in support of circular economy initiatives and implementation (whether through funding research projects, or through the financing of tools or platforms that drive circularity)	+	Support
Taxes on landfilling (amount/ton of waste)	+	Support
Number of green suppliers	+	Support
Number of green deals	+	Support
Number of NGOs, organizations, and associations working on advancing CE (e.g., through, collaborations, platform exchanges)	+	Support
Number of people involved in NGOs, organizations, and associations that aim at advancing CE in the built environment sector	+	Support
Number of partner constructions companies involved with CE projects, who are rethinking their production and business models according to CE principles, and aim the implementation of circularity	+	Enable
Number of different partners from the construction industry/built environment sector brought together, attending, and addressed by CE workshops	+	Enable
Activity or frequency level of products/materials reuse platforms (number of times people visit the platform page, number of times people offer reusable products, number of times architects/designers buy from these reuse platforms).	+	Enable
Number of platform initiatives, ideas/solutions/tools devised and established to further promote circularity and facilitate collaboration among the construction industry stakeholder	+	Enable
Number of leadership development programs set in place to raise greater awareness among individuals involved with the construction process and develop individuals (in relation to CE)	+	Enable
Number of online social collaboration platforms that bring together CE organizations and members of those organizations worldwide, enabling more collaboration and sharing, and overall communication	+	Enable
Number and variability of reusable elements collected, offered on reuse platforms and available for designers to choose from	+	Enable
Reverse logistics and take back schemes set in place	+	Enable
Number of architecture companies/bureaux designing/working with re-usable building components	+	Enable
Number of construction companies/participants using specific technologies or active on platforms that promote CE in the C&D sector	+	Enable

such as "measure*" could have resulted in additional contributions to analyze. However, we believe that as a start, the 242 search results offered a valuable initial point to derive insights and drive the discussion during the interviews held with experts.

Moreover, a certain level of subjectivity influences the categorization of interventions. As previously highlighted, other frameworks have been developed that categorize interventions in multiple ways (e.g., Prendeville et al., 2018). For example, we acknowledge that the distinction between the "Enable" and "Support" categories might appear blurred in some cases. However, providing a guide (as in Table 2) can support the replicability of our results. A certain degree of subjectivity also permeates the link between the indicators and the selected RISE category. However, as explained in the methodological section, we took this issue into account and worked to address it.

In regard to the indicator sets analyzed, the number was limited to nine, as the research was performed in English, thus excluding documents published in other languages. A higher number of sets could have provided different results for the statistical analysis, in terms of the coverage of the categories. We only focused on the indicator sets that deliberately assess a CE in the C&D sector. Our approach was intentionally narrow in scope (the C&D sector) to allow for maximum comparability of the results and to show how the framework could be easily operationalized.

As a final limitation of this study, we acknowledge that involving more actors for the interviews could be beneficial for improving the robustness of the results. Specifically in relation to the discussion on the C&D sector, interviewing more actors such as project investors, project developers, and demolishing companies, could add to the perspectives of the C&D experts that participated in our research.

Future research could apply the same indicator-based approach to replicate the analysis in other sectors, potentially eliciting sector-specific peculiarities (e.g., different coverage of the four RISE categories). As highlighted in multiple sections of the paper, we see indicators as information carriers that can offer different types of insights on what is deemed important to be measured by the assessors. Therefore, it would be interesting to perform an analysis of indicator sets based on, for instance, the most used indicators, or the most covered CE topics (such as waste, energy, water). This would highlight the level of overlap among the indicator sets.

Valuable insights about the potential integration of the proposed indicators into future measurement tools could be derived through the involvement of different stakeholders in the C&D sector. Also, by gathering stakeholders' knowledge, additional categorizations could be developed to group the proposed indicators, e.g., based on a distinction among actor, process, and product level. This additional level of categorization could make the indicators' interpretation and application easier.

Further studies could also focus on analyzing policy reports, rather than indicators, to understand the relative importance given to the four RISE categories when planning how to steer a CE transition. Finally, other lines of research could look specifically at the agency of different actors involved within the different categories of the framework, using the framework and the matrix proposed to shed light on actors' roles and potential contributions, and to support them with indicators to track the results of their efforts during a CE transition.

CRediT authorship contribution statement

Valeria Superti: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, review & editing, Visualization. **Cynthia Houmani:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, review & editing, Visualization. **Claudia R. Binder:** Validation, Resources, Writing – original draft, review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2021.105711.

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