INTEGRATIVE REVIEW ON CIRCULAR ECONOMY IN URBAN AREAS

REVISÃO INTEGRATIVA SOBRE ECONOMIA CIRCULAR EM ÁREAS URBANAS

Léa Gejer[1]

Vanessa Gomes da Silva[2]

[1] University of Campinas, Campinas, SP, Brazil, lea.gejer@gmail.com
[2] University of Campinas, Campinas, SP, Brazil, vangomes@unicamp.br

Abstract

Circular economy (CE) has gained relevance as the economic-environmental paradigm to be pursued by humanity. Despite its key role, managing urban areas towards a circular economy has adopted different meanings, approaches, and methods. Therefore, this study aims at conducting an integrative literature review on the application of circular economy to urban areas, and at consolidating the main approaches based on the analysis of the collected information. Firstly, a systematic literature review offered a thorough understanding of the boundaries and divergences within the spatial expression of circularity. Four emphases stood out: (i) managing specific resource flows in urban areas; (ii) integrating flows for resource looping in urban areas; (iii) planning the transition from linear to circular urban areas; and (iv) conceptualizing circular urban areas. Subsequently, the Cradle-to-Cradle approach was considered to encompass the complexity and dynamics required for developing qualitative and quantitative requirements for circular urban areas. As a result, four criteria, fifteen categories and possible indicators identified in the literature link the various perspectives on the subject and provide an initial methodological organization for implementing CE in urban areas. This contribution synthesizes and connects the main conceptual trends and establishes a basis for future research on this topic.

Keywords: Circular urban areas. Circular city. Circular economy. Cradle to Cradle. Regenerative urban systems.

Resumo

A economia circular (EC) ganhou relevância como o paradigma econômico-ambiental a ser perseguido pela humanidade. Apesar de seu papel fundamental, a gestão das áreas urbanas em direção à economia circular tem tomado diferentes significados, abordagens e métodos. Por isto, o objetivo deste estudo é realizar uma revisão integrativa da literatura sobre a aplicação da economia circular em áreas urbanas, consolidando as principais abordagens com base na análise das informações obtidas. Inicialmente, foi realizada uma revisão sistemática da literatura, o que permitiu a compreensão dos limites e divergências da expressão espacial de circularidade. Quatro ênfases foram destacadas: (i) fluxos específicos de recursos em áreas urbanas; (ii) integração de fluxos para ciclagem de recursos em áreas urbanas; (iii) planejamento da transição de áreas urbanas lineares para circulares e (iv) conceituação de áreas urbanas circulares. Posteriormente, considerou-se que a abordagem *Cradle to Cradle* abarca a complexidade e a dinâmica necessárias para o desenvolvimento de requisitos qualitativos e quantitativos para áreas urbanas circulares. Como resultado, quatro critérios, quinze categorias e possíveis indicadores identificados na revisão integrativa da literatura vinculam as diversas perspectivas do tema e fornecem uma organização metodológica inicial para implementação da EC em áreas urbanas. Esta contribuição sintetiza e conecta as principais tendências conceituais e estabelece uma base para pesquisas futuras no tema.

Palavras-chave: *Áreas urbanas circulares. Cidade circular. Economia circular. Cradle to Cradle. Sistemas urbanos regenerativos.*

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Introduction

Currently, 55% of the world's population lives in urban centers (UN, 2018). In countries of the southern hemisphere, this figure is even higher; in Brazil, for example, cities accommodate 84% of the population, and it is estimated that by 2030, 90% of Brazilians will live in cities (Ferretti, 2026). Urban areas also play a significant role in the economy, contributing around 80% of the global GDP (McKinsey Global Institute, 2012) and account for roughly the same amount of global resource use, carbon release, and solid waste production (UN, 2013).

Traditionally, urban areas operate on a linear model, which is based on so-called "cradle- to-grave" flows. In this model, industries mainly produce non-renewable materials and products for rapid consumption and disposal, water and nutrients are rarely recycled effectively, and most energy systems operate inefficiently. This results in the depletion of natural resources, accumulation of waste and pollution of water, air, and land (Lakatos *et al*., 2021). In contrast, the circular economy (CE) proposes a break with this linear system, establishing "cradle to cradle" cycles by recirculating resources and extending the life cycles of materials and products. Thus, the circular model proposes strategies to overcome environmental issues and improve the productivity of economic systems, decoupling economic growth from resource consumption (Braungart; McDonough; Bollinger, 2007).

Therefore, the transition to a CE not only offers opportunities to create less vulnerable and more competitive urban areas, regenerating ecosystems and harnessing natural resources as local capital, but also drives innovation and new economic opportunities and positively integrates urban areas with their surroundings (De Medici; Riganti; Viola, 2018; Lakatos *et al.,* 2021). However, this transition requires a systemic change at different planning levels, from industrial systems and building construction to urban infrastructure and public policies (Lakatos *et al.,* 2021).

Countries, such as Germany and Japan, have been pioneers in adopting CE policies focused on cities. For example, Germany ratified the "Closed Substance Cycle and Waste Management Act" in 1996, while Japan established regulations and laws to guide waste management and recycling (Bîrgovan *et al.,* 2022). In 2015, the European Union established a "Circular Economy Action Plan" earmarking significant funds for the transition from a linear to a circular model (European Commission, 2015). In addition, the "European Green Deal", created in 2019, defines strategies to tackle climate and environmental challenges and decouple economic growth from resource use (European Commission, 2020).

More recently, Latin American countries and cities are also adopting CE policies. For example, Colombia has developed its National Circular Economy Strategies (Colombia, 2019) and Bogotá, its capital, has implemented neighborhoods aimed at combating climate change and improving the population's quality of life (Ramírez, 2022). The municipality of São Paulo, meanwhile, formalized a partnership with the Ellen Macarthur Foundation and launched the "Connect the Dots" project, which promotes urban agriculture associated with food security for the most vulnerable population (UN, 2022).

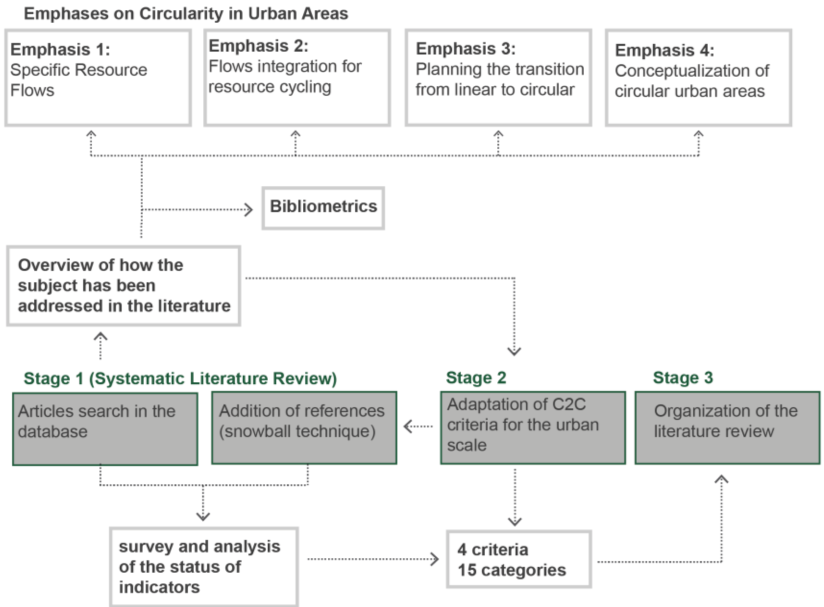
Thus, the concept of circular urban areas has become clearer, moving beyond waste management and system efficiency towards reducing input and valuing internal resource cycles. However, there is still no single definition for circular urban areas, nor a *framework* to measure performance and guide process improvement. The transition to circular urban areas requires integrating different actors and urban layers, making it essential to define requirements and indicators that simplify and guide the evaluation of relevant information for decision-making (Bîrgovan *et al.,* 2022).

Thus, this study aims to (i) generate an integrative literature review to study CE approaches in depth applied to urban areas, identifying the main trends and (ii) synthesize the concept of circular urban areas, creating an organization with possible criteria, categories, and indicators, which can serve as a basis for future research. The Systematic Literature Review (SLR) method enabled for an analysis of existing approaches, and based on the preliminary findings, it was suggested that the *Cradle-to- Cradle* (C2C) model, as proposed by McDonough and Braungart (2002), offers a holistic perspective of the CE that can guide the conceptual framework of circular urban areas. As a result, this study contributes by synthesizing the main trends, organizing the criteria, categories, and indicators identified in the literature, thus establishing a basis for future research, and promoting connections between existing conceptual approaches.

Methods

The integrative literature review was carried out in three major stages (Figure 1). Firstly, a Systematic Literature Review (SLR) was conducted based on the methodology proposed by Kitchenham (2004), to understand the theoretical trends and main characteristics of circular urban areas and to identify the main conceptual trends and characteristics related to circular urban areas (Appendix A). Articles from the Scopus database were analyzed when addressing the following research questions: "How has the Circular Economy been applied in the context of urban planning and management?", "What are the predominant trends in the academic debate on circularity in urban areas?" and "Which categories and indicators have been used to evaluate circular urban areas, and how are they being implemented?".

Figure 1- Stages of the integrative literature review and results



Source: the authors.

After analyzing titles and abstracts, 120 articles were examined, resulting in the identification of four complementary emphases on the subject. To complement the sample and broaden the set of indicators surveyed, the application of the "snowball" technique incorporated six specific documents that offer guidelines and strategies for implementing CE in urban areas and regions (Appendix A): two institutional documents that outline the strategy for implementing CE in two pioneering cities - Amsterdam (EU, 2020) and London (LWARB, 2017); a guiding institutional document related to the CE strategy in Europe (European Commission, 2015); a document containing the United Nations guidelines for the development of cities in the face of climate change (UN, 2013); a document aimed at policymakers to implement CE (Ellen Macarthur Foundation, 2015); and an article exploring the application of the *Cradle-to-Cradle* methodology in the context of the built environment (Mulhall; Braungart, 2010).

Once the sample had been defined, the criteria currently used in the *Cradle-to-Cradle* product certification program standard were examined to assess their applicability at the urban scale. This examination resulted in identifying four criteria and fifteen categories that characterize the application of CE in urban areas (Stage 2). Finally, to conclude the integrative review, the indicators identified in the literature were organized based on these criteria and categories (Stage 3).

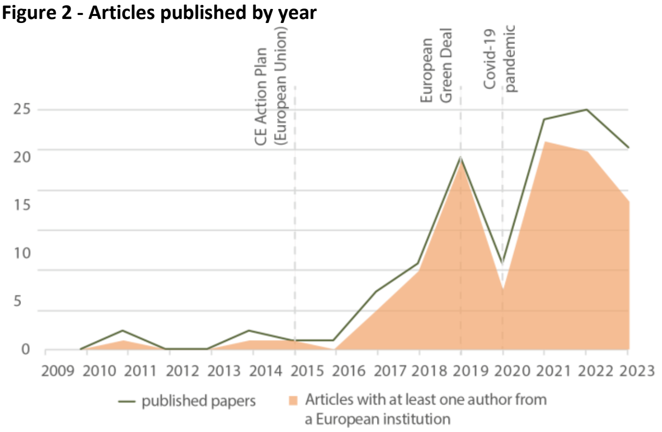
Results

Research localization and publication intensity

The leading research on circularity in the built environment is concentrated in Europe, with more than 75% of the authors originating from this continent. In the European context, most researchers are based mainly in the United Kingdom (12%), the Netherlands and Italy (both with 9%), with considerable research collaboration with twenty other European countries. Other countries, such as the United States, China and Australia, jointly contribute 14% of the authors, while Asia makes up 12%. South and Central America account for around 3% of the authors in the sample, and Africa for 1%.

The number of articles published has grown remarkably in recent years. Circularity in urban areas received little attention from 2010 to 2016, with an average of just one article per year. However, the situation changed in 2017 and 2018, when 5 and 6 articles were published respectively. Since then, the debate has grown substantially. In 2019, 20 new articles were published, representing an approximate 200% increase on the previous year. Although the sample decreased in 2020, with a total of 9 articles, there was a steady resumption of growth in subsequent years, with 24 articles in 2021, 25 in 2022 and 21 by September 2023, when the research was conducted (Figure 2). The graph shows that, despite being a recent topic, there has been a considerable increase in publications, especially in Europe, which can be attributed to the strengthening of recent CE policies on the continent.

Figure 2 - Articles published by year



Source: the authors.

Emphases on circularity in urban areas

To understand how CE has been applied in urban areas, four emphases were identified addressing different aspects related to circular urban areas (Figure 1). These emphases are as follows: (i) Specific Resource Flows in Urban Areas, (ii) Integration of Flows for Resource Cycling in Urban Areas, (iii) Transition Planning from Linear to Circular Urban Areas and (iv) Conceptualization of Circular Urban Areas. These four emphases are intrinsically interconnected and complement each other, which exposes the interdisciplinary and complex nature of the application of CE applied to urban areas. The following sections detail each of these emphases.

Specific resource flows within Urban Areas

The first emphasis addresses the debate around specific flows of resources that make up the complexity of an urban area. These articles investigate technologies, management and planning for each urban resource or flow, often establishing criteria, requirements, and indicators. The flows identified in the SLR were grouped into the following categories: municipal waste, municipal organic waste and urban tree waste, food, plastics, building material stocks, water, air quality, and land use (Appendix B).

Flows integration for resource cycling in urban areas

These articles refer to the integration of resource flows in urban metabolic systems. Urban areas are recognized as complex ecosystems, as they consume and produce a wide range of materials, natural resources, and food, while relying significantly on imported resources and generating pollution and waste. To illustrate strategies toward circularity, the work of Szyba and Mikulik (2023), for example, focuses on the management of municipal organic waste, aiming at biogas production. Similarly, Paiho *et al.* (2021) suggest integrating transportation, energy, and food systems to achieve greater circularity in the urban context.

Other works investigate the Nexus model, implemented in Sweden and China. Nexus is an approach aimed at conserving and regenerating water, energy, and food systems (Al-Azzawi; Gondhalekar; Drewes, 202; Xue; Liu; Casazza; Ulgiati, 2018, Piezer *et al.*, 2019). This model can also be associated with waste flow (Valencia; Zhang; Chang, 2022), as well as sanitation (Nhamo *et al.*, 2021), infrastructure, and land use (Williams, 2019b). In all these cases, the Nexus is proposed as the basis for achieving urban resilience by integrating interconnected flows. This involves both green and built infrastructures, promoting the reuse, recycling, and recovery of urban resources.

In addition, a significant number of articles investigate the application of Nature-Based Systems (NBS) as strategies to address the challenges of urban circularity and foster biodiversity (Langergraber *et al.*, 2020; Atanasova *et al.*, 2021; Pearlmutter *et al.*, 2020). NBSs are recognized to provide a wide range of beneficial ecosystem services to urban areas, such as microclimate regulation, flood prevention, water treatment, and food provision. However, most NBS are implemented to serve only a single purpose. By connecting NBS to the CE concept, which involves combining different types of services and reintegrating resources into the city, benefits achieved by urban areas can be significantly extended (Langergraber *et al.*, 2020).

Planning the transition from linear to circular urban areas

CE research has mainly focused on technical and managerial strategies for closing resource cycles through new industrial production technologies and business models (*Kirchherr; Reike;* Hekkert, 2017). However, when expanding the concept to a spatial perspective, infrastructure and land use also become crucial, as they materialize the physical connection between flows and people (Giezen, 2018). Thus, this group of articles explores urban planning, governance, and social and cultural engagement, for the empowerment of citizens in creating a long-term vision to face possible uncertainties.

As circular potential varies according to the characteristics of each urban system, CE strategies can be adapted to each reality. It is up to managers to delimit the strategic area, which can vary in terms of geographical boundaries, such as a specific neighborhood or industrial district, or in terms of economic reality, covering a variety of activities or productive sectors (Sánchez Levoso *et al.,* 2020). In addition, the transition to CE should focus on participatory processes oriented towards meeting local demand, involving diverse actors, raising citizen awareness, and encouraging technological development (Obersteg *et al.,* 2019).

Conceptualization of circular urban areas

The fourth emphasis focuses on concepts and methods that evolve from existing approaches, adapting them to the perspective of CE in the urban context. Some authors adapt CE frameworks initially developed for businesses (Prendeville; Cherim; Bocken, 2018; Williams, 2019a) or for product design (Baffour Auwah; Booth, 2014; Booth *et al.,* 2012) to apply them at the urban scale. Others suggest adapting the UN sustainability agenda (Cavaleiro de Ferreira; Fuso-Nerini, 2019), the urban ecology principles (Pelorosso, Gobattoni and Leone, 2017), or the optimization of "ecocity" models (Marin; De Meulder, 2018) in the transition to CE.

These concepts and methods identified in the literature sample can play a key role in structuring circular urban areas. Four of them stand out in the literature review: ReSOLVE, Low Entropy City, Regenerative Circularity for the Built Environment (RC4BE) and *Cradle-to-Cradle*. The following sections present these approaches.

ReSOLVE

The Ellen MacArthur Foundation developed the ReSOLVE *framework to* guide companies towards CE. ReSOLVE consists of six principles: Regenerate, Share, Optimize, Circulate, Virtualize and Exchange (Ellen MacArthur Foundation, 2015). Two articles in the SLR suggest adapting it to urban environments. However, according to one of them, although ReSOLVE is the most comprehensive and successful CE framework for businesses, it has significant limitations when applied to cities. The author identifies three key components - Adaptation, Scale and Localization, which must be added to ReSOLVE to deal with the inherent complexity of urban ecosystems (Williams, 2019a). At the same time, the article suggests eliminating the Virtualize and Exchange principles, which would result in a significant modification of the original *framework.* To address these limitations, Prendeville, Cherim and Bocken (2018) propose the simultaneous application of *top-down* and *bottom-up* processes for each ReSOLVE principle. *Top-down* processes are guided by government institutions, such as strategies and public policies. *Bottom-up* processes are driven by civil society, including activities organized by NGOs, communities, and companies. In summary, the two articles suggest a structural modification of ReSOLVE, which raises questions about the effectiveness of adapting this approach, originally developed for business, to the urban context.

Low entropy city

The concept of a "low entropy city" is based on the idea that CE is based on the principles of nature, and when applied to urban environments, refers to the "thermodynamics of open systems". Urban areas are considered as autopoietic systems, maintaining their autonomy while remaining open to interact and compensate for the inevitable losses according to the second law of thermodynamics. This model highlights the fundamental role of green infrastructure and nature-based solutions (NBS) in reducing entropy. As a result, resources are locally harvested, and the waste generated by human activities is reused and transformed into benefits for the population and the environment. This minimizes waste, improves public health, and fosters positive relationships among different components of the urban system (*Pelorosso ; Gobattoni,* 2017).

Regenerative Circularity for the Built Environment (RC4BE)

Sala Benites, Osmond and Prasad (2022) point out some gaps in the CE approach when applied to urban environments, highlighting its predominantly technical emphasis, narrow focus on resource metabolism and limitations in addressing social aspects. To overcome these shortcomings, the authors present the conceptual model of Regenerative Circularity for the Built Environment (RC4BE) and suggest five pillars to ensure its dynamism and adaptability to different contexts: (1) Circular Urban Metabolism: this focuses on the management of urban resource flows and stocks; (2) High Quality Adaptable and Resilient Urban Systems: this aims to create resilient urban systems that offer a high quality of life and well-being; (3) Healthy and Bioconnected Urban Ecosystems: this involves the interconnection of urban green spaces; (4) Good Governance and Thriving Communities: this highlights the importance of effective governance and the strengthening of local communities, contributing to a thriving economy and a healthy community environment; and (5) Systemic Approach and Positive Impact: this emphasizes the need for a holistic and systemic approach to generate positive impacts on both a local and global scale.

Cradle-to-Cradle (C2C)

The *Cradle-to-Cradle* (C2C) paradigm, proposed by McDonough and Braungart (2002), presents an approach to circular product design and is one of the theoretical foundations of the CE, as pointed out by the Ellen MacArthur Foundation (2015). This model aims to develop healthy, circular, and regenerative processes that eliminate waste through the design of products and systems, while maximizing the use of renewable resources and promoting local diversity.

Based on an understanding of how natural ecosystems work, C2C suggests three fundamental principles for creating products and systems designed for society:

- **waste is food:** closing water and nutrient cycles, differentiated into biological and technical cycles.
- **use the current solar income:** capture local, clean, and renewable energy.
- **celebrate diversity:** exploring local potential, materials, and cultures.

Since 2012, industrial products have been able to obtain C2C certification, validating this approach as a continuous optimization measure for CE. To date, thousands of products have been evaluated based on their performance in five categories: **Material Health, Product Circularity, Air and Climate Protection, Water and Soil Stewardship, and Social Fairness.** (Cradle to Cradle Products Innovation Institute, 2020). For its application at the building scale, the C2C approach establishes guidelines for the creation of building elements that allow for their deconstruction and high-quality recycling, within technical and biological cycles. Additionally, these buildings are designed to integrate water and biological nutrient flows, while actively promoting biodiversity and contributing to improved air quality and climate (Mulhall; Braungart, 2010).

Although C2C has been successfully applied to a variety of industrial products and inspired building projects, its expansion to the urban scale is still under development. Despite the existence of some exemplary developments that demonstrate this possibility, there is no clear evidence of its systematic application (Booth *et al.,* 2012). Therefore, these existing successful cases could become units for studying the application of CE in urban areas.

Park 20/20, for example, was conceived as the first urban system developed to implement the C2C approach. This development, covering an area of 114,000m², was designed in 2010 by William McDonough and Partners in Hoofddorp, the Netherlands. Its Master Plan promotes regenerative design at various scales, highlighting the following key points: (1) orientating buildings to optimize the capture of solar and wind energy; (2) developing a regenerative landscape with diversification of vegetation, landscaped corridors, and additional green areas on roofs and parking lots; (3) implementing decentralized facilities for water treatment and renewable energy production; and (4) adopting the C2C agenda to eliminate waste generation, including using building materials designed for disassembly and safe return to their cycles (ASLA, 2010).

Another example of the application of C2C principles in urban areas is integrated biosystems, which provide solutions for decentralization of wastewater treatment in cities of emerging countries, providing a range of benefits to the local population. The Brazilian NGO 'O Instituto Ambiental' develops these systems in Haiti and Brazil, treating domestic wastewater through filters with macrophyte plants and fish tanks, while recycling biological nutrients to produce agricultural fertilizers. These systems also recover the methane generated from the organic sludge decomposition to produce domestic gas. Community residents operate these systems, generating clean water, biogas, and food, thereby improving public health, and regenerating local ecosystems (OIA, 2021).

Discussion

The application of the CE in urban areas is intrinsically related to specific local factors such as the resource availability, territorial characteristics, and cultural demands. In addition, it involves structural and systemic changes that require collaboration of diverse societal actors. These transformations occur at multiple scales, ranging from materials, products, industrial systems, and buildings to cities and regions. In this context, identifying and synthesizing the main trends, organizing categories, and indicators used in the literature can serve as a basis for further research and, in the future, support the design and guidance of stakeholders interested in co-creating circular urban areas.

Although the approaches investigated in the SLR demonstrate success in promoting circularity across various scales, they still have limitations regarding the scope and dynamics to address the challenges of implementing CE in urban areas. Some of the articles analyzed in the sample, notably those authored by Prendeville, Cherim and Bocken (2018) and Williams (2019a), adapted the ReSOLVE framework, originally conceived for businesses, aiming to apply it in urban contexts. However, even after reconfiguring these models, circularity in urban areas proves to be more complex and comprehensive than that focused on businesses, as it inadequately reflects the multiple urban challenges and fails to establish connections between the various spatial practices and necessary structures.

Models such as the Low Entropy Cities (Pelorosso; Gobattoni; Leone, 2017) and RC4BE (Sala Benites; Osmond; Prasad, 2022) focus on triggering systemic change at various levels of urban planning. Although these approaches aim to identify gaps in CE paradigms in urban areas, there is still a need for a more in-depth examination of their practical implications, as well as the definition of metrics to evaluate and optimize projects and the development of circular urban areas. These frameworks are still in the early conceptual stages, and the authors recognize the need to refine them in future research, detailing the requirements and indicators more clearly to guide their implementation and replication in different contexts.

Contrastingly, the *Cradle-to-Cradle* (C2C) model, conceived by McDonough and Braungart (2002), despite originating at the industrial product scale, shows potential scalability at the urban level, as demonstrated in the case studies. The C2C certification program has successfully promoted the practice of developing industrial products for CE in various production chains based on its methodological principles and criteria. Although it requires adaptations to deal with the complexities of urban areas, its principles cover essential CE issues, especially by successfully addressing the emulation of natural ecosystems functioning in systems produced by society. Clearly, the model can be adjusted for different areas of urban planning, maintaining their consistency throughout this adaptation.

Systematized results

The C2C approach served as the basis for synthesizing and organizing the information in the literature sample, which has been justified by its provision of fundamental principles and criteria for the natural systems regeneration and by its comprehensive vision of CE. This approach has proven effective at other scales and demonstrated adaptability to urban contexts. It was therefore assumed that the C2C principles can form a solid basis for structuring the qualitative and quantitative measures needed to create circular urban areas. At the same time, these principles can help to communicate crucial information for decision-making, enabling connections between the concepts, categories, and indicators discussed and their potential applications in circular urban projects.

Thus, the C2C principles and the certification criteria from the Cradle-to-Cradle Products Innovation Institute (2020) were adapted for application in urban areas. This adaptation resulted in four criteria: **(i) Clean and Renewable Energy, Healthy Air and Climate Protection, (ii) Health and Circularity of Material Flows, (iii) Water and Soil Management and Gains in Local Biodiversity, and (iv) Strong, Equitable and Just Communities**. The product certification criteria "Material Health" and "Product Circularity" were merged into a single criterion for the urban scale, "Health and Circularity of Material Flows", as detailed in Appendix C. This unification recognizes the need to address material health in conjunction alongside effective material flow management in urban areas. The newly established criteria branched out into fifteen project categories identified in the sample (Figure 3). The status of each category was analyzed based on the frequency and depth of discussion of the indicators within the examined sample (**Erro! Fonte de referência não encontrada.**).

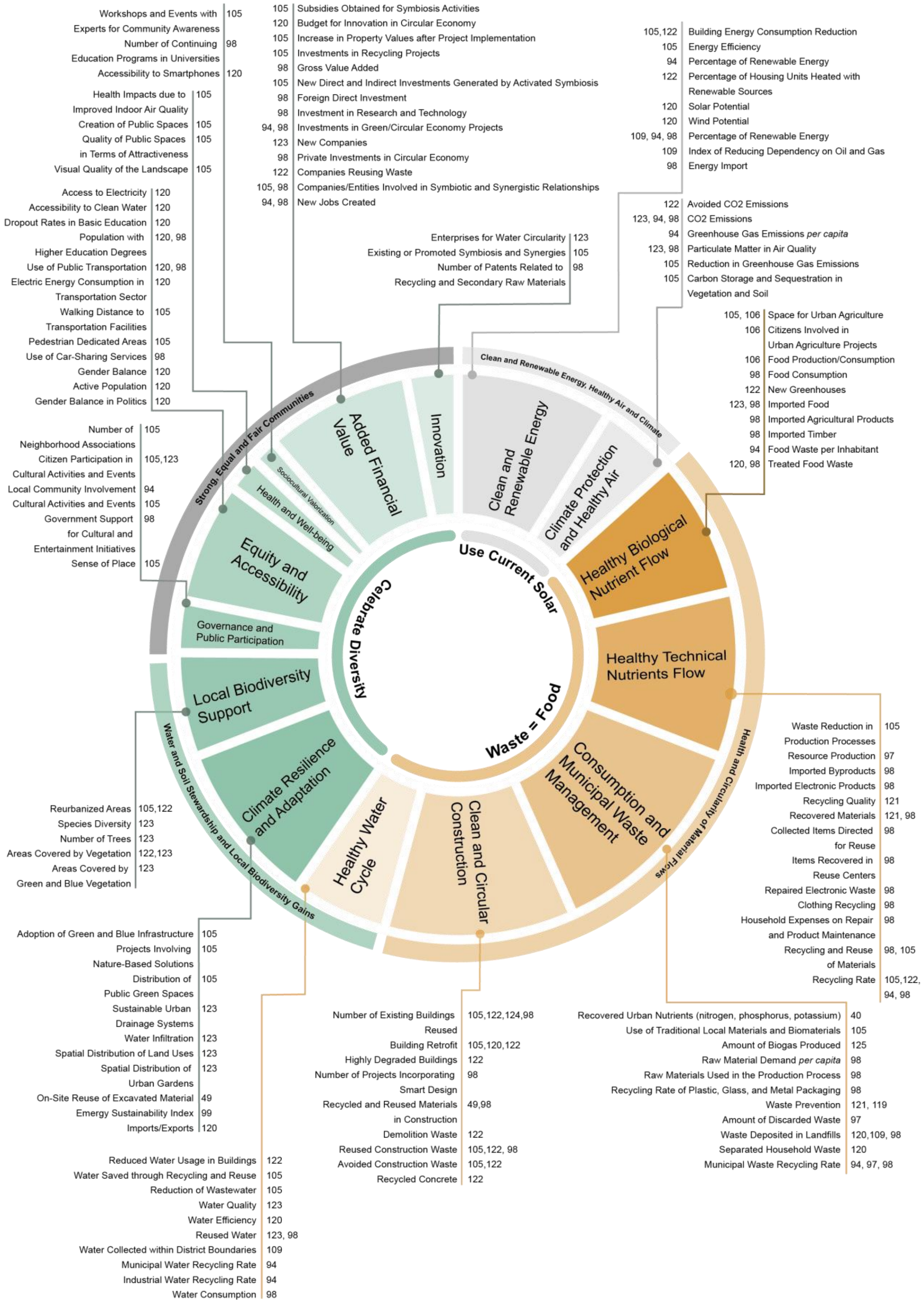
Figure 3. Representation of the organized literature. C2C principles (inner circle), criteria for the urban scale (outer circle) and categories in the middle circle

Source: the authors.

The organization proposed to synthesize the concept of circular urban areas, based on the criteria and categories generated, is aligned with the three C2C key principles (Figure 4). This alignment allows the structure to provide a comprehensive understanding of the subject and successfully aims to replicate the principles of natural functioning in urban environment projects, a characteristic that has proven indispensable in the practice of CE in urban settings. Despite the diverse approaches and wide range of indicators found in the literature, the indicators collected in the SLR proved to be balanced between the four established criteria, providing a starting point for understanding how CE is being applied in urban areas.

Notably, the criterion "Health and Circularity of Material Flows" housed the highest number of indicators, mainly focusing on material circularity and urban systems. Within this criterion, the "Consumption and Municipal Waste Management" category stands out, underlining the need to work on both citizen behavior and municipal management to optimize resource circulation. Another highly relevant category is "Climate Resilience and Adaptation", which, along with the categories "Local Biodiversity Support" and "Healthy Water Flow", offers opportunities to regenerate local ecosystems, making the most natural resources in the region, strengthening biodiversity, and creating more resilient and competitive communities. This demonstrates that creating solutions for circularity can incentivize a surplus of positive effects in the region, enabling human activities to progress in climate adaptation, restoration, and regeneration of human and ecological systems.

Figure 4 - Criteria, categories and indicators identified in the literature. Each category slice represents the contribution weighted by number of mentions and depth of discussion in the SLR sample. The numbers represent the corresponding reference within the sample (Appendix A).



Source: the authors.

In addition to working on resource flows in closed metabolisms, the broad presence of the "Strong, Equal and Fair Communities" category represents how CE has the potential to produce a range of benefits for human well-being and ecosystem valorization. These benefits include generating new job opportunities, social and economic inclusion, and reducing socio-environmental inequalities. It is noteworthy that the "Governance and Public Participation" category, although less representated in the sample, deserves special attention, as effective governance and the involvement of local communities are fundamental in coordinating and managing urban metabolism practices, uniting various disciplinary fields in lasting solutions. To this end, engaging local governments, citizens, companies, and organizations in initiatives involving policy adoption, infrastructure investments, and public awareness becomes essential for this transition.

Conclusions and next steps

This article provides an integrative review of CE approaches applied to urban areas, identifying the main trends, criteria, and indicators found in the literature. The study had a dual purpose: to deepen the understanding of CE approaches in urban areas and to create an organized framework of criteria, categories, and possible indicators as a basis for future research. It highlights the growing importance of this topic, reflected in the increase in the number of articles and new approaches published in recent years.

The review also highlighted the complementarity among different emphases in approaches, which include the management and integration of resource flows, planning for the transition from a linear to a circular economy and the challenges related to adapting existing concepts for applying CE in urban areas. Key conclusions underscored that approaches originating in territorial planning require further detailing to enable their application in diverse scenarios, while models adapted from other scales or pre-existing concepts need additional care to preserve their integrity and address the inherent complexities of urban areas. Crucially, all approaches emphasize the importance of understanding and replicating nature's functioning, which is a key factor in achieving the dynamics of circular urban systems.

The material was organized based on the *Cradle-to-Cradle* (C2C) model. Though requiring adjustments to handle urban complexities, C2C provides a robust foundation for CE through its product certification principles and criteria. Thus, the proposed organization would benefit from incorporating the successful product evaluation and certification practices, establishing a bridge for its urban scale application. To encompass the complexity of CE in urban areas and minimize future adaptations, requirements and indicators from other approaches have been included, connecting spatial practices that often operate independently, facilitating the involvement of diverse stakeholders to tackle CE implementation challenges.

Four criteria, fifteen categories, and potential indicators identified in the review link diverse perspectives on the topic, providing an initial methodological organization for implementing CE in urban areas. Undoubtedly, this initial framework can be improved and requires continuous progress. Key challenges include balancing the adaptation of criteria and categories to local characteristics to qualify their transfer and adaption to diverse contexts; managing interactions with regions beyond project boundaries; working on governance and management tools that enable the transition to CE; strengthening social structures that emphasize citizen empowerment; and developing an integrated long-term vision incorporating multiple stakeholders and nature. Successful existing case studies and the corresponding data collection play a key role in assessing practices and guiding new endeavors.

Finally, refining the proposed structure and, in the future, developing a *framework* that suggests its own indicators becomes necessary. This *framework* should be improved, calibrated, and complemented with design standards that describe best practices for circular urban areas.

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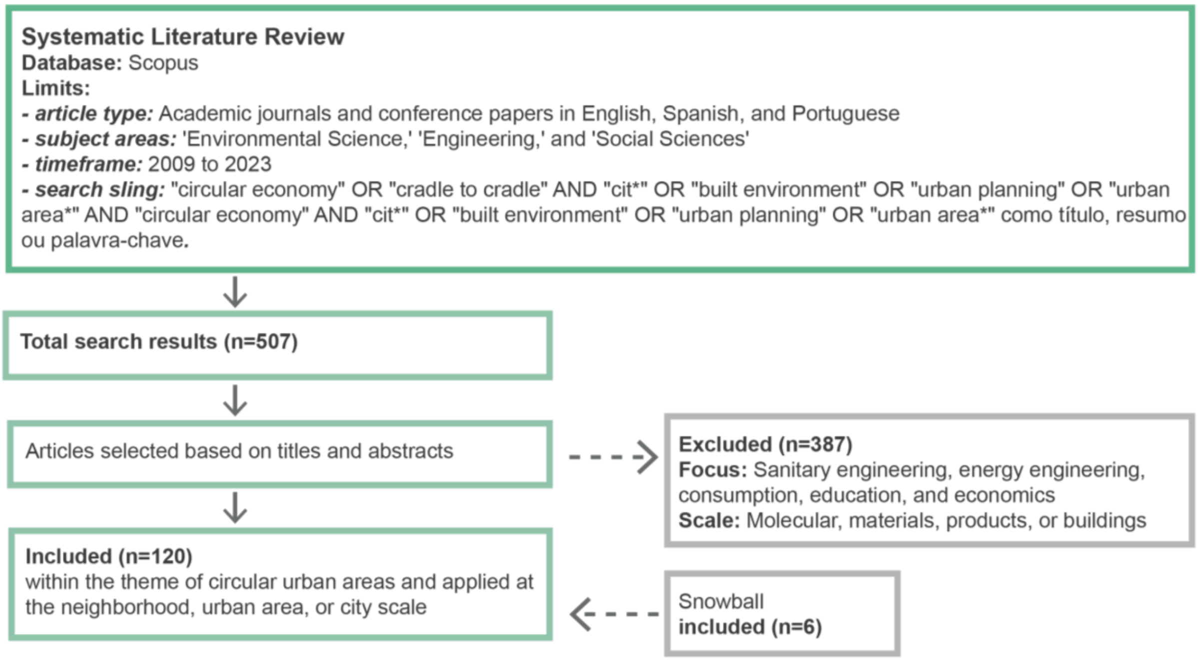
APPENDIX A - Systematic Literature Review Protocol

The Systematic Literature Review (SRL) method, based on the Procedures for Performing Systematic Review by Kitchenham (2004) was used to elucidate trends in the current theoretical context related to the topic in question (Figure 5).

Figure 5 - Systematic Literature Review Protocol



Source: the authors.

To do this, the initial sample of articles was analyzed, using three main research questions as a basis:

- How has CE been applied in the context of urban planning and management?
- What are the prevailing trends in the academic debate on circularity in urban areas?
- What categories and indicators have been used to evaluate circular urban areas, and how are they being implemented?

To answer these questions, the Scopus database was used in September 2023. Scopus was chosen because it is one of the most comprehensive databases in the field. The following search sequence was applied: "circular economy" OR "cradle to cradle" AND "cit*" OR "built environment" OR "urban planning" OR "urban area*" as a title, abstract or keyword. We only included academic journal articles and conference papers written in English, Spanish or Portuguese in the results. In addition, the sample was restricted to articles that apply at least one of the following keywords: 'circular economy'; 'urban area'; 'cities'; and 'urban planning', to the subfields of 'environmental sciences', 'engineering' and 'social sciences' and that are in the final stages of publication. As a result, our initial sample comprised 507 articles.

Of these 507 articles, filtering by titles and abstracts retained articles within the theme of 'circular urban areas' and that worked with scales of neighborhoods, cities, or urban areas, reducing the sample to a final list of 120 articles (Chart 1). Next, we analyzed the 120 articles according to their understanding of CE, and how the authors are implementing their criteria in urban areas, surveying the most used requirements, indicators, existing case studies and ways of monitoring them. Finally, to deepen our understanding of the topic, we complemented the sample using the "snowball" technique, adding bibliographical references relevant to the research.

Using the snowball technique, six specific documents were incorporated that offer guidelines and strategies for implementing CE in urban areas and regions (Chart 2): two institutional documents that outline the strategy for implementing CE in two pioneering cities - Amsterdam (EU, 2020) and London (LWARB, 2017); a guiding institutional document related to the CE strategy in Europe (European Commission, 2015); a document containing the United Nations guidelines for the development of cities in the face of climate change (UN, 2013); a document aimed at policymakers (Ellen Macarthur Foundation, 2015); and an article exploring the application of the *Cradle-to-Cradle* methodology in the context of the built environment (Mulhall; Braungart, 2010).

Chart 1 - Selected articles from the SLR, separated according to conceptual emphases, as described in Figure 1

Numbering within SLR	Title	Author(s)
EMPHASIS 1: SPECIFIC RESOURCE FLOWS		
1	Circularity information platform for the built environment	YU, Y. *et al.* (2023)
2	Evaluation of harvesting urban water resources for sustainable water management: Case study in Filton Airfield, UK	KIM, J. E.; HUMPHREY, D.; HOFMAN, J. (2023)
3	Comparison of environmental impacts related to municipal solid waste and construction and demolition waste management and recycling in a Latin American developing city	FERRONATO, N. *et al.* (2023)
4	Green waste to green architecture: optimizing urban tree systems for renewable construction material supply chains	DICKINSON, S.; DIMOND, K.; LI, S. (2023)
5	Circular economy and waste management to empower a climate-neutral urban future	MÖSLINGER, M.; ULPIANI, G.; VETTERS, N. (2023)
6	Circularity in cities: A comparative tool to inform prevention of plastic pollution	MADDALENE, T. *et al.* (2023)
7	Advancing the Application of a Multidimensional Sustainable Urban Waste Management Model in a Circular Economy in Mexico City	NIEVES, A. J.; RAMOS G. C. D. (2023)
8	Are Rainwater and Stormwater Part of the Urban CE Efficiency?	NOVAES, C.; MARQUES, R. (2023)
9	Sustainability assessment of increased circularity of urban organic waste streams	DDIBA, D. *et al.* (2022)
10	Creating careful circularities: Community composting in New York City	MORROW, O.; DAVIES, A. (2022)
11	In support of circular economy to evaluate the effects of policies of construction and demolition waste management in three key cities in Yangtze River Delta	YU, S. *et al.* (2022)
12	Waste Landscape: Urban Regeneration Process for Shared Scenarios	SPINA, L. D.; GIORNO, C. (2022)
13	Surveying the building stock of Graz with regard to a circular economy in the construction sector	HAUSEGGER; B. *et al.* (2022)
14	Retaining and recycling water to address water scarcity in the City of Cape Town	VAN ZYL, A.; JOOSTE, J.L. (2022)
15	Circular utilization of urban tree waste contributes to the mitigation of climate change and eutrophication	LAN, K;, ZHANG, B.; YAO, Y. (2022)
16	THE STATE OF THE CIRCULAR ECONOMY: Waste Valorization in Hong Kong and Rotterdam	WILDEBOER, V.; SAVINI, F. (2022)
17	Food system transformation for sustainable city-regions: exploring the potential of circular economies	LEVER, J.; SONNINO, R. (2022)
18	Building a model for the predictive improvement of air quality in Circular Smart cities	NUNEZ-CACHO, P. *et al.* (2022)
19	Assessing water circularity in cities: Methodological framework with a case study	ARORA, M. *et al.* (2022)
20	Integrated model and index for circular economy in the built environment in the Indian context	SMITHA, J. S.; THOMAS, A. (2021)
21	Stocks and flows of buildings: Analysis of existing, demolished, and constructed buildings in Tampere, Finland, 2000-2018	HUUHKA, S.; KOLKWITZ, M. (2021)
22	Managing a circular food system in sustainable urban farming. Experimental research at the Turku university campus (Finland)	ERÄLINNA, L.; SZYMONIUK, B. (2021)
23	Inflows and outflows from material stocks of buildings and networks and their space-differentiated drivers: The case study of the Paris region	AUGISEAU, V.; KIM, E. (2021)
24	Combining LCA and circularity assessments in complex production systems: the case of urban agriculture	RUFÍ-SALÍS, M. *et al.* (2021)

25	Knock on wood: Business models for urban wood could overcome financing and governance challenges faced by nature-based solutions	KAMPELMANN, S. (2021)
26	Adaptive re-use of urban cultural resources: Contours of circular city planning	GRAVAGNUOLO, A. *et al.* (2021)
27	Developing an Urban Resource Cadaster for Circular Economy: A Case of Odense, Denmark	LANAU, M.; LIU, G. (2020)
28	Analysis of wastewater production to implement circular economy solutions in a smart city university campus living lab	AGUILAR, M. G. S. *et al.* (2019)
29	The management of municipal waste through circular economy in the context of smart cities development	ACELEANU, M. I. *et al.* (2019)
30	Ecological network analysis of growing tomatoes in an urban rooftop greenhouse	PIEZER, K. *et al.* (2019)
31	Edible City Solutions-One Step Further to Foster Social Resilience through Enhanced Socio-Cultural Ecosystem Services in Cities	SÄUMEL, I. *et al.* (2019)
32	Beyond waterscapes: Towards circular landscapes. addressing the spatial dimension of circularity through the regeneration of waterscapes	AMENTA, L.; VAN TIMMEREN, A. (2018)
EMPHASIS 2: INTEGRATING FLOWS FOR RESOURCE CYCLING		
33	Management of Biodegradable Waste Intended for Biogas Production in a Large City	SZYBA, M.; MIKULIK, J. (2023)
34	The potential of local food, energy, and water production systems on urban rooftops considering consumption patterns and urban morphology	TOBOSO-CHAVERO, S. *et al.* (2023)
35	A Study on the Parametric Design Parameters That Influence Environmental Ergonomics and Sustainability	LÓPEZ-LÓPEZ, D. *et al.* (2023)
36	The role of citizens and transformation of energy, water, and waste infrastructure for an	RODRIGUES, M.; FRANCO, M. (2023)
37	Evaluation of urban metabolism assessment methods through SWOT analysis and analytical hierocracy process	VOUKKALI, I.; ZORPAS, A. A. (2022)
38	Neighborhood-Scale Urban Water Reclamation with Integrated Resource Recovery for Establishing Nexus City in Munich, Germany: Pipe Dream or Reality?	AL-AZZAWI, M. S. M.; GONDHALEKAR, D.; DREWES, J. E. (2022)
39	Sustainability transitions of urban food-energy-water-waste infrastructure: A living laboratory approach for circular economy	VALENCIA, A.; ZHANG, W.; CHANG, N.-B. (2022)
40	Potential Nutrient Conversion Using Nature-Based Solutions in Cities and Utilization Concepts to Create Circular Urban Food Systems	WIRTH, M. *et al.* (2021)
41	A framework for addressing circularity challenges in cities with nature-based solutions	LANGERGRABER, G. *et al.* (2021)
42	Urban nexus and transformative pathways towards a resilient Gauteng City-Region, South Africa	NHAMO, L. *et al.* (2021)
43	Nature-Based Solutions and Circularity in Cities	ATANASOVA, N. *et al*. (2021)
44	Creating a Circular City-An analysis of potential transportation, energy and food solutions in a case district	PAIHO, S. *et al.* (2021)
45	Analyzing material and embodied environmental flows of an Australian university - Towards a more circular economy	STEPHAN, A. *et al.* (2020)
46	Enhancing the circular economy with nature-based solutions in the built urban environment: Green building materials, systems and sites	PEARLMUTTER, D. *et al.* (2020)
47	Implementing nature-based solutions for creating a resourceful circular city	LANGERGRABER, G. *et al.* (2020)
48	Urban waste flows and their potential for a circular economy model at city-region level	ZELLER, V. *et al.* (2019)
49	Development of an urban FEW nexus online analyzer to support urban circular economy strategy planning	XUE, J. *et al*. (2018)
50	Enhanced Performance of the Eurostat Method for Comprehensive Assessment of Urban Metabolism	VOSKAMP, I. M. *et al.* (2017)
51	Wallasea Island Wild Coast Project, UK: Circular economy in the built environment	CROSS, M. (2017)
52	Amsterdam as a sustainable European metropolis: integration of water, energy and material flows	VAN DER HOEK, J. P.; STRUKER, A.; DE DANSCHUTTER, J. E. M. (2017)
53	Research on evaluation of sustainable land use of resource-based city based on circular economy- A case study of Shuozhou city	ZHOU, L.; YUAN, C., WU, Y. (2014)
EMPHASIS 3: TRANSITION PLANNING AND GOVERNANCE		
54	Sustainable circular cities? Analyzing urban circular economy policies in Amsterdam, Glasgow, and Copenhagen	FRIANT, M. C. *et al.* (2023)
55	Circular economy adoption barriers in built environment- a case of emerging economy	MHATRE, P. *et al.* (2023)
56	Ex ante analysis of circular built environment policy coherence	ANCAPI, F. B. (2023)
57	Sustainable housing at a neighborhood scale	DÜHR, S.; BERRY, S.; MOORE, T. (2023)
58	The rising phenomenon of circular cities in Japan. Case studies of Kamikatsu, Osaki and Kitakyushu	HERRADOR, M. (2023)

59	Smart Circular Cities: Governing the Relationality, Spatiality, and Digitality in the Promotion of Circular Economy in an Urban Region	ANTTIROIKO, A. V. (2023)
60	Digitalization driven urban metabolism circularity: A review and analysis of circular city initiatives	D'AMICO, G. *et al*. (2022)
61	Challenges to implementing circular development-lessons from London	WILLIAMS, J. (2022)
62	Make it a circular city: Experiences and challenges from European cities striving for sustainability through promoting circular making	COSKUN, A. *et al.* (2022)
63	Transdisciplinary resource monitoring is essential to prioritize circular economy strategies in cities	PETIT-BOIX, A. *et al.* (2022)
64	Circular Economy for Cities and Sustainable Development: The Case of the Portuguese City of Leiria	ANTUNES, J. C. C.; EUGÉNIO, T.; BRANCO, M. C. (2022)
65	Space Matters: Barriers and Enablers for Embedding Urban Circularity Practices in the Brussels Capital Region	VERGA, G. C.; KHAN, A. Z. (2022)
66	Circular cities: What are the benefits of circular development?	WILLIAMS, J. (2021)
67	Agency in circular city ecosystems-A rationalities perspective	HIRVENSALO, A. *et al.* (2021)
68	Mapping and assessing indicator-based frameworks for monitoring circular economy development at the city-level	PAPAGEORGIOU, A. *et al.* (2021)
69	The lack of social impact considerations in transitioning towards urban circular economies: a scoping review	VANHUYSE, F. *et al.* (2021)
70	Transition to smart and regenerative urban places (SRUP): Contributions to a new conceptual framework	PEPONI, A.; MORGADO, P. (2021)
71	Transition to smart and regenerative urban places (SRUP): Contributions to a new conceptual framework	PEPONI, A.; MORGADO, P. (2021)
72	Governing the Circular Economy in the City: Local Planning Practice in London	TURCU, C.; GILLIE, H. (2020)
73	Multidimensional assessment for "culture-led" and "community-driven" urban regeneration as driver for triggering economic vitality in urban historic centers	SPINA, L. D. (2019)
74	City level circular transitions: Barriers and limits in Amsterdam, Utrecht and The Hague	CAMPBELL-JOHNSTON, K. *et al.* (2019)
75	Circular economy in sustainable development of cities	SOBOL, A. (2019)
76	IDEAL-CITIES - A trustworthy and sustainable framework for circular smart cities	ANGELOPOULOS, C. M. *et al.* (2019)
77	The circular economy approach in cities: An evaluation of municipal measures in Brussels	LICA, I. M. (2019)
78	Transforming rooftops into productive urban spaces in the Mediterranean. An LCA comparison of agri-urban production and photovoltaic energy generation	CORCELLI, F. *et al*. (2019)
79	Urban regions shifting to circular economy: Understanding challenges for new ways of governance	OBERSTEG, A. *et al.* (2019)
80	Barriers and drivers in a circular economy: The case of the built environment	HART, J. *et al*. (2019)
81	Including Urban Metabolism Principles in Decision-Making: A Methodology for Planning Waste and Resource Management	LONGATO, D. *et al.* (2019)
82	Managing anaerobic digestate from food waste in the urban environment: Evaluating the feasibility from an interdisciplinary perspective	FULDAUER, L. I. *et al.* (2018)
83	Design evolution and innovation for tropical liveable cities: Towards a circular economy	FLEISCHMANN, K. (2018)
84	Social-Ecological-Technical systems in urban planning for a circular economy: an opportunity for horizontal integration	VAN DER LEER, J.; VAN TIMMEREN, A.; WANDL, A. (2018)
85	Carbon footprints of urban transition: Tracking circular economy promotions in Guiyang, China	FANG, K. *et al.* (2017)
EMPHASIS 4: CONCEPTUALIZATION OF CIRCULAR URBAN AREAS		
86	A neighborhood-scale conceptual model towards regenerative circularity for the built environment	BENITES, H. S.; OSMOND, P.; PRASAD, D. (2023)
87	A Future-Proof Built Environment through Regenerative and Circular Lenses-Delphi Approach for Criteria Selection	BENITES, H. S.; OSMOND, P.; PRASAD, D. (2023)
88	Sustainability transitions to circular cities: Experimentation between urban vitalism and mechanism	WINSLOW, J.; COENEN, L. (2023)
89	Visions of cities beyond the Green Deal: From imagination to reality	MAGLIO, M. (2022)
90	Embedding Circular Economy Principles into Urban Regeneration and Waste Management: Framework and Metrics	DOMENECH, T.; BORRION, A. (2022)
91	The Global Movement of the Transition from Linear Production to the Circular Economy Applied to the Sustainable Development of Cities	DA SILVA, C. L.; FRANZ, N.M. (2022)
92	Assessing the Inclusion of Water Circularity Principles in Environment-Related City Concepts Using a Bibliometric Analysis	MIRANDA, A. C. *et al.* (2022)
93	Mapping sustainability and circular economy in cities: Methodological framework from Europe to the Spanish case	ALONSO, I. B.; SÁNCHEZ-RIVERO, M.V.; POZAS B. M. (2022)

94	How shall we start? The importance of general indices for circular cities in Indonesia	NURDIANA, J.; FRANCO-GARCIA, M. L.; HELDEWEG, M. A. (2021)
95	Match Circular Economy and Urban Sustainability: Re-investigating Circular Economy Under Sustainable Development Goals (SDGs)	DONG, L.; LIU, Z.; BIAN, Y. (2021)
96	Conceptualizing core aspects on circular economy in cities	LAKATOS, E. S. *et al.* (2021)
97	Evaluating circular economy performance based on ecological network analysis: A framework and application at city level	GAO, H. *et al.* (2021)
98	Seeking circularity: Circular urban metabolism in the context of industrial symbiosis	FEIFERYTĖ-SKIRIENĖ, A.; STASIŠKIENĖ, Ž. (2021)
99	Toward the construction of a circular economy eco-city: An emergy-based sustainability evaluation of Rizhao city in China	LI, J. *et al.* (2021)
100	Implementing a new human settlement theory: Strategic planning for a network of regenerative villages	LIAROS, S. (2020)
101	The role of spatial planning in transitioning to circular urban development	WILLIAMS, J. (2020)
102	Circular cities: the case of Singapore	CARRIÈRE, S. *et al.* (2020)
103	Towards circular cities-Conceptualizing core aspects	PAIHO, S. *et al.* (2020)
104	Combining Industrial Symbiosis with Sustainable Supply Chain Management for the Development of Urban Communities	ROSADO, L.; KALMYKOVA, Y. (2019)
105	Moving towards the circular economy/city model: Which tools for operationalizing this model?	GIRARD, L. F.; NOCCA, F. (2019)
106	Circular Cities: Challenges to Implementing Looping Actions	WILLIAMS, J. (2019)
107	Circular Cities	WILLIAMS, J. (2019)
108	Circular economy strategies in eight historic port cities: Criteria and indicators towards a circular city assessment framework	GRAVAGNUOLO, A.; ANGRISANO, M.; GIRARD, L. F. (2019)
109	A framework for implementing and tracking circular economy in cities: The case of Porto	CAVALEIRO DE FERREIRA, A. C.; FUSO-NERINI, F. (2019)
110	Approach to urban metabolism of Almassora municipality, Spain, as a tool for creating a sustainable city	CHOFRE, I. L.; GIELEN, E.; JIMÉNEZ, J. S. P. (2018)
111	Evaluation of Urban circular economy development: An empirical research of 40 cities in China	WANG, N. *et al.* (2018)
112	Interpreting Circularity. Circular City Representations Concealing Transition	MARIN, J.; DE MEULDER, B.
113	Circular Cities: Mapping 6 cities in transition	PRENDEVILLE, S.; CHERIM, E.; BOCKEN, N. (2018)
114	Toward a Resource-Efficient Built Environment: A Literature Review and Conceptual Model	NESS, D. A.; XING, K. (2017)
115	The low-entropy city: A thermodynamic approach to reconnecting urban systems with nature	PELOROSSO, R.; GOBATTONI, F.; LEONE, A. (2017)
116	Planning framework of the circular economy eco-city	DU, Z. (2016)
117	Integrated management framework for sustainable cities: Insights into multiple concepts and principles	AWUAH, K. G. B., BOOTH, C. A. (2014)
118	Activating eco-city in China: The system engineering for cities' green transition	WANG, X. J. *et al.* (2011)
119	Beyond sustainability: Cradle-to-cradle business innovation and improvement zones in NW Europe	BOOTH, C. A. *et al.* (2011)

Source: the authors.

Chart 2- Articles collected using the 'snowball' technique

SNOW BALL		
Numbering (within sample)	**Title**	**Author(s)**
120	Amsterdam Circular 2020-2025 Strategy	EU (2020)
121	Cities and climate change	UN (2013)
122	Closing the loop - An EU action plan for the Circular Economy	EUROPEAN COMMISSION (2015)
123	Cradle to Cradle' criteria for the built environment	MULHALL, D.; BRAUNGART, M. (2010)
124	Delivering the circular economy: a toolkit for policymakers	ELLEN MACARTHUR FOUNDATION (2015)
125	London's Circular Economy route map	LWARB (2017)

Source: the authors.

APPENDIX B - EMPHASIS 1 ARTICLES GROUPED ACCORDING TO RESOURCE FLOW APPROACH

Chart 3 - Grouping of texts in Emphasis 1 according to resource flow approach

Resource flow	Bibliographical references
Water	KIM, J. E.; HUMPHREY, D.; HOFMAN, J. (2023); NOVAES, C.; MARQUES, R. (2023), VAN ZYL, A.; JOOSTE, J. L. (2022); ARORA, M. *et al*. (2022); AGUILAR, M. G. S. *et al.* (2019)
Municipal Waste	FERRONATO, N. *et al.* (2023); MÖSLINGER, M.; ULPIANI, G.; VETTERS, N. (2023); NIEVES, A. J.; RAMOS G. C. D. (2023); WILDEBOER, V.; SAVINI, F. (2022); ACELEANU, M.I. *et al.* (2019)
Building material / Building stock	YU, Y. *et al. (*2023); FERRONATO, N. *et al.* (2023); YU, S. *et al.* (2022); HAUSEGGER; B. *et al.* (2022); SMITHA, J. S.; THOMAS, A. (2021); HUUHKA, S.; KOLKWITZ, M. (2021); AUGISEAU, V.; KIM, E. (2021); LANAU, M.; LIU, G. (2020)
Municipal organic waste/ composting/ food production	DICKINSON, S.; DIMOND, K.; LI, S. (2023); DDIBA, D. *et al.* (2022); MORROW, O.; DAVIES, A. (2022); LEVER, J.; SONNINO, R. (2022); ERÄLINNA, L.; SZYMONIUK, B. (2021); RUFÍ-SALÍS, M. *et al.* (2021); PIEZER, K. *et al.* (2019); SÄUMEL, I. *et al.* (2019)
Urban tree waste/urban wood	LAN, K;, ZHANG, B.; YAO, Y. (2022); KAMPELMANN, S. (2021)
Land use and occupation	SPINA, L. D.; GIORNO, C. (2022); AMENTA, L.; VAN TIMMEREN, A. (2018)
Plastic pollution	MADDALENE, T. *et al.* (2023)
Air quality	NUNEZ-CACHO, P. *et al.* (2022)
Energy	MÖSLINGER, M.; ULPIANI, G.; VETTERS, N. (2023); NOVAES, C.; MARQUES, R. (2023)
Cultural Heritage	GRAVAGNUOLO, A. *et al.* (2021)

Source: the authors.

APPENDIX C - ADAPTATION OF C2C CRITERIA FROM PRODUCT CERTIFICATION TO THE URBAN SCALE

Chart 4. Adaptation of the C2C Criterion 'Clean Air and Climate Protection' from Product Certification to the Urban Scale

C2C principles McDonough and Braungart (2002a)	C2C criteria for industrial products (adapted from Cradle-to- Cradle Products Innovation Institute, 2020)	Adaptation of the C2C criteria to the urban scale (the authors)	Application categories for circular urban areas (the authors)
Use Current Solar Source	Clean Air and Climate Protection	Clean and Renewable Energy, Healthy Air and Climate Protection	
	The manufacture of a product should result in a positive impact on air quality, the supply of renewable energy, and the balance of greenhouse gases that affect the climate through clean energy and environmental protection.	Circular urban areas have the potential to exert a beneficial impact on energy supply by promoting the use of clean and renewable energy sources, avoiding energy losses and emissions of gaseous pollutants, and keeping energy in high-quality cycles. In an ideal scenario, these urban areas do not only meet their own energy needs from clean and renewable sources, but also produce energy surplus, making it available to local communities or reintegrating it into the electricity grid. In addition, circular urban areas should prioritize the responsible management of pollutant emissions, guaranteeing the maintenance of high air quality and thermal and acoustic comfort for their inhabitants. It is essential to optimize the capture of sunlight, ensure adequate ventilation, as well as promote high-quality public transport systems and encourage mobility on foot.	Clean and Renewable Energy: works on energy efficiency and the generation of energy from clean and renewable sources. Climate Protection and Healthy Air: addresses emissions control and sustainable mobility.

Source: The authors.

Chart 5. Adaptation of C2C Criteria 'Material Health' and 'Product Circularity' from Product Certification to the Urban Scale

Princípios C2C McDonough e Braungart (2002)	Critérios C2C para produtos industriais (adaptado de Cradle to Cradle Products Innovation Institute, 2020)	Adequação dos critérios C2C para escala urbana (as autoras)	Categorias de aplicação de áreas urbanas circulares (as autoras)
Waste is Food	Material Health	Health and Circularity of Material Flows	
	To ensure that materials are safe for humans and the environment, the chemicals and materials used in products are selected with priority for the protection of human health and the environment. Thus, it may have a positive impact on the quality of materials available in future cycles.	Circular urban areas must ensure the continuous circulation of nutrients in healthy systems within biological and technical cycles. To this end, the importance of conscientious consumption by citizens and effective municipal waste management is emphasized, through the implementation of information systems, collection, and disposal of these materials. Encouraging the flow of healthy biological nutrients in urban areas implies returning these nutrients appropriately to the soil, creating value from solid organic waste and minimizing food waste. These actions are associated with reducing the distances traveled in the production of quality food and the inclusion of the population, encouraging their participation in other sectors of the bioeconomy. The integration of urban areas into the CE also encompasses material flows related to the technical cycle, as cities are the largest consumers of industrial products. Urban areas can implement and facilitate systems for reusing, repairing, remanufacturing, and recycling technical products and materials. Furthermore, the potential of the construction sector is highlighted, as it has major environmental impacts caused by the current linear model but also ample regenerative possibilities for the circular transition. New buildings should be designed with the premise of reusing their materials in subsequent cycles. This implies adopting modular and dismountable construction systems, enabling the reuse of components in new projects. In addition, it is essential to maximize the use of existing building stocks, promoting renovations and adaptations that enhance and prolong their use.	Healthy Biological Nutrient Flow: includes local food production and organic waste management. Healthy Technical Nutrients Flow: works on the recirculation of materials from technical production chains. Clean and Circular Construction: this covers the maintenance and reuse of existing building stock, as well as the dismantling of building systems, components and materials designed for future cycles. Consumption and Municipal Waste Management: this deals with reducing consumption so as not to generate waste, separating household waste and disposing of it.
	Circularity of the product		
	To enable CE through the design of products and processes, they must be deliberately designed to facilitate their next use and be actively reintegrated into their respective paths within planned technical and biological cycles.		

Source: The authors.

Chart 6. Adaptation of C2C Criteria 'Water and Soil Management' and 'Social Justice' from Product Certification to Urban Scale

Princípios C2C McDonough e Braungart (2002)	**Critérios C2C para produtos industriais (adaptado de Cradle to Cradle Products Innovation Institute, 2020)**	**Adequação dos critérios C2C para escala urbana (as autoras)**	**Categorias de aplicação de áreas urbanas circulares (as autoras)**
Waste is Food	Water and Soil Stewardship	Water and Soil Stewardship and Local Biodiversity Gains	
	The manufacture of a product must ensure that water and soil are treated as precious, shared resources. Watersheds and soil ecosystems are protected, and clean water and healthy soils are available to people and all other living organisms.	This criterion aims to expand the area available for local biodiversity, revitalize the soil, restore the hydrological functionality of the urban landscape, and improve the quality of life of the population. In this context, water and soil are considered precious and shared resources. Mixed land use, nature-based solutions and the recovery of degraded areas are tools that promote resilience and adaptation to climate change, while providing a favorable environment for local biodiversity. To ensure a healthy water cycle, it is essential to adopt practices such as rainwater harvesting, preventing water contamination, and treating effluents.	Healthy Water Flow: considers aspects related to local capture, efficient use, and recirculation of water. Resilience and Climate Adaptation: includes nature-based solutions, soil permeability, and land use distribution. Support for Local Biodiversity: addresses the implementation of green areas and trees, species diversity, and the restoration of degraded areas.
Celebrate Diversity	Social Fairness	Strong, Equal and Fair Communities	
	Companies must be committed to respecting human rights and adopting fair and equitable business practices, embracing safe, fair and equitable labor practices that promote human rights and strong communities.	Communities in circular urban areas should be committed to promoting equity and accessibility for all their inhabitants, ensuring effective public participation and the well-being of the community. The socio-cultural diversity that should be valued, seeking to add financial value, and stimulating innovation as an intrinsic part of their development vision. Governance plays a key role in promoting these principles and ensuring that urban policies, regulations, and actions are aligned with building CE in strong, equal and just communities. Robust governance can help translate these intentions into effective practices, ensuring democratic participation, equitable distribution of resources and compliance with the principles of equality and justice in all aspects of urban life.	Governance and Public Participation: Highlights participatory governance and the collaboration of the local population in promoting circular practices. Equity and Accessibility: Focuses on the fair distribution of resources and accessibility to essential services. Health and Well-being of the Population: Addresses aspects related to the quality of life and health of the community. Sociocultural Appreciation: Involves the valorization and preservation of local sociocultural heritage. Added Financial Value: Covers the financial impact of circular urban practices. Innovation: Tackles challenges through new solutions for the CE

Source: the authors.

1 **Léa Gejer**
Architect and Urban Planner. Msc in Urban Environmental Management. PhD candidate in the Graduate Program in Architecture, Technology, and City, State University of Campinas. Postal address: Programa de Pós-Graduação em Arquitetura Tecnologia e Cidade, Unicamp, Av. Albert Einstein, 951 - Cidade Universitária Zeferino Vaz, CEP 13083-970, Campinas, SP - Brasil - Caixa-postal: 6021

2 **Vanessa Gomes da Silva**
Architect and Urban Planner. PhD in Civil Engineering. Full Professor at the School of Civil Engineering, Architecture, and Urban Planning, State University of Campinas. Postal address: Departamento de Arquitetura e Construção,

Unicamp, Av. Albert Einstein, 951 - Cidade Universitária Zeferino Vaz, CEP 13083-970, Campinas, SP - Brasil - Caixa-postal: 6021