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A framework to transition urban areas towards a circular economy

Um *framework* para a transição de áreas urbanas em direção à economia circular

Campinas

Léa Gejer Struchiner

A FRAMEWORK TO TRANSITION URBAN AREAS TOWARDS A CIRCULAR ECONOMY

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“Quando pensamos na possibilidade de um tempo além deste, estamos sonhando com um mundo onde nós, humanos, teremos que estar reconfigurados para podermos circular. Vamos ter que produzir outros corpos, outros afetos, sonhar outros sonhos para sermos acolhidos por esse mundo e nele pudermos habitar. Se encararmos as coisas dessa forma, isso que estamos vivendo hoje não será apensa uma crise, mas uma esperança fantástica, promissora.”

"When we think about the possibility of a time beyond this one, we are dreaming of a world where we, humans, will have to be reconfigured so we can circulate. We will have to produce other bodies, other affections, dream other dreams to be welcomed by this world and to be able to inhabit it. If we look at things this way, what we are experiencing today will not just be a crisis, but a fantastic, promising hope."

- Ailton Krenak

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Para David Henrique, Leon e Ivan.

RESUMO

A economia circular (EC) tem ganhado destaque como o paradigma econômico-ambiental a ser perseguido pela humanidade. Apesar de seu papel fundamental, a gestão de áreas urbanas em direção à economia circular tem assumido diferentes significados, abordagens e métodos. Portanto, este estudo visa esclarecer as abordagens para a circularidade em áreas urbanas, identificando as principais tendências na academia e na prática urbana, e propondo um *framework* para o design e avaliação de sistemas urbanos para circularidade. Para alcançar esse objetivo, os conceitos existentes na literatura para a aplicação da EC no contexto urbano foram explorados. A revisão da literatura realizada identificou que as áreas urbanas devem ser guiadas por quatro qualidades circulares essenciais: circulação de recursos e, regeneração, distribuição e conexão, e orientação local. Além disso, a pesquisa destacou a importância de mimetizar processos naturais em ambientes urbanos, uma estratégia que tem sido fundamental na prática da economia circular. Assim, o framework foi estruturado em torno dos princípios do *Cradle to Cradle* (Berço ao Berço/ C2C), que são inspirados no funcionamento da natureza, e complementado por outros sistemas de avaliação de sustentabilidade para áreas urbanas. Isso resultou no desenvolvimento de um framework composto por duas ferramentas complementares: uma ferramenta de avaliação de desempenho com indicadores quantitativos e uma linguagem de padrões para orientar o design e planejamento qualitativos. A aplicação do framework passou por uma prova de conceito por meio de um workshop e questionário envolvendo um grupo de profissionais da área de planejamento urbano, e testada e calibrada através do estudo de caso do projeto da Fazenda Argentina. Esse processo permitiu uma análise detalhada dos indicadores e revelou formas de incorporar padrões de design de EC para melhorar os resultados do projeto. O estudo de caso serviu como um exemplo prático, demonstrando a operacionalização da teoria da EC na prática urbana, destacando o potencial para replicabilidade e adaptação em outros contextos urbanos, e identificando os principais obstáculos encontrados em sua aplicação. Como resultado, o estudo avança no entendimento e aplicação do conceito da EC no desenvolvimento urbano, fornecendo uma estrutura com indicadores mensuráveis e padrões de design para profissionais de desenvolvimento urbano, facilitando a tomada de decisões informada e a implementação de estratégias circulares. O estudo de caso ilustra o potencial transformador do framework, destacando sua capacidade de possivelmente contribuir para a construção de um futuro em que áreas urbanas em todo o mundo possam prosperar em harmonia com o ambiente natural.

ABSTRACT

Circular economy (CE) has gained prominence as the economic-environmental paradigm to be pursued by humanity. Despite its fundamental role, the management of urban areas towards the circular economy has taken on different meanings, approaches, and methods. Therefore, this study aims to clarify the approaches to circularity for urban areas by identifying the main trends in academia and urban practice and proposing a framework for designing and evaluating urban systems for circularity. To achieve this goal, we began with an in-depth exploration of the existing concepts for applying the CE in the urban context. The literature review identified that urban areas follow four essential circular qualities: resource looping, regeneration, distribution and connection, and local orientation. Furthermore, the research underscored the critical role of mimicking natural processes in urban environments, which has been instrumental in practicing circular economy. The functioning of nature has inspired the Cradle to Cradle (C2C) principles, which aim to apply these principles in industrial products, architecture, and urban settings. Hence, these principles are the foundational cornerstone for urban areas' transition towards a circular economy. This approach is further complemented by integrating additional sustainability assessment systems tailored for urban contexts to design a framework comprising two complementary tools: a performance evaluation tool with quantitative indicators and a pattern language for orientating qualitative design and planning. The framework underwent a proof of concept through a workshop and questionnaire involving a group of urban practitioners and calibrated and tested through the case study of Argentina Farm. This process allowed for a detailed analysis of the indicators and revealed how incorporating CE design patterns can serve as a tool to improve project results. The case study served as a practical example, demonstrating the operationalization of CE theory in urban practice, highlighting the potential for replicability and adaptation in other urban contexts, and identifying the main obstacles encountered in its application. As a result, the study advances the understanding and application of the CE concept to urban development by providing a structure with measurable indicators and design dimensions for professionals in urban development, facilitating informed decision-making, and implementing circular strategies. The case study illustrates the transformative potential of the framework, highlighting its ability to possibly contribute to building a future where urban areas worldwide can thrive in harmony with the natural environment.

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1. Introduction

1.1. Context and research justification

1.1.1. *Sustainability in urban areas*

Human beings have continually altered nature to settle, survive, and prosper. We have benefited from surrounding environments by converting resources into new values and forms. For centuries, we have lived in cities that have served as hubs of culture, innovation, and knowledge exchange. Urban conglomerations and their resource utilization have emerged as significant facets of human existence on Earth, reshaping the interplay between humanity, ecosystems, and the planet they inhabit. Presently, 55% of the global population lives in urban areas (United Nations, 2018). In Southern countries, this figure is notably higher; in Brazil, for instance, cities encompass 84% of the population, and forecast shows that 90% of Brazilians to be urban dwellers by 2030 (Governo Do Brasil, 2021). Urban areas represent approximately 80% of the generated GDP (McKinsey Global Institute, 2012), consume 80% of all generated energy, and account for roughly the same amount of global resource use, carbon release, and solid waste production (UN-Habitat, 2013). Planning processes and urban policies have been geared toward sustainable development in recent decades, signaling that the built environment is the most promising sector for a transition toward sustainability (United Nations, 2012).

Despite the intensive efforts to formulate policies and methodologies for evaluating and implementing sustainability in urban areas, the advancements in this domain and the speed and scope of the changes it generates remain ineffective. There are some limits and discrepancies in its implementation as well as in the meaning of the concept of 'sustainability' (Baffour Awuah & Booth, 2014; Berardi, 2013; Morelli et al., 2013). The lack of a universally agreed-upon definition contributes to this challenge. While the Brundtland report initially defined 'sustainable development' and initiated the discourse and its challenges on the global agenda (Comissão Mundial sobre Meio Ambiente e Desenvolvimento, 1988), the concept has since garnered over a hundred different interpretations, with new interpretations still emerging (Hopwood et al., 2005).

Moreover, assessing urban sustainability across its diverse dimensions encounters several challenges. Although its core principles typically stem from the three pillars of sustainability (social, environmental, and economic), social and economic aspects often receive comparatively less emphasis and evaluation (Baffour Awuah; Booth, 2014). These challenges become even more evident in developing countries, where there exists a long way to go in regulating and democratizing decision-making in the urban environment and an imminent need to reduce social and economic inequality while simultaneously addressing substantial social and economic disparities, demanding balancing in distributing environmental costs and benefits associated with sustainability endeavors. Additionally, evaluation systems should adapt to distinct geographical and situational contexts, accommodating environmental and social features and agendas, construction and design practices, and market receptivity (Silva et al., 2003). Furthermore, existing methods for evaluating urban sustainability tend to adopt a static outlook, limiting their comprehensiveness and continuity. Typically initiated by developers at the onset of community development, these evaluation processes often need more active involvement of future users, leading to infrequent follow-ups on progress over time (Innes & Booher, 2000).

Finally, while sustainability is pivotal in reshaping urban environments, the prevalent perspective revolves mainly around 'eco-efficiency' objectives. This perspective aims to minimize environmental and social detriments through initiatives targeting "zero carbon," "zero waste," or "zero emission" (Ankrah et al., 2015a; Braungart et al., 2007; Van Dijk et al., 2014). However, this approach falls short in offering a definitive solution to environmental and urban challenges as it fails to break away from the current linear paradigm reliant on the 'production-consumption-disposal' system, perpetuating resource consumption, extraction, and emissions directly linked to economic growth (Pomponi & Moncaster, 2016). Consequently, waste generation persists at the end of a linear system, and its accumulation will continue to generate harmful impacts, albeit at a reduced speed (Booth et al., 2012).

1.1.2. *Circular economy as a new paradigm for urban areas*

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 in healthy metabolisms and extending the life cycles of materials and products. In this way, the circular model proposes strategies to overcome environmental issues and improve the productivity of economic systems, decoupling economic growth from resource consumption (Braungart, McDonough and Bollinger, 2007).

The transition to a CE in urban areas not only offers opportunities to create less vulnerable and more competitive regions, regenerating ecosystems and harnessing natural resources as local capital while driving innovation, new economic opportunities, and positive integration of urban areas with their surroundings (De Medici, Riganti and 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 like Germany and Japan have pioneered the adoption of 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", allocating significant funds to 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 have also adopted CE policies. For example, Colombia has developed its National Circular Economy Strategies (Gobierno de la Republica de Colombia, 2019), and Bogotá, its capital, has implemented neighborhoods aimed at combating climate change and improving the population's quality of life (Alcadía de Bogotá, 2022). The municipality of São Paulo, meanwhile, formalized a partnership with the Ellen Macarthur Foundation and launched the "Connect the Dots" (*Ligue os Pontos*) project, which promotes urban agriculture associated with food security for the most vulnerable population (Circular Economy Coalition Latin America & the Caribbean, 2022).

Thus, the concept of circular urban areas has become more precise, moving beyond waste management and system efficiency. It now focuses on reducing input, valuing internal resource cycles, and prioritizing the emulation of nature’s functionality, a pivotal element in achieving the dynamics of circular urban systems. However, there still needs to be a single definition for circular urban areas, nor a framework to measure performance and guide its development toward process improvement. The transition to circular urban areas requires the integration of 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).

The widespread adoption of CE principles and circular design practices within urban contexts hinges upon closing the innovation cycle by developing a design methodology and evaluation system. These approaches aim to establish comparable performance benchmarks that contribute to assessing existing and future projects while fostering continuous improvement in developed circular urban areas.

1.2. Hypothesis

The Cradle to Cradle (C2C) paradigm distinguishes itself from circular economy approaches by offering principles derived from natural systems, adaptable design criteria for urban contexts, and a commitment to fostering continuous improvement processes. Consequently, this study's central hypothesis asserts that **the C2C principles can establish a robust and multifaceted basis for constructing a methodological framework that addresses the intricate and diverse factors essential for the transition to circular urban areas.**

This framework would integrate qualitative and quantitative measures, complemented by existing sustainability assessment tools adapted explicitly for urban scales, and include a comprehensive set of requirements and performance metrics. Moreover, the C2C principles and methodology are instrumental in facilitating the communication of vital information for decision-making, bridging the concepts, categories, and indicators discussed with their practical implementation in circular urban initiatives, thereby demonstrating the capability of C2C to meet the complex demands of urban CE transitions.

1.3. Objectives

1.3.1. *Main research objective*

The main research objective is **to formulate a comprehensive design and evaluation framework, grounded in the Cradle to Cradle principles, that assists urban developers in transitioning towards circular urban areas.** This framework will encompass relevant key areas, categories, indicators, and design patterns adaptable to diverse contexts and local conditions, promoting circular economy practices within urban environments. This framework will serve as a tool to identify opportunities, guide project development and implementation strategies, establish policies, standardize processes, and direct progress.

1.3.2. *Specific objectives*

1. To conceptualize circular urban areas by delineating design qualities and criteria for implementing and measuring performance, ensuring alignment with the C2C principles to foster a regenerative and restorative approach.
2. To create design patterns and performance indicators within selected topics to structure the evaluation system, which involves understanding the intricate nature of urban environments, integrating critical elements of circular design, identifying synergies with the C2C framework, and encompassing pertinent aspects found in existing tools for delineating circular urban areas.
3. To establish performance criteria by identifying typical urban design practices and, conversely, practices of excellence (circular urban environments) within the evaluated topics for formulating performance scales.
4. To validate and assess the proposed evaluation framework's efficacy by testing it in at least one pilot case study. This will measure its capacity to evaluate and identify improvement opportunities.

2. Methods

The methods employed in this study followed a structured approach encompassing four distinct stages: (1) Integrative Literature Review; (2) Hypothesis Verification and Framework Structuring; (3) Framework Proposing and Testing; and (4) Conclusions and Research Continuation.

Figure 1 depicts the progression of this work through these stages, illustrating the respective outcomes according to the research objectives and the location of the information in the subsequent chapters. The following sections also describe these stages.

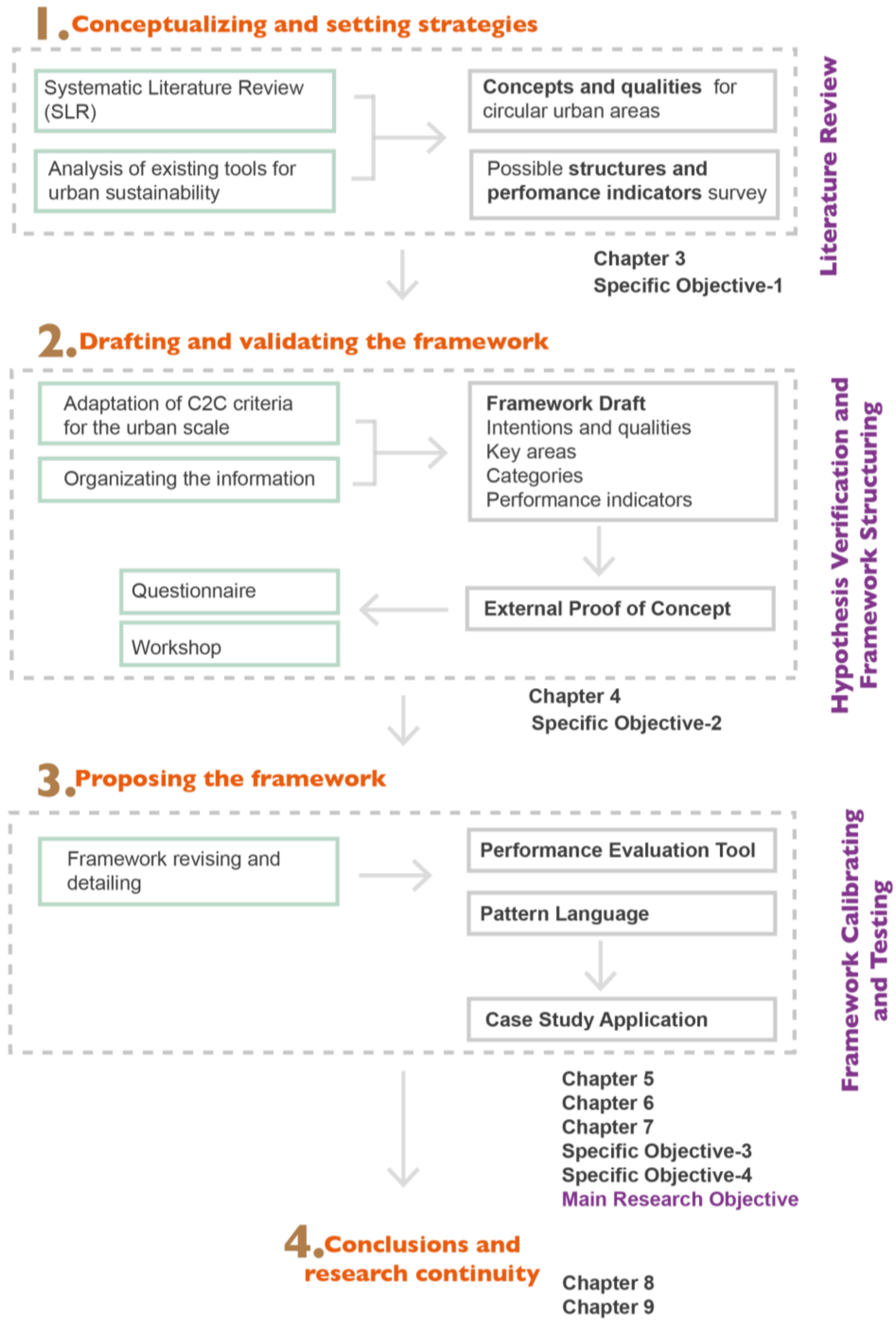


Figure 1. Thesis organization, stages of the research, and outcomes.

2.1. Integrative Literature Review

We carried out the integrative literature review in four major stages (Figure 2. Stages of the integrative literature review and results). Firstly, we conducted a Systematic Literature Review (SLR) based on the methodology Kitchenham (2004) proposed to identify the main conceptual trends and characteristics related to circular urban areas (Annex A - Systematic Literature Review Protocol). 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 ""What categories and indicators do researchers use to evaluate circular urban areas, and how do they implement them?".

After analyzing titles and abstracts, we examined 120 articles, identifying 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:

- 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),
- An article exploring the application of the Cradle to Cradle methodology in the built environment (Mulhall; Braungart, 2010).

Once we had defined the sample, we examined the criteria currently used in the Cradle to Cradle product certification program standard to assess their applicability at the urban scale. This examination identified four key areas and fifteen categories that characterize the application of CE in urban areas (Stage 2).

Simultaneously, we analyzed existing tools available for sustainable urban projects to evaluate how the urban environment has been accessed for sustainable issues. We examined the five most prominent evaluation systems for sustainable neighborhood, community, or city scales. This survey aimed to identify pivotal elements for implementing sustainable solutions in urban areas while highlighting gaps in achieving CE qualities within these frameworks. The analysis primarily focused on exploring the key questions: "What specific aspects do these evaluation systems measure?", "How do these systems evaluate the performance of urban areas?", "How do these systems facilitate the design, development, and optimization of circularity within urban settings?" and "What are the key elements or criteria that are absent in the evaluation systems for urban sustainability and are essential for achieving circularity?" (Stage 3). In the sequence, the indicators identified in the literature were organized based on these key areas and categories (Stage 4).

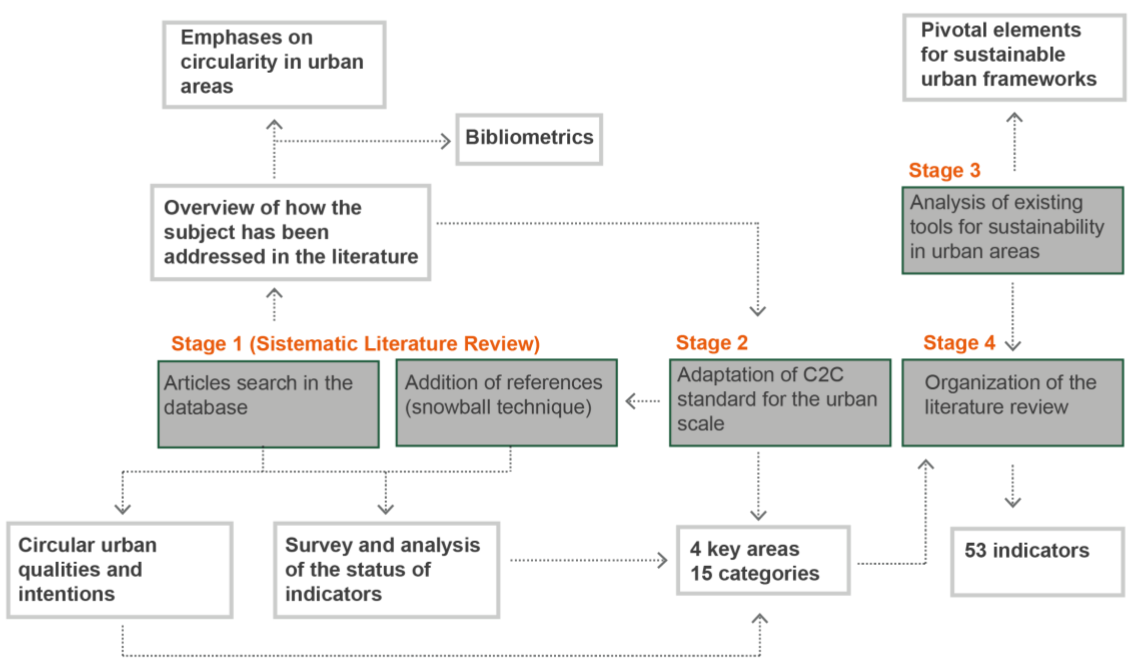


Figure 2. Stages of the integrative literature review and results

2.2. Hypothesis Verification and Framework Structuring

To verify the hypothesis, we adopted the Cradle to Cradle (C2C) approach (McDonough & Braungart, 2002) to structure the framework for circular urban areas. We embraced the three C2C principles to support the design of urban areas to mimic natural systems. The Cradle to Cradle Certified® Version4 standard, developed by the Cradle to Cradle Products Innovation Institute (2021) to implement CE aspects in materials and industrial products, was adapted for application in urban settings.

The examination of the five key areas currently used in the C2C product certification program standard led to the identification of four circular urban key areas and fifteen categories that characterize the application of CE in urban areas. Subsequently, we analyzed the status of each category based on the frequency and depth of discussion of the indicators within the literature sample examined. Finally, a set of indicators derived from literature, complemented by others developed by the author to complete the system, was organized based on the determined key areas and categories for the evaluation system.

This structure also served as the foundation for basing a pattern language to support the application of CE concept to urban areas. Within this pattern language, each key area and category was transformed into a distinct pattern. Furthermore, each category branched into an array of design dimensions, each evolving into new, individual patterns. The selection was based on literature and enriched by workshop and questionnaire participants' contributions.

In sequence, we detailed twelve patterns, derived from two pattern strings, Biological Nutrient Cycle and Construction Materials Cycles. These pattern strings were set to exemplify the pattern language structure. The selection of patterns was a strategic decision that reflects the intention to demonstrate the applicability of the framework at different levels of action and complexity. The selection of two pattern strings that range from high to low levels of hierarchy (from the most comprehensive to the most detailed) allows for a clearer understanding of how circular economy practices can be applied at different scales and levels of detail, facilitating the transition from conceptual knowledge to practical application.

In the Biological Nutrient Cycle pattern string, the existence of previous strategies in the case study provided a platform to test the chosen patterns. These strategies allowed for evaluating the patterns' effectiveness in a tangible context while offering the opportunity to refine the pattern structure, ensuring their alignment with the project's specific needs. In contrast, we selected the Construction Materials Cycles pattern string due to its critical importance in advancing circular urban development. Despite its significance, the case study revealed a notable absence of those specific guidelines. Thus, by choosing this pattern string, we aimed to illustrate the potential for innovation in sectors where CE principles have not yet been widely implemented.

The individual structure of each pattern was inspired by the work of Alexander et al. (1977) and adapted with the intention of simplifying and making the actions more direct and applicable. The sketches of the patterns were created using Adobe Illustrator, a tool for creating vector graphics, and are essential for visualizing the proposed solutions and facilitating the understanding of the concepts.

Finally, we established a performance criterion for each indicator in the performance evaluation tool. We evaluated the case study to provide practical parameters for accessing typical urban design practices. We compared each category and indicator result from the case study to practices of excellence in circular urban environments to create a performance scale to quantify and benchmark the success of implementing circular economy strategies within the urban context. This comparison allowed us to set realistic yet ambitious targets for urban development projects, aiming to reach or surpass these standards of excellence. The performance scale acts as a guiding metric for continuous improvement and innovation, encouraging urban planners and developers to strive for higher levels of circularity.

2.2.1. *External Proof of Concept*

The preliminary framework was structured around four key areas, encompassing 15 categories and 53 indicators. We conducted a questionnaire and workshop involving practitioners from architecture, urban planning, sustainability, circular economy, environmental engineering, and environmental management to validate the proposed framework. We invited sixty-six individuals to participate, resulting in 36 registrations, 27 workshop participants, and 20 questionnaire respondents. Both the questionnaire and the workshop have previously been approved by the Ethics Committee of the State University of Campinas (CEP-CHS), with respective approvals according to the CAEE numbers 72539523.6.0000.8142 and 65070722.0.0000.8142.

The workshop was co-organized with the Center for Studies on Urbanization for Knowledge and Innovation (CEUCI), a science center for development based at the Faculty of Civil Engineering, Architecture, and Urbanism at the State University of Campinas (Unicamp). CEUCI is one of the Science Centers for Development approved in the 2022 call by the São Paulo Research Foundation (FAPESP) for Science Centers for Development. Its mission is to contribute to the development of urban areas focused on knowledge and innovation, particularly those in fringe or urban expansion zones, guided by the 17 UN Sustainable Development Goals. CEUCI has used HIDS and Fazenda Argentina as case studies and collaborates with the coordination of HIDS Unicamp in the development plan for Fazenda Argentina.

Although this research is not a direct outcome of the CEUCI group, I, Léa Gejer, am an associate researcher with the group, which supported the workshop by helping prepare the guest list, organizing the event, and facilitating and moderating the sessions. Additionally, researchers from CEUCI contributed to the research by providing access to data related to the case study.This collaboration allowed for a more in-depth and contextualized analysis, enriching the results of the workshop and questionnaire.

The preparation of the moderators involved three meetings between the moderators and colleagues from CEUCI, in which the initial framework was explained, as well as the patterns to be evaluated. In these meetings, the best methodologies and tools to achieve the expected results were discussed, including the use of Zoom and Miro, in addition to the visual organization of the collaborative panel in Miro. These meetings also allowed for aligning expectations and ensuring that all moderators were familiar with the chosen tools and methodologies, promoting an effective and collaborative conduct of the workshop.

For the workshop participants' invitations, a list containing potentially specialized invitees was compiled and shared in spreadsheet format with the CEUCI researchers, aiming for a representation of various sectors (public, private, and civil society) capable of contributing to the studied scope. This phase included professionals working in the areas of circular economy and sustainability within urban planning and development, many of whom were associated with the HIDS (International Hub for Sustainable Development) project and the development of the Argentina Farm. The invitations were delivered by email commencing on October 9, 2023, and were reiterated approximately one week before the workshop. Additionally, the invitation was disseminated through the CEUCI newsletters and social media.

(i) Workshop: testing the pattern language

The workshop occurred online on November 08, 2023, and lasted for four hours. The meeting aimed to test the conceptual framework of CE in urban areas through an application study within the HIDS (International Hub for Sustainable Development) urban project. It utilized Zoom for video conferencing and discussion recording in thematic rooms while Miro was employed for interactive collaboration, visual organization, and didactics (Figure 3).

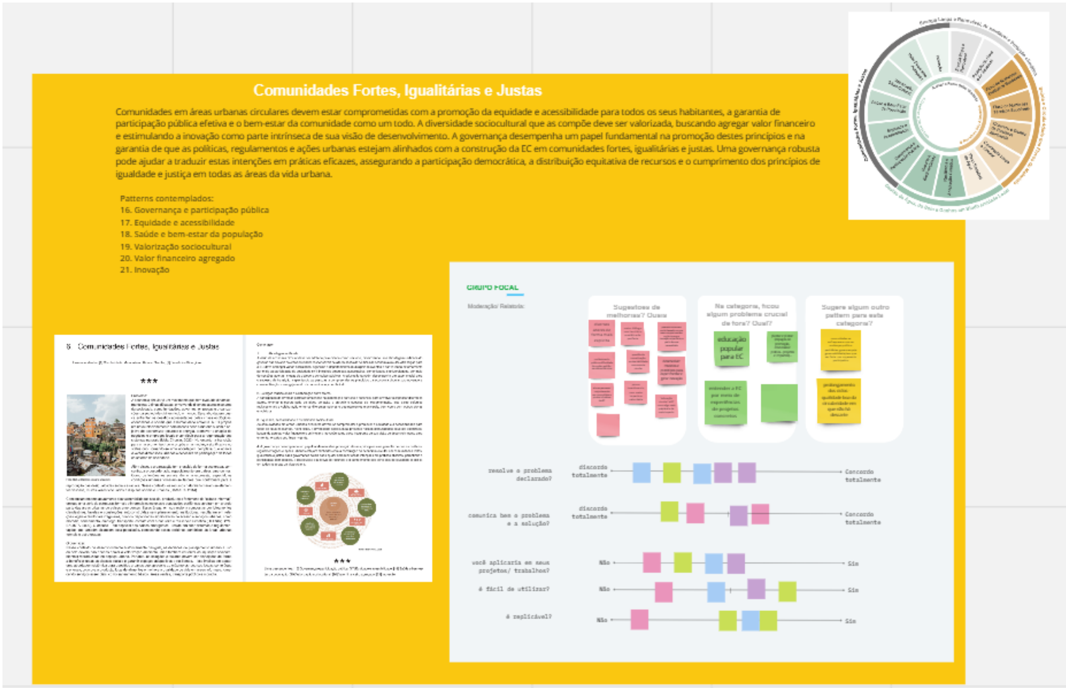


Figure 3. Example of the Miro framework organization for the workshop

The event started with two presentations introducing the problem discussion: the first involved discussions about the circular urban areas' framework being developed in this research, while the second focused on the case study of HIDS occupation plan. Next, participants were divided into four thematic rooms, each centered on a specific key area of circular urban areas: Clean and Renewable Energy, Healthy Air and Climate Protection, Health and Circularity of Material Flows, Water and Soil Management, and Local Biodiversity Gains; and Strong, Equal, and Fair Communities. During the sessions, we presented a design pattern related to each room's theme, allowing for an exploration of its specific applicability in urban areas, particularly in the case study. A moderator and a reporter led each room, guiding discussions, recording information, and taking notes.

To initiate discussions about each pattern presented, each moderator contextualized the pattern based on their objectives: offering guidance to designers for circular actions in new projects and steering ongoing improvements in existing projects. Subsequently, the debate on the design pattern ensued, addressing the following questions:

(a) Open questions

- What improvement suggestions do you propose for this pattern?
- Is there any crucial problem not addressed within the pattern? If so, what?
- Do you suggest any other pattern for this category?

(b) Using a Likert scale

- Does it address the stated problem? [strongly disagree ... strongly agree]
- Does it effectively communicate the problem and the solution? [strongly disagree ... strongly agree]
- Would you apply this pattern in your projects/work? [no ... yes]
- Is it easy to use? [no ... yes]
- Is it replicable? [no ... yes]

(ii) Questionnaire: endorsing the evaluation system

The questionnaire, administered via Google Forms, consisted of a list of open-ended and multiple-choice questions to endorse the key areas, categories, and indicators from the performance evaluation tool and to calibrate metrics by assessing the importance level of each proposed indicator within the framework. We evaluated the collected data from open-ended questions based on comments and suggestions to enhance the evaluation system. For closed-ended questions, the assessment involved aggregating the importance levels assigned by participants to each indicator, ranking them, and calibrating the weights within the framework. The complete questionnaire can be found in Annex C - Questionnaire.

2.2.2. *Detailing the Performance Criteria and the Pattern Language*

We adopted a desk research-centered methodology for detailing the proposed framework. This approach involved revising the framework based on feedback received during the proof of concept phase, which included a workshop and a questionnaire with urban practitioners. To detail the indicators, we conducted research encompassing technical and academic literature, information on governmental and institutional websites, and existing urban sustainability frameworks. We based the definition of the performance indicators scale and the patterns detailing on a review of existing academic literature and website research. This methodology allowed for identifying and defining precise and measurable indicators and for establishing patterns that can guide the implementation of urban practices aligned with the principles of the circular economy.

2.2.3. *Application of the Framework to a Case Study*

In this phase, we tested the framework within the confines of Fazenda Argentina. Acquired by the State University of Campinas (Unicamp) in 2013, the area is situated in the Barão Geraldo District, adjoining the existing campus. Situated on the outskirts of Campinas, São Paulo, much of the area remains undeveloped. This area is envisaged to be part of the future International Hub for Sustainable Development (HIDS).

The HIDS was established in 2013 following the acquisition of the Argentine Farm by Unicamp. The area spans 1.4 square kilometers and strategically contributes to Campinas' urban expansion (Figure 4). Over time, the HIDS concept has evolved to cover an area exceeding 1100 hectares, comprising higher education institutions, technology research and development centers, hospitals, and private technology and innovation companies. The primary objective of the HIDS project is to establish a framework that consolidates and coordinates initiatives, fostering partnerships and collaboration among institutions with expertise and shared interests in making tangible contributions to sustainable development (Unicamp, 2021a).

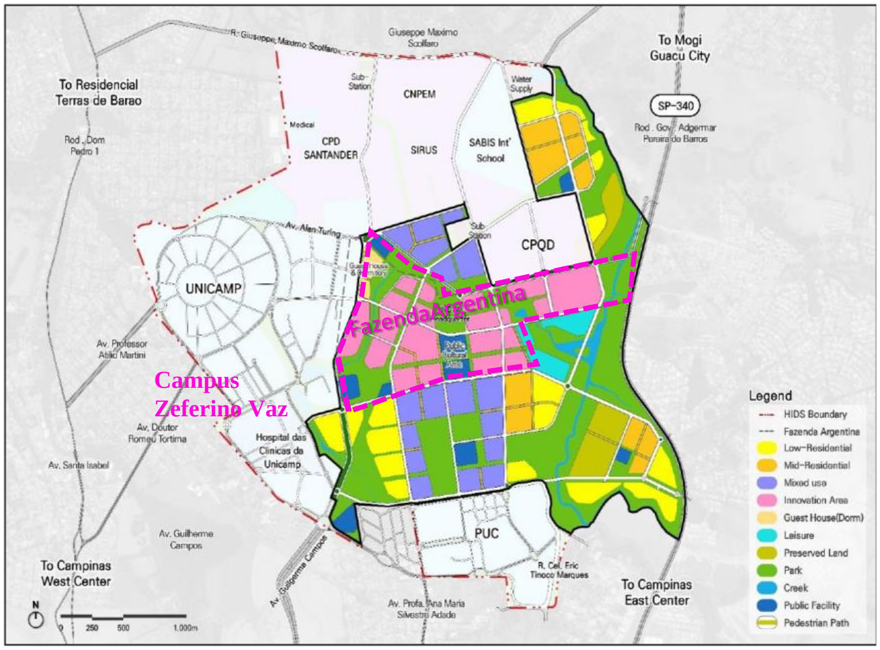


Figure 4. O HIDS e a Fazenda Argentina. Source: KRIHS (2022)

In March 2020, Unicamp and the Inter-American Development Bank (IDB) forged a partnership to finance the HIDS Masterplan developed by the Korean Research Institute for Human Settlement (KRIHS) (Unicamp, 2021a). KRIHS proposed urban planning principles and strategies rooted in New Urbanism and Transit-Oriented Development (TOD). These guidelines advocate for increased urban density and compactness, diversification of spatial uses, promotion of active mobility for short-distance travel, and encouragement of public transportation for longer trips (Noronha, 2023).

The KHRIS Masterplan hinges on introducing complementary activities to support and realize the objectives of establishing a fourth-generation innovation ecosystem based on knowledge society and economy in the region. Within this context, using the Argentine Farm for research, development, and innovation projects provides an opportunity to implement the UN's Sustainable Development Goals within a knowledge and innovation territory (CEUCI, 2022).

Hence, in the context of HIDS, Fazenda Argentina was selected as a focal area for this study to aid in constructing and applying CE issues to the conceptual spatial model, intending to facilitate its replicability in other regions with similar contexts. This case study delves into the KRIHS project centered around the Argentina Farm area and the plans and regulations governing Unicamp's Zeferino Vaz Campus, which will annex Fazenda Argentina. We aim to evaluate the institution's strategies aligning with the circular urban area framework and identify pivotal patterns capable of driving innovative design and development solutions for circular economy.

It was estimated a population of 10,551 individuals at the Argentina Farm. This estimate was based on a comparison with the number of current users at Unicamp’s “Zeferino Vaz Campus”, (Unicamp, 2021b) adjusted to the expectations of the case study of the Argentina Farm, as outlined in the Masterplan developed by KRIHS (2022).

We applied the Performance Evaluation Tool for Circular Urban Areasto the Masterplan KRIHS. We gathered secondary information by reviewing official documents and studies about the area. Additionally, we interviewed employees from the Unicamp administration and researchers from different faculties involved in the HIDS project.

The insights gained from the practical application of the framework within the context of the HIDS Masterplan allowed for a more nuanced understanding of the specific intricacies and requirements of the urban area under study. Thus, upon reviewing the challenges and opportunities encountered during the application of the case study, we have adjusted the initial framework proposal. This iterative process enabled refinement and enhancement of the framework, considering its applicability and replicability to other projects.

3. Concepts and Strategies for Circular Urban Areas

This section presents the outcomes of the integrative literature review, offering a perspective on transformative strategies for the transition toward circular urban areas. The section starts with "Conceptualizing Circular Urban Areas," a subsection where foundational principles and definitions anchoring the CE concept within urban contexts are analyzed. Subsequently, the exploration moves to "Indicators in Literature," raising relevant indicators identified in the SLR to gauge the effectiveness of circular urban strategies. This stage is followed by defining "Qualities of Circular Urban Areas," which delineates the key attributes that set circular urban environments.

The section concludes with "Frameworks for Urban Sustainability," including existing frameworks that facilitate the implementation of sustainability at the urban level. This overview pinpoints tools and methodologies that have been instrumental in driving urban sustainability innovations and may be adapted or refined to align with the CE principles. It provides insights into how urban areas can track performance, guide continuous improvements, and ultimately achieve an effective transition to circular practices.

3.1. Conceptualizing circular urban areas

The circular economy approach proposes a break with the current linear production model, which operates on cradle-to-grave flows, presenting a set of strategies to generate healthy metabolisms that function from cradle-to-cradle. The term 'metabolism' draws parallels between material flow systems and the internal processes of living organisms, highlighting the need for healthy and circular processes. In Cradle to Cradle processes, waste is minimized from the outset through the deliberate design of products and systems in distinct technical and biological metabolisms (Braungart; Mcdonough; Bollinger, 2007).

When applying this logic to the urban scale, Girardet (2015) describes urban areas as regenerative and complex systems, hubs of vibrant interaction between human beings and the environment.

Cities are likened to dynamic ecosystems, possessing inputs of energy and materials, with social and cultural dimensions interwoven within nature's biotic and abiotic systems (Newman, 1999). Moreover, an anthropocentric perspective emerges within this context, as urban areas inherently respond to human needs and aspirations. Thus, envisioning a positive future for urbanization necessitates integrating enduring measures to enhance the quality of life and social aspects of sustainability (Berardi, 2013).

In this context, urban centers stand as key elements in the transition to a CE, which has gained relevance as a new economic-environmental paradigm to overcome environmental issues by decoupling resource use and economic growth. Closing metabolic cycles within urban areas addresses environmental concerns, fosters ecological regeneration, improves social and health conditions, and maximizes regional economic opportunities by integrating urban areas with their supporting regions. However, transitioning to circular urban areas faces numerous challenges due to multiple urban layers, actors, sectors, and locally rooted cultural, political, and social contexts.

A clear concept for circularity in urban areas may allow urban practitioners to replicate and transfer criteria and requisites to different scenarios. Despite the debate over the past decade, the conceptualization of CE still needs to be discussed and clarified: Kirchherr; Reike; Hekkert (2017) found over 114 definitions in their review. This lack of consensus worsens when applying CE approach to cities. Cities are complex systems where interactions between human beings and the environment are more intense than those observed for products and businesses. Furthermore, many of the existing CE frameworks focus on micro-level activities (industrial products) and meso-level (buildings), while studies on macro-level (cities) are still missing (Pomponi; Moncaster, 2016). Designing such multi-dimensional circular cities requires the connection of multiple spatial practices and frameworks that are currently disconnected (Marin; De Meulder, 2018).

The Systematic Literature Review (SLR) showed that Europe has concentrated the leading research on circularity in the built environment, 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 contributes 12%. South and Central America account for around 3% of the authors in the sample, and Africa for 1%.

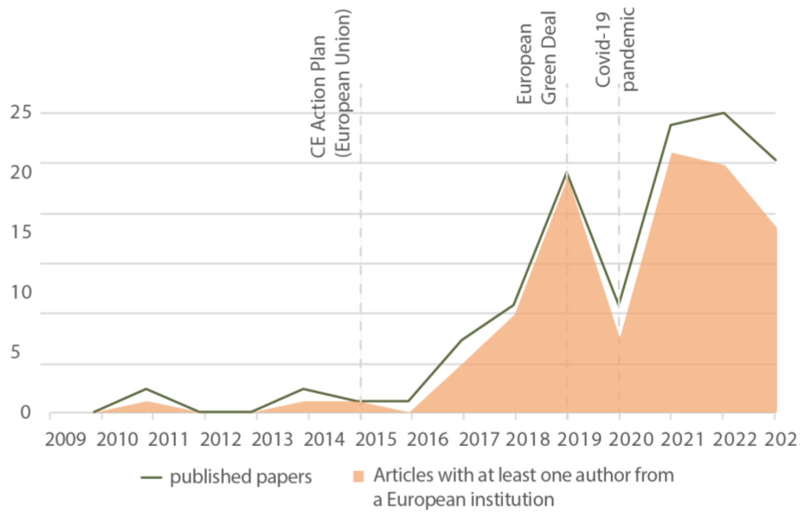


Figure 5. Articles published by year.

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 from 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 5). 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.

The SLR identified four emphases addressing different aspects related to circular urban areas. 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,
(iv) Conceptualization of Circular Urban Areas.

These four emphases are intrinsically interconnected and complement each other, exposing the interdisciplinary and complex nature of CE in urban areas. The following sections detail each of these emphases.

(i) 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 (Annex B - Articles According to Resource Flow).

(ii) 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, which was implemented in Sweden and China. Nexus is an approach aimed at conserving and regenerating water, energy, and food systems (Al-Azzawi et al. 2022, Xue, J. et al., 2018, Piezer, K. et al.,2019). This model can also be associated with waste flow (Valencia, Zhang and Chang, 2022), sanitation (Nhamo et al., 2021), infrastructure, and land use (Williams, 2019b). In all these cases, the Nexus energes as the basis for achieving urban resilience by integrating interconnected flows and involving 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 implemented NBSs 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, it becomes possible to significantly extend the benefits achieved by urban areas (Langergraber et al., 2020).

(iii) 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 and 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 to empower citizens to create a long-term vision to face possible uncertainties.

Since circular potential varies according to the characteristics of each urban system, urban areas can adapt CE strategies to each reality. It is up to urban practitioners 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, promoting citizen awareness, and encouraging technological development (Obersteg et al., 2019).

(iv) 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 and Bocken, 2018; Williams, 2019a) or for product design (Baffour and Booth, 2014 and Booth et al., 2012) to apply them at the urban scale. Others suggest adapting the UN sustainability agenda (de Ferreira and Fuso-Nerini, 2019), the urban ecology principles (Pelorosso, Gobattoni and Leone, 2017), or the optimization of "ecocity" models (Marin and 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 has developed the ReSOLVE framework to guide companies towards CE. ReSOLVE comprises 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 (2019b). At the same time, the article suggests eliminating the Virtualize and Exchange principles, which would significantly modify the original framework. Prendeville, Cherim and Bocken (2018) propose simultaneously applying top-down and bottom-up processes for each ReSOLVE principle to address the same limitations. Government institutions, such as strategies and public policies, guide top-down processes. 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, initialy developed for business, to the urban context.

- ***Low entropy city***

The concept of a "low entropy city" bases itself on the idea that the principles of nature underpin CE, and when applied to urban environments, it refers to the "thermodynamics of open systems." Urban areas maintain their autonomy as autopoietic systems while remaining open to interaction and compensating 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, local harvesting of resources occurs, and human activities transform the generated waste into benefits for the population and the environment by minimizing waste, improving public health, and fostering positive relationships between different components of the urban system (Pelorosso; Gobattoni; Leone, 2017).

- ***Regenerative Circularity for the Built Environment***

Sala Benites, Osmond, and Prasad (2023) point out some gaps in the CE approach when applied to urban environments, highlighting its predominantly technical emphasis, a 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: focuses on managing urban resource flows and stocks.

(2) High-Quality Adaptable and Resilient Urban Systems: This initiative aims to create resilient urban systems that offer a high quality of life and well-being.
(3) Healthy and Bioconnected Urban Ecosystems: involves the interconnection of urban green spaces.
(4) Good Governance and Thriving Communities highlight the importance of effective governance and the strengthening of local communities, which contribute to a thriving economy and a healthy community environment.
(5) Systemic Approach and Positive Impact: emphasizes the need for a holistic and systemic approach to generate positive impacts on both a local and global scale.

- ***Cradle to Cradle***

The Cradle to Cradle (C2C) paradigm, proposed by McDonough and Braungart (2002a), 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 [n.d.]. This model seeks to develop healthy, circular, and regenerative processes that eliminate waste by designing products and systems while maximizing 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 (Figure 6).
- **Use the current solar income** by capturing local, clean, and renewable energy.
- **Celebrate diversity** by exploring local potential, materials, and cultures.

Since 2012, C2C certification has been obtainable by industrial products, 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 creating building elements that allow for their deconstruction and high-quality recycling within technical and biological cycles. Additionally, designers integrate water and biological nutrient flows into these buildings while actively promoting biodiversity and contributing to improved air quality and climate (Mulhall and Braungart, 2010).

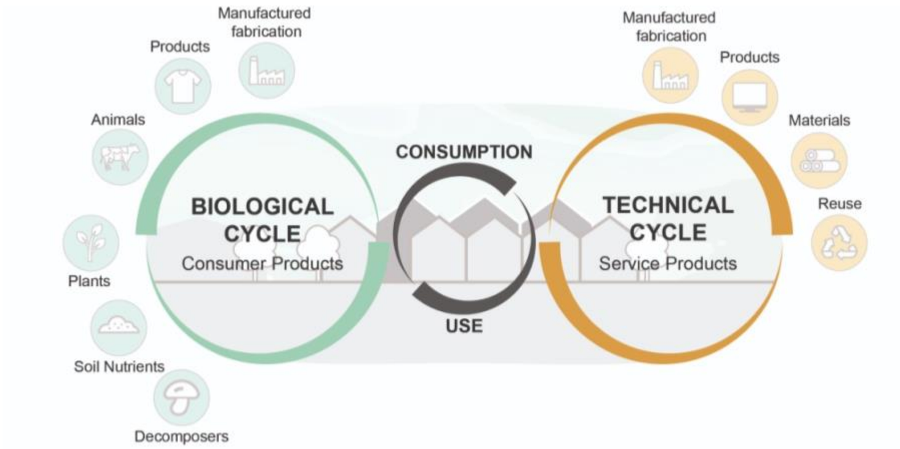


Figure 6. Technical and biological metabolisms. Adapted from McDonough & Braungart (2002).

Although C2C has been successfully applied to various industrial products and inspired building projects, its expansion to the urban scale is still under development. Despite some exemplary developments demonstrating 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.

Figure 7. Park 20/20. Source: William McDonough and Partners, 2017.

Park 20/20, for example, was conceived as the first urban system developed to implement the C2C approach (Figure 7). This development, covering an area of 114,000m², was designed in 2010 by William McDonough and Partners in Hoofddorp, the Netherlands. Its Masterplan promotes regenerative design at various scales, highlighting the following key points: (1) orientating buildings to optimize the capture of solar and wind energy; (2) the development of a regenerative landscape with diversification of vegetation, landscaped corridors, and additional green areas on roofs and parking lots; (3) the implementation of decentralized facilities for water treatment and renewable energy production; and (4) the adoption of the C2C agenda to eliminate waste generation, including the use of building materials designed for disassembly and safe return to their cycles (American Society of Landscape Architects, 2010).

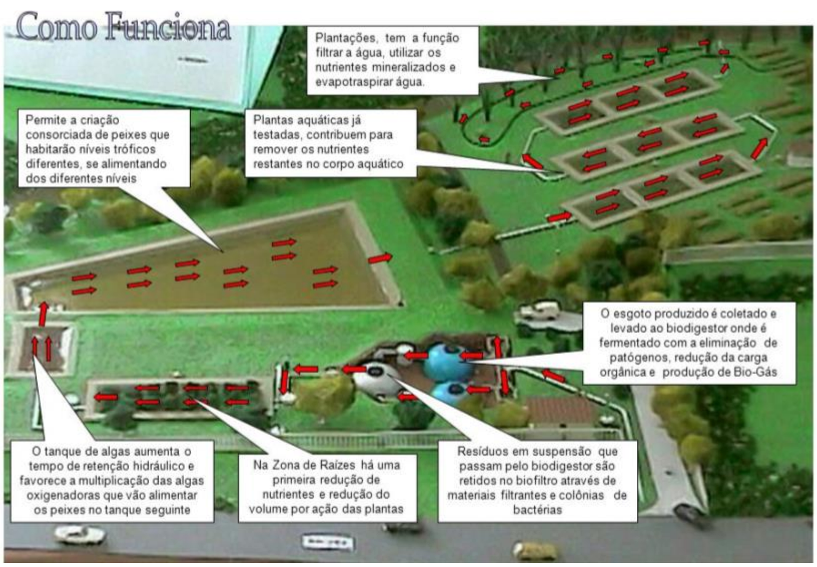


Figure 8. Integrated Biosystems. Source: O Instituto Ambiental (2017).

Another example of applying C2C principles in urban areas is the integrated biosystems, which provide solutions for the decentralization of wastewater treatment in cities of emerging countries, providing a range of benefits to the local population (Figure 8). 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 from organic sludge decomposition to produce domestic gas. Community residents operate these systems, generating clean water, biogas, and food, improving public health, and regenerating local ecosystems (O Instituto Ambiental, 2017).

3.1.1. *Discussion about CE existing concepts*

The application of the CE in urban areas is intrinsically related to specific local factors such as resource availability, territorial characteristics, and cultural demands. In addition, it involves structural and systemic changes that require the 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, initially 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 et al., 2017) and RC4BE (Sala Benites et al., 2023) focus on triggering systemic change at various levels of urban planning. Although these approaches seek to identify gaps in CE paradigms in urban areas, there is still a need for a more in-depth examination of their practical implications and 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 model, conceived by McDonough and Braungart (2002a), despite originating at the industrial product scale, shows potential scalability at the urban level, as demonstrated in the case studies. Furthermore, 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 urban planning areas, maintaining consistency throughout this adaptation.

3.2. Indicators in literature

During the SLR, indicators were identified and organized into four key areas that outline the organization of circular urban areas, as represented in Figure 9. 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 (Annex A - Systematic Literature Review Protocol).

This organization is thoroughly explained in Section 3, and the key areas are:

(1) Clean and Renewable Energy, Healthy Air, and Climate Protection,

(2) Health and Circularity of Material Flows,

(3) Water and Soil Management and Enhancements in Local Biodiversity,

(4) Strong, Equitable, and Just Communities.

Despite the diverse approaches and extensive range of indicators discovered in the literature, they are well-balanced among the four established key areas. This balance offers a foundational understanding of how urban contexts have been directing the implementation of the CE.

Notably, the key area "Health and Circularity of Material Flows" housed the highest number of indicators, mainly focusing on material circularity and urban systems. Within this key area, 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. The importance of these categories highlights 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.

In addition to working on resource flows in closed metabolisms, the "Strong, Equal, and Fair Communities" category's broad presence represents how CE can 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. Notably, the "Governance and Public Participation" category, although less represented in the sample, deserves special attention since 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.

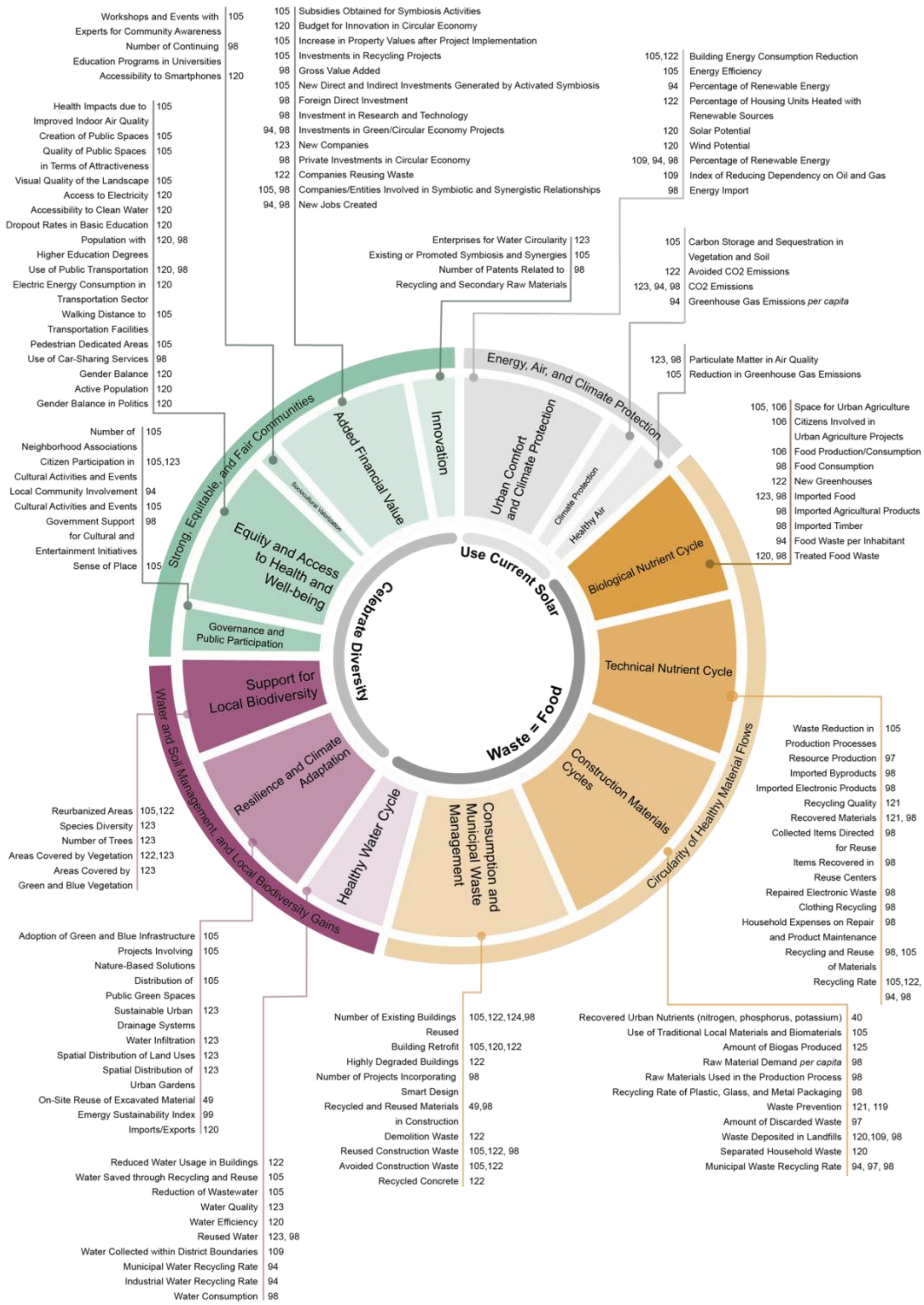


Figure 9. Criteria, categories, and indicators identified in the literature.

3.3. Qualities of Circular Urban Areas

The transition from a harmful, anthropocentric society that exploits nature to a regenerative model requires a fundamental shift in how we live, work, and interact with our environment. This paradigm shift demands the acknowledgment that humans are part of nature, not separate from it (Roös, 2021). Thus, to successfully achieve circular urban environments, human systems must mimic the functioning of natural ecosystems present in society-produced systems as part of this totality. Urban projects should encourage a surplus of positive effects in the region to advance human activities in climate adaptation, restoration, and regeneration of human and ecological systems. Moreover, they should strategically disperse circular practices throughout the territory instead of concentrating them. This approach leverages local opportunities to diffuse and perpetuate the value generated, emulating the spiraling dynamics of resource distribution found in natural ecosystems.

Our literature review revealed four essential urban qualities for the successful practice of nature's functioning in urban systems. While the literature repeatedly identifies these qualities as distinct elements, they are, in essence, interrelated concepts that must be collectively realized: Resource Looping, Regeneration, Distribution and Connectivity, and Locality. While often explored in isolation, each of these qualities synergistically contributes to the holistic development of circular urban areas. The following sections describe these qualities.

- ***Resource Looping***

When we look at urban areas from a resource perspective, we see them mainly as consumers of materials and generators of waste. Every day, a significant amount of resources enters a typical city. After consumption, some flows, such as wastewater or debris, are directed out of the urban system. In contrast, others, like construction systems, metals, or plastics, remain internally, constituting urban stocks (Voskamp et al., 2017).

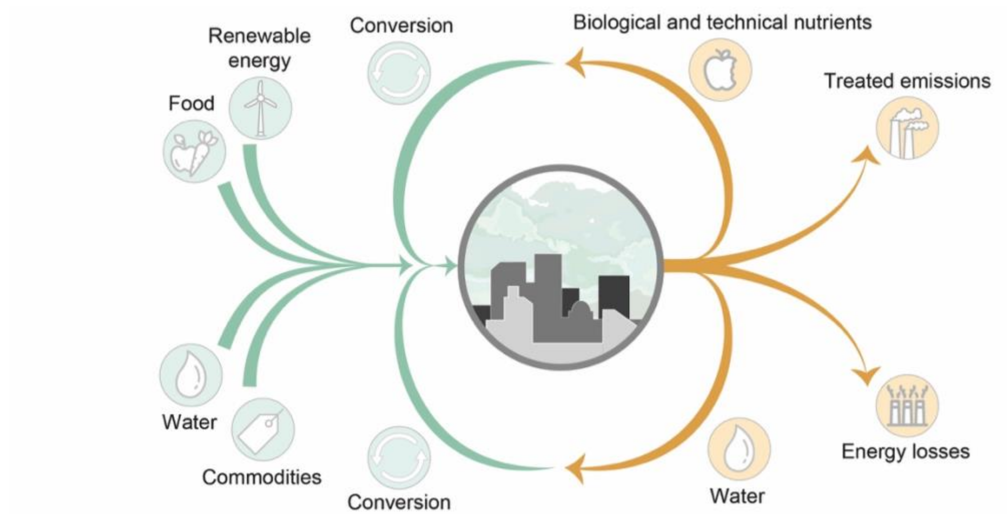


Figure 10. Circular Urban Metabolism. Adapted from (Girardet, 2015)

Although often labeled as waste, certain elements of production and urban stocks contain a set of latent potential resources that can be recovered, recycled, and reused, along with other renewable and beneficial resources. Urban areas can then be seen as reservoirs of these resources, as they can become producers of primary and secondary resources of nutrients, water, and energy, positively transforming the outcomes of human activities (Voskamp et al., 2017).

To ensure the continuous, high-quality cycle of nutrients, water, and energy, urban areas demand the development of effective strategies for the transition from linear to circular urban metabolisms, understanding the dynamics of the inflows and outflows, and defining clear objectives for their continuous optimization. Additionally, it is fundamental to seek the highest process efficiency, optimizing resource use, prioritizing local and renewable materials, recirculating resources, and enhancing positive effects, considering the following flows: energy, water, biological and technical nutrients, construction materials, within specific land use, and local biodiversity (Figure 10).

- ***Regeneration***

Urban Ecology offers a straightforward framework illustrating the interactions between nature and people, emphasizing their mutual impacts, both positive and negative (Figure 11). Within our current societal structure, the predominant interaction—humans affecting nature—holds the highest significance and concern, resulting in predominantly adverse effects that hinder positive societal and environmental development. Consequently, as more than half of the global population resides in urban areas, cities have expanded their ecological footprints, substantially covering the Earth's surface and strongly contributing to climate change (Forman, 2013).

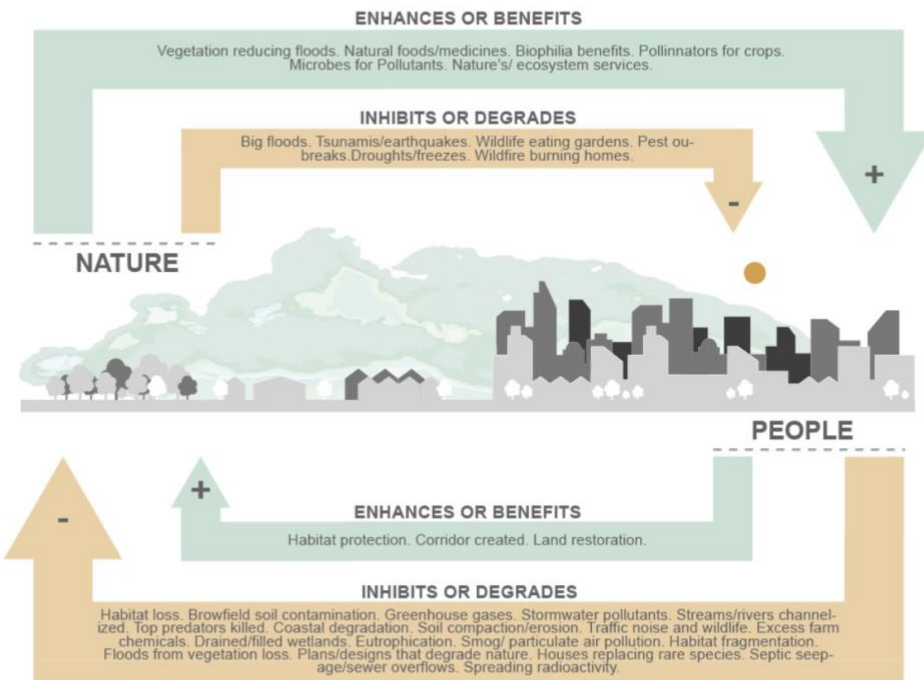


Figure 11. Urban Ecology model for nature-and-people interaction. Adapted from Forman (2013).

Hence, the present challenge extends beyond the creation of merely sustainable cities; it now demands the establishment of truly regenerative cities. These cities must not only strive for resource efficiency and low carbon emissions but actively seek to enhance the ecosystem services they receive from environments beyond their boundaries (Figure 12). The aim is to ensure urban areas not only minimize human activities that degrade the environment but also maximize activities that restore and regenerate ecological systems. Regeneration involves continually enhancing resources by integrating natural processes, community initiatives, and human behaviors (Girardet, 2015).

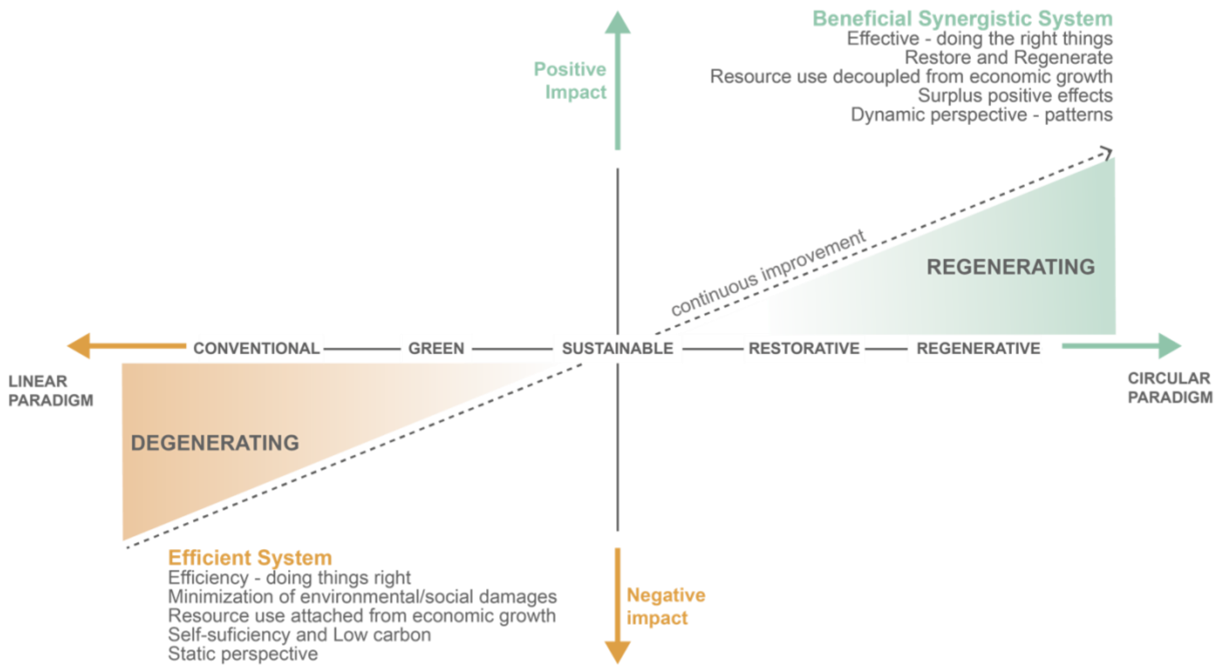


Figure 12. Range of sustainability approaches. Adapted from Reed (2007).

In this context, circular economy embraces the concept of regeneration (Ellen MacArthur Foundation and McKinsey & Company, 2014). While the term 'circular' logically aligns with the transition toward a circular economy, the objectives of 'circular urban areas' extend beyond solely closing metabolic loops or designing low-carbon, self-sufficient regions. These areas aim to elevate the capacity of systems, fostering conditions wherein urban structures, biospheres, and cultures can restore, rejuvenate, and thrive.

- ***Distribution and connectivity***

Circular urban areas distribute conditions to settle the interaction of organisms, built structures, and the physical environment, forming complex and dynamic systems of connected mosaics, flows, and movements. Besides, the land mosaic has structure, function, and dynamic. Structure refers to spatial patterns (components and arrangements), and function relates to flows, movements, and interactions. Dynamic means altering structural patterns and functioning over time, as in a changing mosaic (Figure 13). One can view an entire city as an ecosystem or its smaller components, such as lake ecosystems, woodland ecosystems, and residential community ecosystems, as legitimate units for study and management (Forman, 2013).

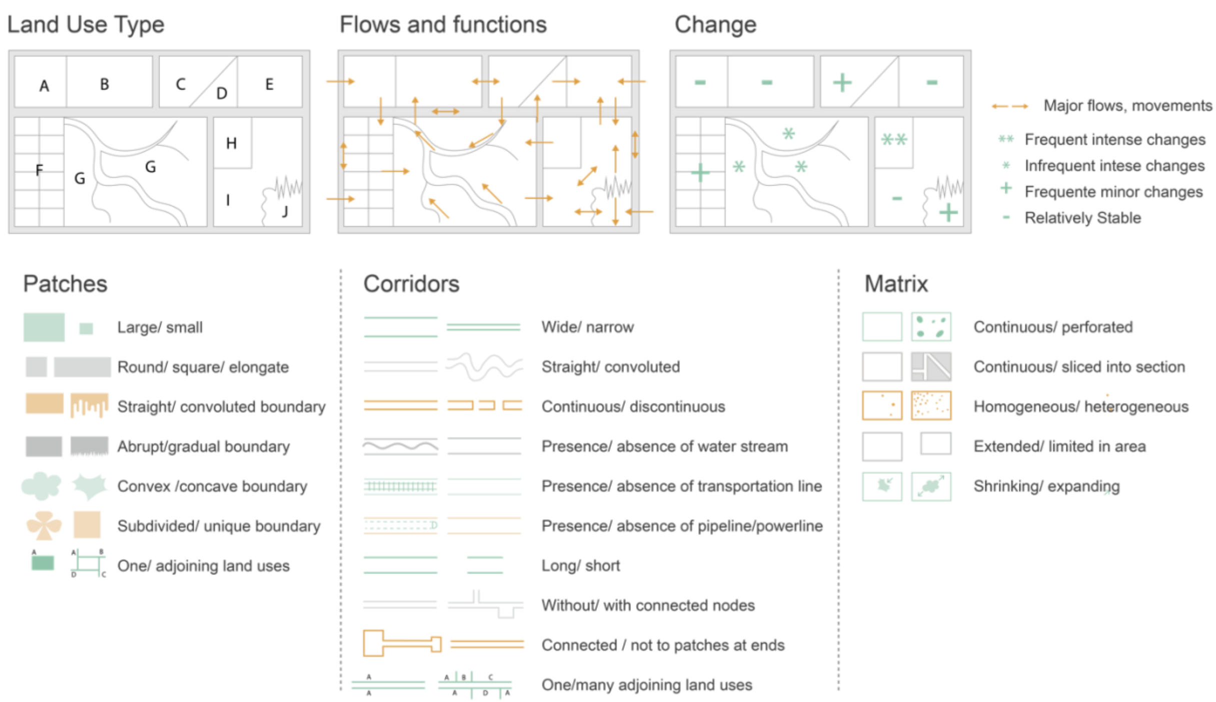


Figure 13. Urban systems are complex and dynamic systems. Adapted from Forman (2013).

Thus, units of study should be addressed as a starting point to foster transition, and gradually disperse regenerative solutions for other units, and explore potential characteristics for each city or region. However, these units of study should not be isolated elements, they should be connected as it occurs in the web of nature (Alexander, 1979). In essence, in nature, everything is, at the same time, **distributed and connected**, linked in levels of scale, forming a “webstring network” (Roös, 2021).

Being distributive refers to dispersing and circulating created value instead of concentrating it. Thus, planners should design distributive economies that naturally form a network whose many nodes, larger and smaller, are connected, as in a web of flows or as in nature's networks. These networks are structured by branched fractals, ranging from a few larger ones to many medium-sized ones, to a myriad of small ones, imitating the structures of, for instance, rivers tributaries, branches of trees, blood vessels in the body, or the veins of a leaf. Resources such as energy, matter, and information can flow through this network to achieve a fine balance in the system (Raworth, 2017). The land mosaic model strengthens the distribution of resources and the diversity of systems and activities in determined boundaries, providing conditions for the system's efficiency and resiliency in a circular urban area (Pelorosso et al., 2017).

Finally, urban areas are intrinsically connected to other systems as they exchange materials and energy with areas outside urban limits to maintain internal levels of complexity, organization, and functionality (Pelorosso et al., 2017). Hence, although architects and urban ecologists suggest the importance of self-sufficiency for ecological optimization in built environments, resources tend to flow at various scales within and outside their boundaries, like in any other ecosystem. Therefore, the effectiveness of a system depends not only on the system itself, but in its interrelation with other systems beyond its boundaries. This distributive interconnected network of systems strengthens urban fabrics towards a more resilient and adaptive model.

- ***Locality***

Locality is an essential quality that respects the uniqueness of each urban context, fostering tailored solutions that are culturally relevant and ecologically integrated. Although CE for urban areas can be formulated and discussed in general terms, its implementation depends on the specific local potentials, e.g., resource availability, geophysical aspects, and local needs. Harvesting local resources and closing metabolic loops encourage CE practices and regenerating local natural capital, mainly by providing powerful motivation for changing social practices, lifestyles, and provision systems (Williams, 2019a).

Moreover, features inherent to urban neighborhoods and district areas, e.g., physical proximity, complexity, and connectivity, also facilitate closing metabolic cycles due to relatively short distances, and possible joint investments in a community (Dobbelsteen, 2008). Furthermore, the emergence of local businesses, industry, and financial institutions increases economic self-reliance, promotes local environmental protection, and builds local human capital. In this context, local infrastructure for connecting symbiotic flows is essential in successfully implementing circular strategies (Williams, 2019a).

Locality also refers to local knowledge, which creates appropriate solutions for protecting natural capital, local resource availability, physical environment, and social and cultural practices (Williams, 2019a). Local knowledge integrates our daily experience and inspires our choices about the place we want to live and our experiences as communities, overcoming a 'civilizing abstraction' where humans have detached from the earth, rivers, and landscape (Krenak, 2019). Exploring local potentialities fortifies diversity in the form of biodiversity, increasing systems' resiliency and regeneration, and of multiculturalism, which can be especially powerful to emerging economies to explore the enormous potential of contribution of local peoples to re-construct our relationship with land and its resources.

3.3.1. *Discussion of Circular Urban Qualities*

The literature identifies the essential circular urban qualities – Resource Looping, Locality, Distribution and Connectivity, and Regeneration – as distinct yet interrelated concepts. Among these, the quality of "Locality" stands out for its critical role, acting as a foundational thread that not only connects but also significantly enhances the other attributes. By emphasizing locality integration into urban initiatives, we ensure the optimal use of locally available resources, recognizing that these resources vary across different contexts. This emphasis on Locality promotes the effective use of local resources, thereby fostering Resource Looping and strengthening the qualities of Regeneration, Distribution, and Connectivity. It accomplishes this by customizing solutions to align with each area's unique cultural, social, and environmental characteristics. In this way, Locality serves as a critical enabler that ties together the framework's diverse elements, ensuring that benefic urban development is resonant with its environment's specific needs and potentials.

Both quantitative and qualitative tools are indispensable to operationalizing these qualities and intentions. Quantitative tools, such as metrics and indicators, provide measurable benchmarks for tracking progress and outcomes. These include data on energy consumption, waste generation, water usage, locally sourced materials, among others. These tools enable policymakers and practitioners to assess resource flows, the effectiveness of regenerative practices, and the extent of connectivity and distribution within the urban fabric.

On the other hand, qualitative tools are equally important as they capture the nuanced aspects of urban systems that numbers alone cannot reflect. These tools include design patterns and dimensions to create narrative frameworks that articulate community values, cultural significance, and technologies for continuous optimization processes. They help ensure that CE principles are context-sensitive, culturally relevant, and socially inclusive.

Together, these quantitative and qualitative tools can form a robust methodology for implementing the essential qualities in urban areas. They support a dynamic and iterative process of planning and development that is responsive to the evolving needs of urban systems and their inhabitants. By leveraging both types of tools, urban planners and decision-makers can create a detailed roadmap for the transition to circular urban areas, informed by empirical evidence and enriched by local knowledge and community aspirations. In summary, this section underscores the necessity of a holistic and adaptive approach that treats the four circular urban qualities as an integrated whole, thereby addressing the inherent complexity of the CE transition in urban contexts. It also points to the need for a refined framework with improved design patterns and indicators to guide this multifaceted transition effectively.

The following section provides an overview of the application of quantitative and qualitative tools within existing frameworks of sustainable urban areas to set the ground for the current implementation of sustainability within urban settings. It also identifies the gaps in achieving the intended circular urban qualities.

3.4. Existing frameworks for urban sustainability

The first environmental assessment systems for urban areas were introduced by the building and construction sector and mainly consisted of two categories. First, these frameworks promote sustainable construction through market mechanisms, such as LEED, CASBEE, and BREEAM. These frameworks usually apply a simple structure in the format of a checklist to be easily absorbed by designers and the market in general. Second, research-oriented methods, e.g., Green Building Challenge, and SBTool, are more centered in methodological development of scientific exploratory and academic knowledge (Silva, 2003).

Despite the high attention given to *green buildings* assessment systems, they have shown not to guarantee the sustainability of the built environment as a whole. The existing frameworks often overlook several aspects that may affect the impact of the built areas. In response to this criticism, experts have scaled up the scope of these tools from the building level to the built environment level (Berardi, 2013). Therefore, this study has analyzed the structure, and methodological discussion of the following environmental assessment systems for urban scales:

- LEED for Neighborhood Development (USGBC, 2014);
- CASBEE for Urban Development (Institute for Building and Energy Conservation, 2015),
- SBTool for small urban areas (Larsson, 2016),
- Living Community Challenge (International Living Future Institute, 2017),
- Life Cycle Analysis for Neighborhoods (Lotteau et al., 2015)

- ***LEED Neighborhood Development***

The Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND) rating system, established in 2007, assesses neighborhood sustainability across five credit categories: Smart Location & Linkage, Neighborhood Pattern & Design, Green Infrastructure and Buildings, Innovation and Design Process, and Regional Priority Credits. Projects must fulfill prerequisites and earn a minimum of 40 points for certification, with higher scores achieving Silver to Platinum levels. Points based on the relative importance of its contribution to the goals are allocated to each credit in the rating system. The result is a weighted average: credits that most directly address the most important goals are given the most significant weight (Figure 14) (USGBC, 2014).

LEED v4 for Neighborhood Development Plan
Project Checklist

Project Name:
Date:

Yes	?	No			
0	0	0	**Smart Location & Linkage**		**28**
Y			Prereq	Smart Location	Required
Y			Prereq	Imperiled Species and Ecological Communities	Required
Y			Prereq	Wetland and Water Body Conservation	Required
Y			Prereq	Agricultural Land Conservation	Required
Y			Prereq	Floodplain Avoidance	Required
			Credit	Preferred Locations	10
			Credit	Brownfield Remediation	2
			Credit	Access to Quality Transit	7
			Credit	Bicycle Facilities	2
			Credit	Housing and Jobs Proximity	3
			Credit	Steep Slope Protection	1
			Credit	Site Design for Habitat or Wetland and Water Body Conservation	1
			Credit	Restoration of Habitat or Wetlands and Water Bodies	1
			Credit	Long-Term Conservation Management of Habitat or Wetlands and Water Bodies	1
0	0	0	**Neighborhood Pattern & Design**		**41**
Y			Prereq	Walkable Streets	Required
Y			Prereq	Compact Development	Required
Y			Prereq	Connected and Open Community	Required
			Credit	Walkable Streets	9
			Credit	Compact Development	6
			Credit	Mixed-Use Neighborhoods	4
			Credit	Housing Types and Affordability	7
			Credit	Reduced Parking Footprint	1
			Credit	Connected and Open Community	2
			Credit	Transit Facilities	1
			Credit	Transportation Demand Management	2
			Credit	Access to Civic & Public Space	1
			Credit	Access to Recreation Facilities	1
			Credit	Visitability and Universal Design	1
			Credit	Community Outreach and Involvement	2
			Credit	Local Food Production	1
			Credit	Tree-Lined and Shaded Streetscapes	2
			Credit	Neighborhood Schools	1

Yes	?	No			
0	0	0	**Green Infrastructure & Buildings**		**31**
Y			Prereq	Certified Green Building	Required
Y			Prereq	Minimum Building Energy Performance	Required
Y			Prereq	Indoor Water Use Reduction	Required
Y			Prereq	Construction Activity Pollution Prevention	Required
			Credit	Certified Green Buildings	5
			Credit	Optimize Building Energy Performance	2
			Credit	Indoor Water Use Reduction	1
			Credit	Outdoor Water Use Reduction	2
			Credit	Building Reuse	1
			Credit	Historic Resource Preservation and Adaptive Reuse	2
			Credit	Minimized Site Disturbance	1
			Credit	Rainwater Management	4
			Credit	Heat Island Reduction	1
			Credit	Solar Orientation	1
			Credit	Renewable Energy Production	3
			Credit	District Heating and Cooling	2
			Credit	Infrastructure Energy Efficiency	1
			Credit	Wastewater Management	2
			Credit	Recycled and Reused Infrastructure	1
			Credit	Solid Waste Management	1
			Credit	Light Pollution Reduction	1
0	0	0	**Innovation & Design Process**		**6**
			Credit	Innovation	5
			Credit	LEED® Accredited Professional	1
0	0	0	**Regional Priority Credits**		**4**
			Credit	Regional Priority Credit: Region Defined	1
			Credit	Regional Priority Credit: Region Defined	1
			Credit	Regional Priority Credit: Region Defined	1
			Credit	Regional Priority Credit: Region Defined	1
0	0	0	**PROJECT TOTALS (Certification estimates)**		**110**

Certified: 40-49 points, **Silver:** 50-59 points, **Gold:** 60-79 points, **Platinum:** 80+ points

Figure 14. LEED-ND v.4 checklist. Source: USGBC (2014).

While LEED-ND aims to enhance the use of natural resources, encourage regenerative practices, and balance environmental and human impacts in construction, it predominantly favors 'Smart Location & Linkage' and 'Neighborhood Pattern & Design'. This focus facilitates certification for projects in optimal locations, addressing urban issues like density and urban sprawl. However, it falls short in promoting green construction and technology comprehensively. Furthermore, despite its support for social equity, LEED-ND has not effectively spurred actions towards environmental justice or ensured adequate affordable housing in sustainable neighborhoods, which is crucial for the sustainability's equity dimension (Szibbo, 2016).

- ***Living Community Challenge***

The International Living Future Institute in Seattle envisions an equitable, culturally thriving, and environmentally healing future. Its Living Community Challenge (LCC) is a comprehensive framework for creating inclusive, sustainable communities at all scales, from local neighborhoods to city-wide projects. LCC promotes regenerative urban spaces that are energy and water positive, and encourages walkability and public transit use, aiming to enhance both human and ecological well-being (International Living Future Institute, 2017).

Unlike other sustainability models, LCC measures tangible outcomes, focusing on enhancing existing urban areas. Its structure revolves around seven "Petals" representing key performance areas—Place, Water, Energy, Health and Happiness, Materials, Equity, and Beauty—with strict "Imperatives" for each. Communities can pursue certifications for individual Petals or strive for Zero Energy. While the rigorous Imperatives ensure high standards, they may limit the framework's flexibility across different contexts. Despite this, LCC's participatory approach and emphasis on community involvement offer a transformative blueprint for sustainable urban development (Figure 15) (International Living Future Institute, 2017).

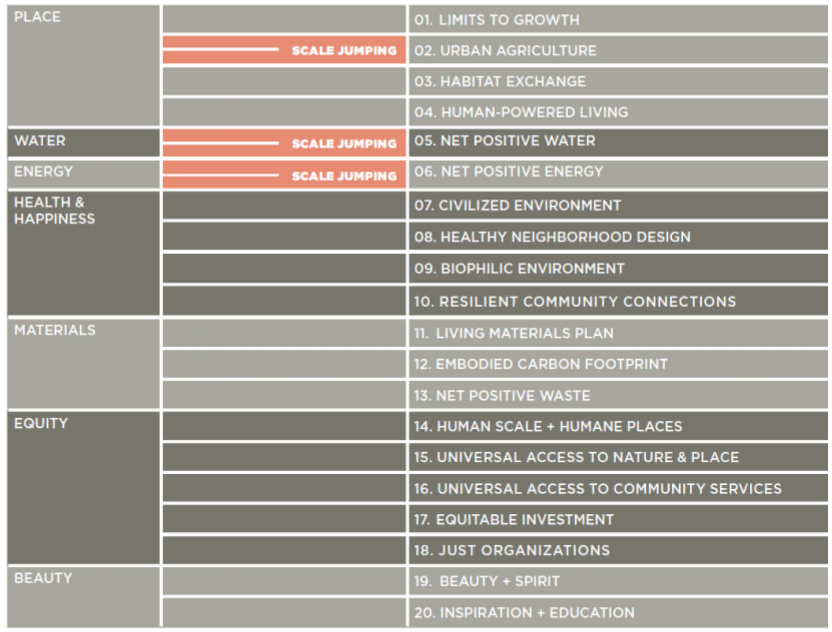
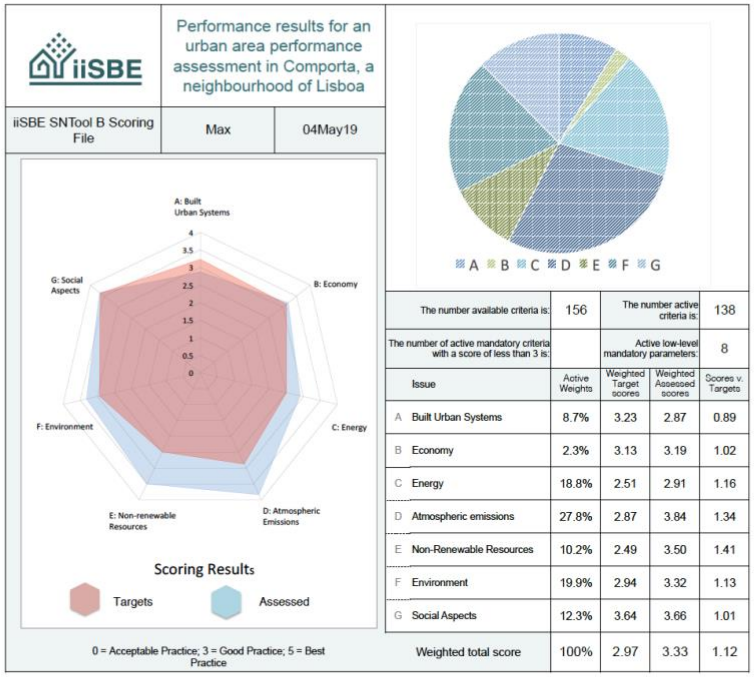


Figure 15. LCC Petals and Requirements. Source: International Living Future Institute (2017)

- ***SBTool***

The SBTool is an evolving system for assessing the performance of small urban areas. It was developed by the International Initiative for a Sustainable Built Environment (iiSBE) to support sustainable urban development by providing a framework to evaluate and compare neighborhoods' current and targeted performance. This tool focuses on time-series analysis within the same urban area, allowing for tailored adjustments to fit each location's unique geophysical, architectural, and cultural characteristics (Larsson, 2016).

The SBTool facilitates a comprehensive assessment and target-setting process adaptable to a wide spectrum of sustainability concerns. It offers flexibility in its application, with a scalable range of 26 to 156 criteria across seven key issues: Context and Vulnerabilities, Built Urban Systems, Economy, Energy, Non-Renewable Resources, Environment, and Social Aspects. These issues are further broken down into categories with specific criteria and indicators. The system employs a weighted scoring method to reflect the significance and potential impact of each criterion on the primary systems. The final scores present an integrated view of performance, showing the actual results and how they are measured against the set targets (Figure 16) (Larsson, 2016).



The number available criteria is:	156	The number active criteria is:		138
The number of active mandatory criteria with a score of less than 3 is:		Active low-level mandatory parameters:		8
Issue	Active Weights	Weighted Target scores	Weighted Assessed scores	Scores v. Targets
A Built Urban Systems	8.7%	3.23	2.87	0.89
B Economy	2.3%	3.13	3.19	1.02
C Energy	18.8%	2.51	2.91	1.16
D Atmospheric emissions	27.8%	2.87	3.84	1.34
E Non-Renewable Resources	10.2%	2.49	3.50	1.41
F Environment	19.9%	2.94	3.32	1.13
G Social Aspects	12.3%	3.64	3.66	1.01
Weighted total score	100%	2.97	3.33	1.12

Figure 16. SBTool Scoring Results. Source: Larsson (2016)

- ***CASBEE***

The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is a Japanese method for evaluating the environmental performance of the built environment, including housing, buildings, and cities. Developed in 2001 by a collaborative research committee, CASBEE is supported by the Japan Sustainable Building Consortium under the Ministry of Land, Infrastructure, Transport and Tourism (Institute for Building and Energy Conservation, 2015).

CASBEE assesses environmental efficiency by evaluating both the environmental load (L) a city imposes externally, measured by greenhouse gas emissions, and the quality (Q) within the city, encompassing environmental, social, and economic aspects. Indicators are ranked from 1 (basic compliance) to 5 (highest current standards). A city with a low L and high Q scores well in Built Environment Efficiency (BEE), indicating sustainability.

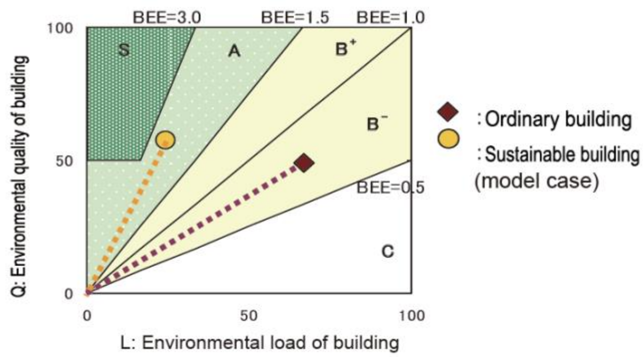


Figure 17. CASBEE Environmental Labeling. Source: IBEC (2015)

The BEE value is a ratio of Q over L, presented on a graph with L on the X-axis and Q on the Y-axis. Cities are then classified from C (poor) to S (excellent) based on their BEE score, providing a clear sustainability ranking (Figure 17) (Institute for Building and Energy Conservation, 2015).

- ***Urban LCA***

Life-cycle Assessment (LCA) consists of a process for assessing environmental impacts related to the life-cycle stages of an industrial product, process, or activity, covering the extraction and processing of raw materials (cradle); manufacturing, transportation, and distribution; use, reuse, maintenance; recycling and final disposal (grave). The process identifies and quantifies uses of energy, matter, and environmental emissions; assesses the environmental impact of these resources and emissions; and finds and evaluates opportunities for environmental improvements (Society of Environmental Toxicology and Chemistry, 1991). Thus, the LCA quantitatively analyses the complex interaction of a system - which can be a material, a component, or a set of components - with the environment throughout its life cycle, which is known as the “cradle-to-grave” approach (Silva et al., 2003).

The main objectives of an LCA are to portray the interactions between the process under consideration and the environment in the most complete possible way, to contribute to the understanding of the global and independent nature of the consequences of human activities on the environment, and to produce objective information that allows the identification of opportunities for environmental improvements (Society of Environmental Toxicology and Chemistry, 1991). Specifically in civil construction, LCA has been applied to evaluating construction materials and improving product processes, environmental product labeling, computational tools to support decision-making, and project assistance schemes for environmental assessment and certification of buildings (Silva et al., 2003).

The typical life cycle analysis methodology comprises four stages:

(1) The scope of the study is set, establishing the objective of the study, its depth, system limits, possible public comparisons, and reasons for conducting it.

(2) A life cycle inventory (LCI) is developed, which consists of data collection, validation, relation, and aggregation. Energy and material inputs (consumption of resources) and outputs (emissions to air, water, and soil) are identified, and the product's associated environmental impacts are quantified throughout its life cycle.

(3) The life cycle impact assessment (LCIA) is calculated, and the flows of resources and emissions are characterized according to a defined series of environmental impact indicators, e.g., incorporated energy, emissions, resource consumption, potential for recycling, and toxicity. The LCIA is also responsible for the classification, characterization, normalization, grouping, weighing and data quality analysis.

(4) The final step is data interpretation, and the study should be able to respond to the goals and scope of the study. This phase starts during the previously described stages and identifies significant issues, evaluates completeness, uncertainty, consistency, and limitations, and finalizes the study with conclusions and recommendations (ISO 14040: 2006a).

Although the LCA framework for construction provides valuable guidelines, it does not entirely clarify issues such as the quality of data or which system boundary must be adopted. LCA analysis has a few limitations, mainly when applied to buildings and areas in different locations, since LCA analysis are hardly generalizable due to geographically specific datasets (Cottafava & Ritzen, 2021). Therefore, it becomes evident that, depending on its depth and scope, quantifying all the impacts involved in a system can quickly turn complex, expensive, and very extensive, which is the main limitation of using this methodology in its purest form. However, although this proves to be extremely laborious, the central idea is to promote the collection of environmental data on construction materials and products and use them in the overall assessment of buildings (Silva, 2003).

Hence, the LCA framework has been increasingly used to assess the environmental impacts of construction products and buildings during the last decades and tends to also be applied to larger systems such as urban areas or neighborhoods. The main challenges are defining a functional unit, adapting and contextualizing methodologies to data availability, and addressing the diverse neighborhood development phase. Although different LCAs for neighborhoods provide quantitative information to policy makers or designers, they are based on different scopes and focus on other issues, resulting in various functional units and system boundaries. Hybrid LCA techniques complemented with consumption-based approaches (e.g., ecological footprint) and metabolism-based approaches (e.g., Material Flow Analysis) appear as a promising direction for realizing an optimum consumption-based analysis for complex systems (Lotteau et al., 2015).

3.4.1. *Discussion of existing frameworks for sustainability*

In our pursuit of fully realizing the four essential qualities of circular urban areas—Resource Looping, Regeneration, Distribution and Connectivity, and Locality—we have examined various frameworks based on their structure, objectives, formats, criteria, and indicators. While the extension of green building methods to the urban scale is a relatively recent development, these frameworks are in the process of refinement to address the intricate nature of urban and ecological issues and components. Although most frameworks emphasize quantitative performance evaluation, e.g., LEED-ND, CASBEE, LCA, SBTool, the LCC is the only framework dedicated to the design and planning of the transition process.

Although LCC does not fully integrate both quantitative and qualitative approaches simultaneously, it stands out as the most robust design tool for communities among the frameworks we studied. It provides support for continuous improvement and community involvement in regenerative urban design practices. Structured on the functioning of nature, its set of Petals aims to facilitate the transition to regenerative areas. However, the adaptability and transferability of its design criteria and indicators to various urban contexts, particularly those with limited financial resources, remain challenging.

Moreover, reliance on checklists and a tendency toward generalization can lead to distorted evaluations and challenges in adapting and transferring systems. For example, LEED-ND's weighted checklist prioritizes location and design categories, which may benefit well-situated projects but overlooks land assessment and urban equality. Conversely, CASBEE's approach to labeling simplifies the complexity of urban environments too much, reducing it to a single indicator of 'built environment efficiency' that serves as a comparative rating system. These two systems are geared more towards efficiency and sustainability rather than regeneration, providing tools for classifying and rating urban areas but lacking in fostering community engagement, continuous improvement, and local orientation essential for regenerative growth.

Differently, LCA offers a detailed quantitative analysis of environmental impacts, yielding a transparent depiction of these effects. However, the challenge of collecting local data, which is amplified at the urban scale, is a significant obstacle to its practical application. Additionally, while LCA is adept at assessing environmental issues, it does not account for the anthropogenic layers critical for transitioning to a CE. Nevertheless, due to its thorough environmental assessment capabilities, LCA could be complemented with social, cultural, and economic considerations and design methods to aid in developing regenerative urban areas.

Yet, the SBTool is particularly notable for its unique approach, which focuses exclusively on quantitative measures. It is uniquely designed to facilitate time-series comparisons within individual urban areas rather than making comparisons across different areas and communities. It also comprehensively embraces urban complexity by offering various performance assessment indicators for sustainability. The SBTool can be tailored to suit different geophysical settings, occupancy types, local issues, and targets, making it a versatile tool for assessing and advancing urban sustainability.

In conclusion, the exploration of methodological aspects within the context of circular urban areas has highlighted the diverse approaches and tools available for assessing and guiding the transition towards sustainability. While frameworks like LEED-ND and CASBEE offer valuable insights into sustainable practices, they may fall short in promoting the regenerative and holistic qualities that are essential for the evolution of urban spaces. The LCC, with its nature-inspired Petals, provides an ample design framework that emphasizes community and ecological well-being, yet its application across varied urban contexts requires further adaptation. The SBTool's strength lies in its ability to monitor progress over time within a specific urban area, offering a detailed quantitative assessment that can be customized to local conditions and sustainability objectives. Each framework contributes uniquely to the overarching goal of creating sustainable urban areas. At the same time, integrating quantitative and qualitative measures, along with community engagement and adaptability, will be crucial for successfully implementing CE principles in urban settings.

4. Drafting the circular urban framework

As we delve into circular urban areas, our guidance comes from the aspiration to emulate the seamless functioning of natural systems within urban areas. This aspiration led to the development of the Framework to Transition Urban Areas Towards a Circular Economy based on the Cradle to Cradle (C2C) principles, which defined the urban intentions and qualities, as well as the key areas and categories. These, in turn, branched out into the Performance Evaluation Tool through the definition of an indicators system and into the Pattern Language through the development of a structure for the design patterns (Figure 18).

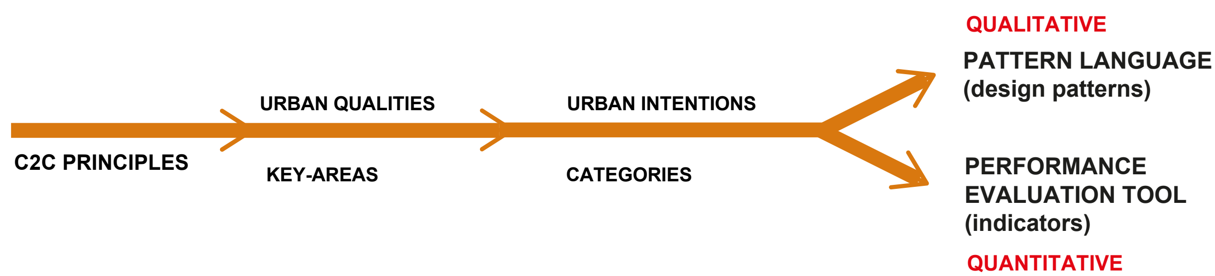


Figure 18. Structuring the Framework for Circular Urban Areas.

The Performance Evaluation Tool for Circularity in Urban Areas is a quantitative instrument equipped with indicators and metrics designed to measure and guide the performance of urban areas towards circularity. Complementing the evaluation tool, the Pattern Language for Circular Urban Areas serves as a qualitative blueprint for creating and continuously improving urban design projects. It offers direction in instances where a category is either undeveloped or poorly rated due to a lack of data from the performance evaluation tool, thus establishing a foundation for project advancement and the pursuit of circularity.

The initial draft of the framework presented in this chapter serves as a guide for formulating strategies and practices for incorporating the principles of the CE into urban planning and development. Subsequently, Sections 5 and 6 present the framework's proof of concept and refinement.

4.1. Circular urban qualities and intentions

The development of the proposed framework for implementing the Circular Economy (CE) in urban areas involved identifying four essential qualities as fundamental for successfully emulating natural systems in urban contexts. These qualities, as detailed in the section 3.3, include Resource Looping, Regeneration, Distribution and Connectivity, and Locality (Figure 19).

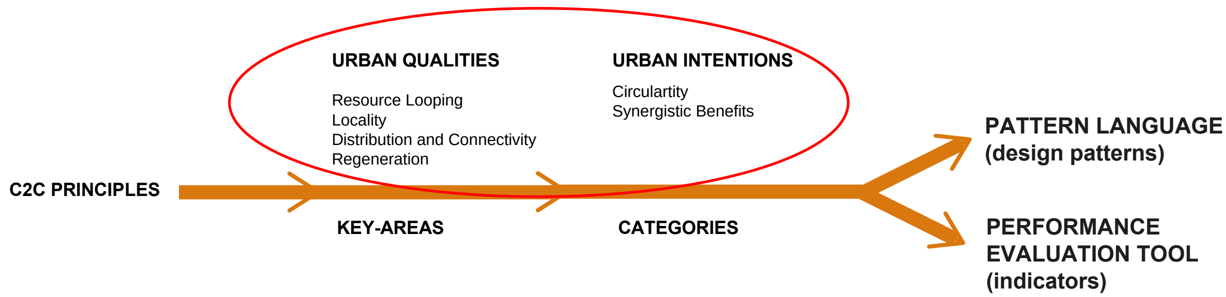


Figure 19. Urban Qualities and Intentions in the framework structure.

The quality of "Locality" is particularly crucial, as it acts as a guiding thread that permeates and enriches the other qualities. By incorporating locality into urban projects, one can maximize the use of locally available resources, which varies according to each specific context. This quality promotes Resource Looping, through the optimization of the use of local resources, while strengthening the qualities of Regeneration, Distribution and Connectivity, by adapting solutions to the cultural, social, and environmental characteristics of each place.

Given the interconnection and the central role of Locality, the proposal conceptualizes these qualities into two primary circular urban intentions: Circularity and Synergistic Benefits (Figure 20). Under this framework, Circularity includes both Resource Looping and Locality, highlighting the significance of closing resource cycles in a manner that acknowledges and utilizes local characteristics. Synergistic Benefits include Regeneration, Distribution and Connectivity, and Locality, highlighting how integrating these qualities can generate mutual and amplified benefits for both societal and natural systems.

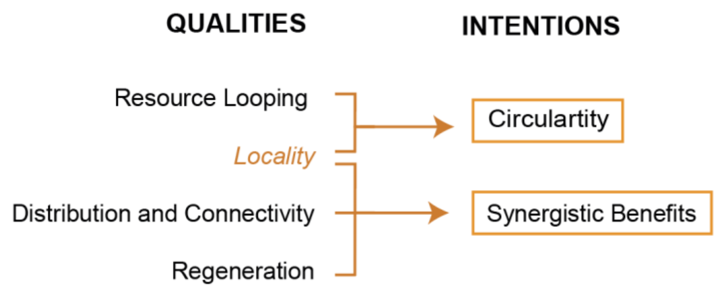


Figure 20. Circular Urban Qualities and Intentions

4.2. Principles, key areas, and categories

The C2C approach served as the basis for synthesizing and organizing the information in the literature sample. Its justification lies in its ability to provide fundamental principles and criteria for applying natural systems' regeneration to human processes, along with its comprehensive vision of the CE. The C2C methodology has been pivotal in synthesizing and organizing literature on circular urban areas, providing a framework that aligns with the principles of natural system regeneration within human processes. Its comprehensive perspective on the CE has been validated by its successful application across various scales, demonstrating its versatility and adaptability to the complexities of urban environments.

Hence, the C2C principles have offered a structured approach to formulating both qualitative and quantitative measures essential for developing circular urban areas. Moreover, they have played a crucial role in facilitating the communication of vital information that informs decision-making processes by establishing clear connections between theoretical concepts, practical categories and patterns, and measurable indicators (Figure 21).

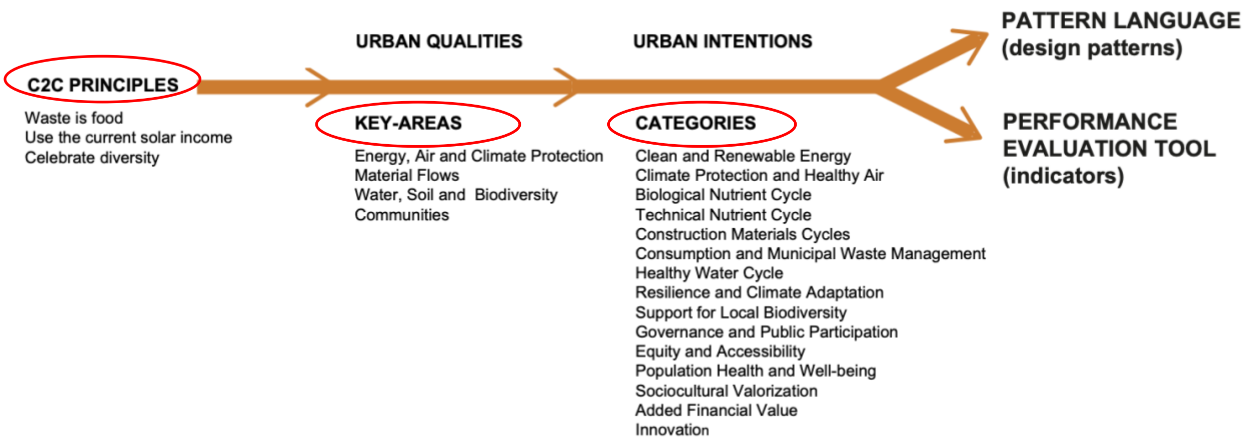


Figure 21. Principles, key-areas, and categories in the framework structure.

These principles are: (1) Waste is food: closure of water and nutrient cycles, distinguishing between biological and technical cycles to ensure that waste serves as a resource; (2) Use the current solar income: capture and use of local, clean, and renewable energy sources, aligning human activities with the use of natural energy; and (3) Celebrate diversity: exploration of local potential, materials, and cultures, recognizing the strength and resilience that diversity brings to urban systems.

In light of this, the principles and categories outlined by the Cradle to Cradle Certified® Version4 standard, developed by the Cradle to Cradle Products Innovation Institute (2021), have been adapted for urban applications. This adaptation led to the establishment of four key areas (Figure 22):

(1) Clean and Renewable Energy, Healthy Air and Climate Protection
(2) Health and Circularity of Material Flows
(3) Water and Soil Management and Gains in Local Biodiversity
(4) Strong, Equitable, and Just Communities

Notably, the product certification categories "Material Health" and "Product Circularity" have been merged into a single category for the urban scale, “Health and Circularity of Material Flows.” This unification recognizes the need to address material health in conjunction with effective material flow management in urban areas. Tables 1, 2, and 3 elucidate the intricacies of this adaptation.

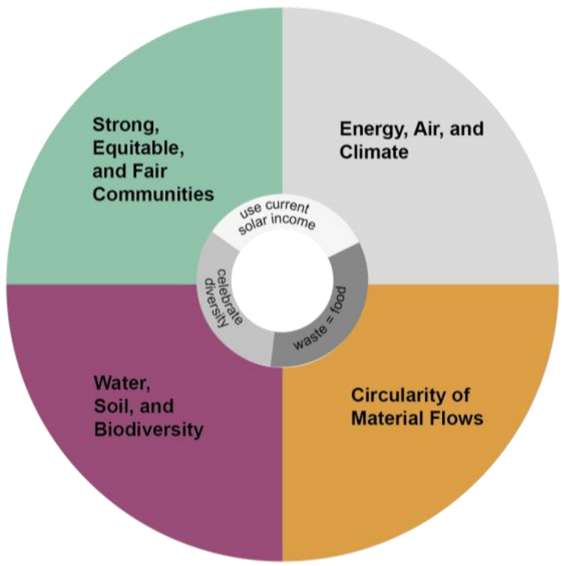


Figure 22. Key areas and C2C principles.

The newly established key areas branched out into fifteen project categories identified in our SLR. These four key areas encapsulate the multifaceted nature of the circular economy in urban contexts and are instrumental in structuring both the pattern language and the performance evaluation tool. They are the stem for creating design dimensions and indicators that will guide the concerted efforts in planning and implementing a circular economy within urban areas.

Table 1. Adaptation of the Key Area 'Clean Air and Climate Protection' to the Urban Scale

C2C principles McDonough and Braungart (2002a)	**C2C key areas for industrial products (adapted from Cradle to Cradle Products Innovation Institute, 2020)**	**Adaptation of the C2C key areas 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 positively impact 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 meet their own energy needs from clean and renewable sources and produce an 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 high air quality and thermal and acoustic comfort for their inhabitants. Optimizing the capture of sunlight, ensuring adequate ventilation, promoting high-quality public transport systems, and encouraging mobility on foot are essential.	**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.

Table 2. Adaptation of the Key Areas 'Material Health' and 'Product Circularity' to the Urban Scale

C2C principles McDonough and Braungart (2002a)	**C2C key areas for industrial products (adapted from Cradle to Cradle Products Innovation Institute, 2020)**	**Adaptation of the C2C key areas to the urban scale (the authors)**	**Application categories for circular urban areas (the authors)**
Waste is Food	**Material Health**	**Health and Circularity of Material Flows**	
	To prioritize protecting human health and the environment, selecting chemicals and materials used in products ensures they are safe for humans and the environment. Thus, it may positively impact 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 achieve this, emphasizing the importance of citizens' conscientious consumption and effective municipal waste management involves implementing information systems and collecting and disposing 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. Integrating 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 and ample regenerative possibilities for the circular transition. Architects and planners should be able to design new buildings with the premise that their materials will be reused in subsequent cycles. This implies adopting modular and dismountable construction systems, which enable 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 recirculating materials from technical production chains. **Clean and Circular Construction:** covers the maintenance and reuse of existing building stock and dismantling building systems, components, and materials designed for future cycles. **Consumption and Municipal Waste Management**: deals with reducing consumption to avoid generating 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.		

Table 3. Adaptation of the Key Areas 'Water and Soil Management' and 'Social Justice' to Urban Scale

C2C principles McDonough and Braungart (2002a)	**C2C key areas for industrial products (adapted from Cradle-to- Cradle Products Innovation Institute, 2020)**	**Adaptation of the C2C key areas to the urban scale (the authors)**	**Application categories for circular urban areas (the authors)**
Waste is Food	**Water and Soil Stewardship**	**Water and Soil Stewardship and Local Biodiversity Gains**	
Waste is Food **Celebrate Diversity**	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 population's quality of life. In this context, water and soil are considered precious and shared resources. Ensuring a healthy water cycle becomes essential, leading to the need for practices such as rainwater harvesting, preventing water contamination, and treating effluents. Mixed land use, nature-based solutions, and the recovery of degraded areas promote resilience and adaptation to climate change while providing a favorable environment for local biodiversity.	**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**	
Celebrate Diversity	Companies must respect human rights and adopt fair and equitable business practices, embracing safe, fair, and equitable labor practices that promote human rights and strong communities.	Communities in circular urban areas commit to promoting equity and accessibility for all inhabitants, ensuring effective public participation and the community's well-being. They value sociocultural diversity, aim to add financial value and stimulate innovation as an intrinsic part of their development vision. Governance is key to 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 resource distribution, 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

4.3. Structuring the Performance Evaluation Tool and the Pattern Language

The Framework to Transition Urban Areas Towards a Circular Economy is composed of two complementary tools: the Evaluation Performance Tool and the Pattern Language for Circular Urban Areas. The evaluation tool, with its quantitative nature, provides a solid foundation for measuring the success of urban interventions through carefully selected indicators that stem from categories derived from the urban qualities and key areas. Conversely, the pattern language, with its qualitative character, acts as a guide for projectual improvement, transforming these same categories into design dimensions that inform and inspire the creation of circular urban spaces.

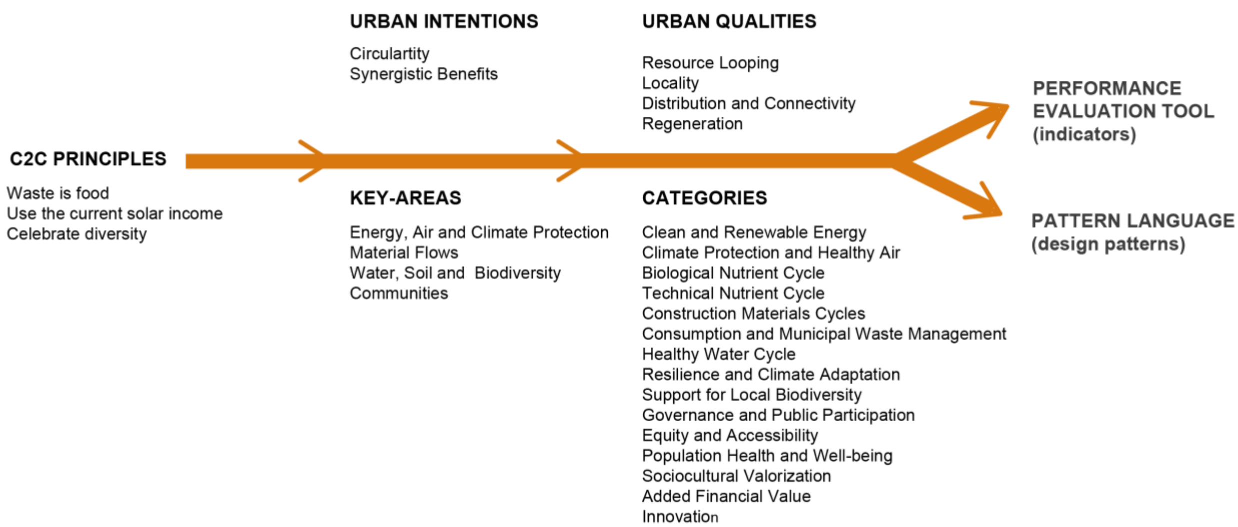


Figure 23. Framework to Transition Urban Areas Towards a Circular Economy

The structure of both components of the framework begins in a unified manner, ensuring a consistent integration between quantitative assessment and qualitative guidance, as illustrated in Figure 23. Consequently, the initial version of the Performance Evaluation Tool is organized around four key areas, featuring 52 indicators spread across 15 categories, as detailed in Table 4. Similarly, the draft structure of the pattern language has been organized into design layers that mirror the urban intentions, key areas, and categories, further enriched by the addition of a layer dedicated to design tools.

Figure 24 maps the first proposal for structuring The Pattern Language for Circular Urban Areas from its overarching urban qualities to its specific design dimensions. This structure intends to turn abstract concepts into possible concrete actions. It starts with the foundational circular urban intentions, branching into the four key areas, and the fifteen categories designed for circular urban contexts. Following this, these categories evolve into new design dimensions, crafted to transform the visionary qualities of circular urban areas into actionable urban circular tools.

During this drafting phase, four patterns, each corresponding to a key area, were developed to test the design of each pattern and its feasibility to urban practitioners. The deliberate selection of these four initial patterns is justified as it aims to provide a broader scope or a comprehensive overview of the framework's structure and to ensure that the foundational aspects of the framework are accessible and understandable. The visualization of these draft patterns can be found in Annex D – Draft version of initial patterns.

Table 4. Draft of the Performance Evaluation Tool. Components highlighted in red underwent modifications during revision.

Key area 1: Clean and Renewable Energy, Healthy Air, and Climate Protection	
category	indicator
Clean and Renewable Energy	Circular Sources - Energy
	Circular Content - Energy
	Active Cycles - Energy
Climate Protection and Healthy Air	Air Quality
	Night Polution
	Acoustic Comfort
	Access to Sunlight
	Reducing Heat Island Effect
	Renewable Energy in Mass Transportation

Key area 2: Health and Circularity of Material Flows	
category	indicator
Biological Nutrient Cycle	Circular sources - Biological Cycle
	Circular content - Biological Cycle
	Active cycles - Biological Cycle
Technical Nutrient Cycle	Circular sources - Technical Cycle
	Circular content - Technical Cycle
	Active cycles - Technical Cycle
Construction Materials Cycles	Circular sources - Construction
	Circular content - Construction
	Active cycles - Construction 1
	Active cycles - Construction 2
Consumption and Municipal Waste Management	Source separation of materials
	Collection and disposal

Key area 3: Water and Soil Management, and Local Biodiversity	
category	indicator
Healthy Water Cycle	Circular Sources - Water
	Circular Content - Water 1
	Circular Content - Water 2
	Active Cycles - Water
Resilience and Climate Adaptation	Mixed-use areas
	Productive local green area
	Surface soil quality
	Recovery of degraded soil
Support for Local Biodiversity	Green and blue infrastructure
	Biodiversity protection area
	Green corridors

Key area 4: Strong, Equitable, and Fair Communities	
category	indicator
Governance and Public Participation	Dissemination of good practices
	Educational initiatives
	New public policies to encourage CE
	New partnerships established for synergistic processes
	People involved in the recycling process
Equity and Accessibility	Access to potable water supply
	Access to sanitation systems
Population Health and Well-being	Access to public and pedestrian-oriented mobility and human-powered transportation
	Access to green zones and recreational areas
Sociocultural Valorization	Regional materials
	Retrofitting of buildings and urban areas revitalization
Added Financial Value	New investments to activate CE
	New jobs related to CE projects
Innovation	Number of patents related to CE projects
	New startups working with CE
	Research projects addressing CE

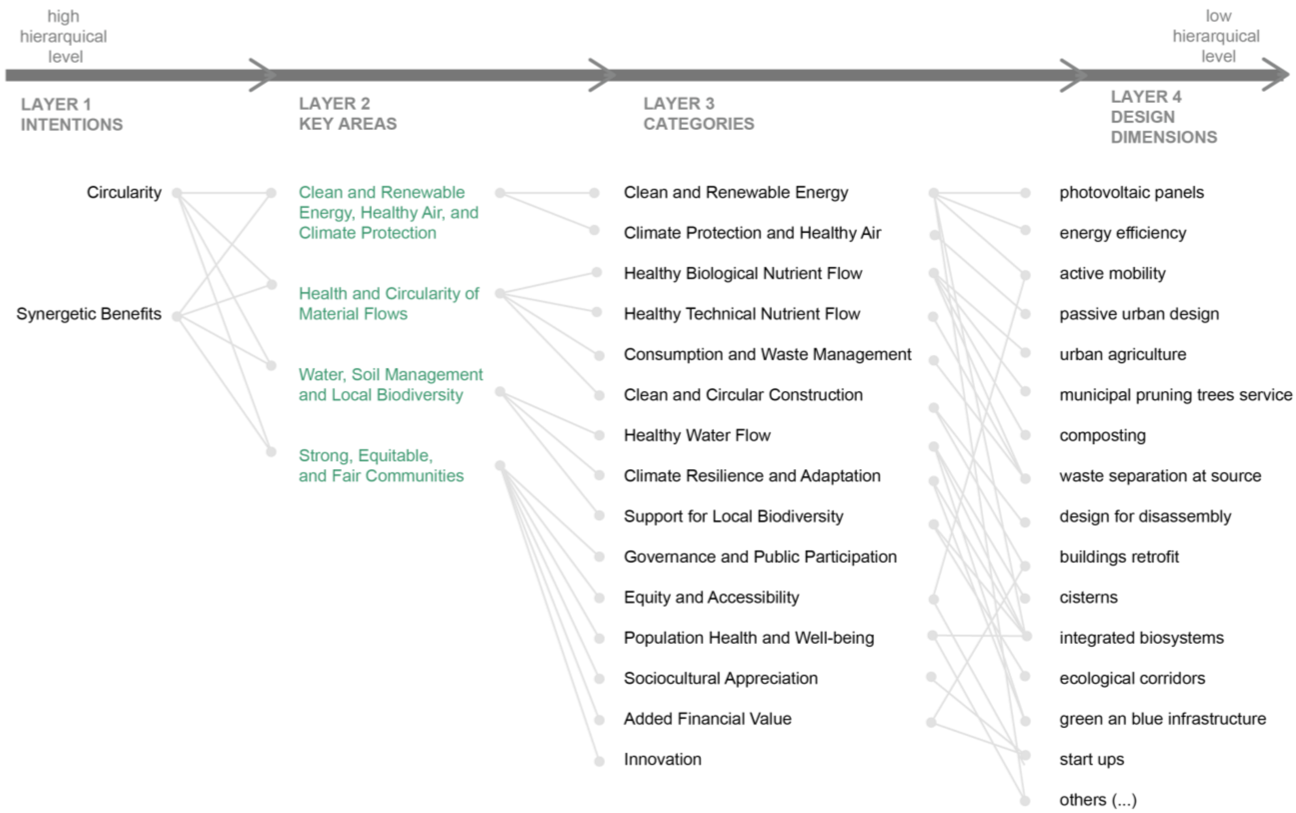


Figure 24. The initial structure for the Pattern Language for Circular Urban Areas. Components highlighted in green were the patterns selected to test the general design of each pattern.

4.4. Proof of concept for the initial framework

The framework's proof of concept is a crucial step to ensure its effectiveness and applicability in diverse urban contexts. The following section is dedicated to this essential task, presenting an initial proof through consultations with field urban practitioners. A two-step approach was employed in the process of external proof of concept, engaging professionals in the fields of CE, sustainability and urban planning. The first step involved a wide-ranging questionnaire, to assess the importance of the presented key areas, categories, and indicators within the assessment tool. Following this, a workshop was conducted to evaluate the efficacy of the pattern language methodology. Specifically, the workshop focused on four foundational patterns to gauge their effectiveness. This focus enabled the collection of valuable insights and critiques from the participants, enriching the discussion and enhancing the overall understanding of the patterns' impact.

The following Sections describe these steps and following results.

4.4.1. *Questionnaire*

The questionnaire application aimed to endorse and assess each component of the framework. Circular urban qualities, key areas, categories, and indicators were presented, and participants were asked about the completeness of the evaluation system and the importance of each proposed item. The complete questionnaire is presented in Annex C - Questionnaire.

Responses regarding the importance of categories and indicators were generally homogeneous, with the majority ranging between 96% and 99%. Only two indicators scored below 90%: "Circular Content" at 88% and "Night Pollution" at 86%. Open-ended questions garnered pertinent comments for indicator improvement, including suggestions for new indicators and changes to names, many of which were incorporated to enhance the framework.

For Key area 1, covering Clean and Renewable Energy, Healthy Air, and Climate Protection, participant responses revealed a variety of comments and suggestions. While some expressed satisfaction with the approach, emphasizing its comprehensiveness and relevance, others proposed specific adjustments to enhance precision and applicability, particularly concerning specific measures for climate protection.

Participants provided a range of comments and suggestions regarding Key area 2: Health and Circularity of Material Flows. Recommendations included emphasizing large-scale material recycling, avoiding toxic substances, and ensuring non-mixing with resources from other cycles. Suggestions highlighted the importance of basing population education as a foundation, simplifying approaches to encourage gradual mindset changes. Contributions suggested incorporating indicators related to material value chain mapping, access to treatable sewage, and treatment quality. Additionally, participants emphasized considering cascading resource use, proximity in material management to reduce transportation costs, and fostering partnerships between companies. Regarding the circularity of biological nutrient flows, there was a recommendation to qualify urban waste management to return nutrient value to the biosphere and restore soil fertility. Additional indicators, such as incentives for renewable and biological construction materials, were proposed, considering durability and reuse.

For Key area 3: Water and Soil Management and Local Biodiversity Gains, participants highlighted the importance of home education to promote water-efficient use. Recommendations included adding indicators measuring water distribution losses, the number of households with access to treated and potable water and considering green corridors not necessarily as straight lines. Suggestions were made to check data availability from CETESB (State of São Paulo Environmental Company) for soil surface quality and degraded soil recovery indicators. In the context of green corridors, conditions for healthier tree coverage, choosing species compatible with land use, and preferring native species were proposed. Additionally, the importance of including the percentage of permeable soil as an informative metric, possibly fitting into existing categories, was mentioned.

Finally, for the Key area 4: Strong, Equal, and Just Communities, some proposals included using payment for environmental services methods and valuing techniques from traditional communities to reduce consumption and reuse materials. A comment emphasized that providing potable water and sanitation is a legal obligation in urbanization, making it unnecessary to question its importance in urban areas. The continuous governance in strengthening communities was emphasized, with specific suggestions for enhancing indicators, including education initiatives covering various age groups and considerations of new policies. Suggestions for changes in indicators related to new jobs in the CE and access to green areas were made, along with considerations about the user's environmental comfort metric, proposing a more comprehensive inclusion of this concept in the category.

Responses to the general research question were largely complimentary, expressing appreciation for the work. Participants praised the researcher's ongoing efforts in promoting CE and raised some concerns, emphasizing the need to include effective means of data collection, storage, and analysis to support decision-making in circular processes. Caution was advised about the large number of indicators, recognizing the complexity of the work but expressing confidence in the chosen path. Additionally, some participants expressed interest in accessing the results of the research when completed, highlighting the value attributed to the comprehensive work undertaken by the research.

4.4.2. *Workshop*

The event started with two presentations introducing the topic, followed by four thematic rooms, each centered on a specific pattern. In each group, the participants worked with one pattern, representing one of the key areas: Energy, Air, and Climate Protection; Circularity of Healthy Material Flow; Water and Soil Management; and Local Biodiversity Gains; and Strong, Equitable, and Fair Communities.

Overall, there was highly active participation, with many relevant suggestions to enhance existing patterns and introduce new ones across all groups. There was a proper understanding within the groups regarding the function of patterns and the theme of CE in urban areas. As the given patterns represented broad urban issues, participants highlighted the need to supplement them with more specific ones. Besides, they emphasized the importance of incorporating an indicator system, making the framework more adaptable for replication in various contexts. Here are the primary considerations noted by the moderators:

- ***Pattern 'Health and Circularity of Material Flows':***

- Map material flows and consider legislation for social inclusion.

- Access reusable material banks with regional variations.
- Raise awareness about impacts throughout the material life cycle.
- Include indicators for management, health of materials and people, and development of technologies for the circular economy.

- ***Pattern 'Clean and Renewable Energy, Healthy Air, and Climate Protection':***

- Work within a holistic approach: energy efficiency, sanitation decentralization, and urban economic metabolism assessment.
- Balance urban inputs and outputs, integrate Nature-Based Solution, and promote sustainable construction.
- Crucial challenges include breaking paradigms in construction, community inclusion, and public policies for innovation and local energy sources.

- ***Pattern 'Water and Soil Management and Local Biodiversity Gains':***

- Inclusion of underground passages for fauna and anticipation of greening and environmental recomposition projects.
- Suggestion of underground cabling to mitigate conflicts in urban settlements.
- Emphasize the water cycle overflow, incorporating "water sensitive design" and "sponge city" concepts.
- Circular management of gardening waste and use of permeable flooring.
- Communication: inventory of flora and fauna, signage, and consideration of soil permeability.
- Water management: separation technologies, community inclusion, public policies for innovation, and local production.

- ***Pattern 'Strong, Equal, and Just Communities':***

- Participants expressed satisfaction with the pattern's format, which highlights qualities and benefits in a macro to micro approach.
- Acknowledgment of the difficulty in making the impact of CE tangible in people's lives, suggesting an opportunity for social innovation within communities.

- Emphasis on the importance of piloting the Fazenda Argentina to promote replicability, emphasizing existing good practices in Brazil and the potential for gradual implementation in communities.
- Central discussion on the need for popular education for CE, encouraging the establishment of spaces for discussion, practice, and promotion of concrete projects.
- Exploration of how political-party changes affect social projects, emphasizing the importance of robust governance, exemplified by participatory budgeting.
- Discussion on extending the solid waste cycle to reduce waste, disposal, and enhance circularity.

4.5. Analysis and implication of the external proof of concept

External proof of concept played a fundamental role in calibrating the framework and guiding the evolution of the Framework to Transition Urban Areas Towards Circular Economy. Through a two-phase process, which included the questionnaire followed by a workshop engaging with urban practitioners, significant enhancements were achieved in the practicality of the developing tool, by facilitating valuable feedback and contributed to refining the tool's usability and effectiveness.

During the initial phase of proof, the questionnaire confirmed the completeness of the framework structure and provided insights that guided the refinement of its structure and indicators. This process led to modifications in the terminology of key areas and categories, enhancing the clarity of the indicator system. Notably, a significant adjustment was the division of the previously unified category, Climate Protection, and Healthy Air, into two distinct categories to streamline future evaluations. Additionally, the framework was enriched with the introduction of new indicators, reflecting a more comprehensive approach to assessment.

However, the questionnaire phase encountered challenges in effectively determining the relative importance of indicators and categories. Despite all indicators and categories being deemed highly important by participants, this uniformity in response could imply equal weighting across the board. A more likely explanation, however, is that the questions designed to elicit information on relative weights needed to be adequately clear. There seems to be miscommunication in the objective, which was to assess the comparative significance of categories and indicators against each other rather than evaluating them solely on their standalone value.

In the second phase of the proof of concept, the workshop proved to be a valuable experience, allowing the presentation of the pattern structure to the participants and generating numerous insights for the pattern language structure, especially in the design dimensions of the different key areas. However, presenting only high-level hierarchical patterns limited the discussion, concluding that the most effective communication of the pattern language is through the presentation of pattern strings or complete sequences, as was later done and presented in section 6. Additionally, the textual density of the presented patterns in the workshop made it difficult to immediately understand the problems and actions, which motivated the simplification of single patterns' final structure and content.

After this revision, the following sections present the Performance Evaluation Tool and the Pattern Language.

5. Performance Evaluation Tool for Circularity in Urban Areas

An environmental performance evaluation tool is designed to enhance managerial decisions regarding the environmental performance of urban areas. It accomplishes this by selecting indicators, gathering, analyzing, and disseminating data on environmental performance criteria, and periodically revising and refining this process (ISO, 1999). Yet, a framework to transition urban areas towards CE, encompassing clear criteria and indicators, allows for the precise collection of data and the establishment of achievable goals and targets for tangible improvements. Consequently, the Performance Evaluation Tool for Circular Urban Areas aims to assist urban systems in measuring their success and optimizing circular performance.

Figure 25. The framework structure: C2C principles (inner circle), circular urban key areas (outer circle), and the categories (in the between)

Organizing the Tool: A C2C-Inspired Approach

The performance evaluation tool is structured based on the Cradle to Cradle (C2C) concept, adapting its methodological principles to the intricacies of urban settings. This methodology benefits from incorporating other successful sustainability frameworks, promoting the use of established indicators, or formulating new ones to fulfill the unique requirements of CE applied to urban areas. Additional local benchmarks can complement this structure, facilitating customization across various urban contexts.

Time-Series Evaluation and Local Customization

The tool functions as a time-series evaluation instrument for individual urban areas, supporting urban areas in evaluating their achievements and enhancing their circular performance. Thus, it emphasizes tracking a single area's progress rather than comparing different projects or communities. It creates a circularity profile, underscoring current performance characteristics and data within an urban area, allowing setting performance benchmarks for a future point, and assessing progress over time. This way, the evaluation tool and benchmarks can fit different geophysical contexts and local requirements.

Urban Intentions

The tool fosters the following circular urban intentions:

- Circularity,
- Synergistic Benefits.

Urban Qualities

The tool fosters the following circular urban qualities:

- Resource Looping,
- Regeneration,
- Distribution and Connectivity,
- Locality.

Key Areas

The performance evaluation tool is divided into four fundamental key areas:

- Energy, Air, and Climate Protection,
- Health and Circularity of Material Flows,
- Water and Soil Management and Local Biodiversity Gains,
- Strong, Equitable, and Fair Communities.

Categories

Figure 25 shows the framework structure, principles, and key areas delineated into fifteen distinct categories. The fourth key area centers on harnessing those synergistic benefits, focusing on Locality, Regeneration, and Distribution and Connectivity. This area delves into community performance, adopting an approach encompassing governance, equity, and sociocultural valorization. It ensures that all community members have equitable access to resources and services, fostering inclusivity and social justice. Additionally, considering the economic benefits of circular urban practices, such as job creation and resource efficiency, adds financial value. At the same time, examining innovation strategies reveals their potential to introduce new solutions for a CE transition.

Table 5 demonstrates the relationship between these categories and the desired qualities and intentions of circular urban areas.

In the first three key areas, the circularity of flows—whether in Energy, Air, and Climate Protection, Health and Circularity of Material Flows, or Water and Soil Management and Local Biodiversity Gains—is evaluated. The evaluation of the Circularity requirement is inspired by the C2C standard for industrial products, ensuring a continuous high-quality cycle of materials, water, and energy within healthy systems. Additional categories and indicators are incorporated to provide a complete evaluation, supporting measuring circularity and identifying and enhancing each key area's synergistic benefits.

The fourth key area centers on harnessing those synergistic benefits, focusing on Locality, Regeneration, and Distribution and Connectivity. This area delves into community performance, adopting an approach encompassing governance, equity, and sociocultural valorization. It ensures that all community members have equitable access to resources and services, fostering inclusivity and social justice. Additionally, considering the economic benefits of circular urban practices, such as job creation and resource efficiency, adds financial value. At the same time, examining innovation strategies reveals their potential to introduce new solutions for a CE transition.

Table 5. Circular urban intentions, qualities, key areas, and categories

	Intentions	Circularity		Synergic benefits	
	Qualities	**Resource Looping**	**Locality**	**Distribution/ Connectivity**	**Regeneration**
Key areas	Energy, Air, and Climate Protection	Clean and Renewable Energy	Healthy Air Urban Comfort and Climate Protection		
	Health and Circularity of Material Flows	Biological Nutrient Cycle Technical Nutrient Cycle Construction Materials	Consumption and Municipal Waste Management		
	Water and Soil Management and Local Biodiversity Gains	Healthy Water Cycle	Resilience and Climate Adaptation Support for Local Biodiversity		
	Strong, Equitable, and Fair Communities	-	Governance and Public Participation Equity and Access to Health and Well-being Sociocultural Valorization Added Financial Value Innovation		

Circularity Evaluation

The evaluation of urban intention 'Circularity' in the first three key areas is adapted from the C2C certification standard for industrial products, aiming to guarantee continuous, high-quality cycles within healthy systems. Three indicators apply it:

- **Circular Sources:** evaluates the ***origins*** of materials, energy, and water used within urban systems. It aims to minimize the consumption of non-renewable resources by prioritizing renewable, recyclable, or biodegradable options. Key measures include the proportion of building materials from recycled content, the share of energy from renewable sources, and the percentage of water sourced from alternative methods like rainwater harvesting and cascading.

- **Circular Content:** promotes high-quality use of energy and materials within urban systems, advocating for energy efficiency by comparing consumption to a baseline for infrastructure and assessing the ***quality*** of materials across biological, technical, and construction sectors. It quantifies the proportion of organic material produced without pesticides, the percentage of non-toxic recyclable or reusable technical materials, and the use of recyclable or remakable construction materials while monitoring water quality for hazardous effluents and system efficiency.

- **Active Cycle:** The Active Cycle indicator promotes ***maintaining high-quality*** energy, material, and water cycles ***within future cycles*** in urban systems. It evaluates the efficiency of renewable energy utilization, the extension of material lifecycles through cascading biological material, recycling, reuse, and remanufacturing across technical and construction sectors, and the local treatment and reuse of wastewater. By tracking the percentage of renewable energy used on-site, the repurposing of technical and construction materials, and adapting existing structures for new uses, this indicator underscores the importance of resource conservation and the maximization of their functional lifespan.

Synergistic Benefits Evaluation

Synergistic benefits refer to the advantages that arise when urban areas transition towards circular practices. These benefits go beyond resource efficiency and low carbon emissions, directing efforts toward enhancing human well-being and ecosystem valorization. This holistic approach to urban development actively generates positive outcomes. These outcomes include creating job opportunities, promoting local biodiversity, fostering social and economic inclusion, and significantly reducing socio-environmental inequalities. By focusing on these synergistic benefits, urban areas can transform into vibrant, sustainable communities that offer a higher quality of life for all residents while respecting and enriching the natural environment.

Performance Criteria

A performance evaluation scale was developed to quantify the progress of urban areas towards the CE. It follows four distinct levels: negative impact (-1), baseline practice (0), commendable practice (3), and exemplary practice (5). A review of existing academic literature and an analysis of information available on websites supported the establishment of the performance indicators scale and levels. This review encompassed a range of practices and observed the results associated with each measure. This scale allows for an analysis of the alignment of urban practices with circularity objectives and continuous monitoring of progress towards circularity goals. Table 6 demonstrates how sub-scales were created for each indicator, exemplified by "Circularity of Healthy Material Flows" category.

Applying the performance scale allows for a detailed analysis of the performance of each indicator and a more comprehensive understanding of that urban context. This approach highlights areas of success and deficiencies and facilitates the identification of issues that require attention and those on the right path to achieving circularity. Figure 26 serves as a visual tool, graphically presenting each indicator's results and category. This visualization highlights the individual performance of each indicator. At the same time, it provides a global view of the results of the urban area as a whole.

Table 6. Performance Criteria applied to the Circularity of Healthy Material Flows category.

Circularity of Healthy Material Flows

Biological Nutrient Cycle

Indicator	benchmark	score
Circular sources - Biological Cycle		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Circular content - Biological Cycle		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 100 %	3
Best practice	> 100%	5
Active cycles - Biological Cycle		
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5

Technical Nutrient Cycle

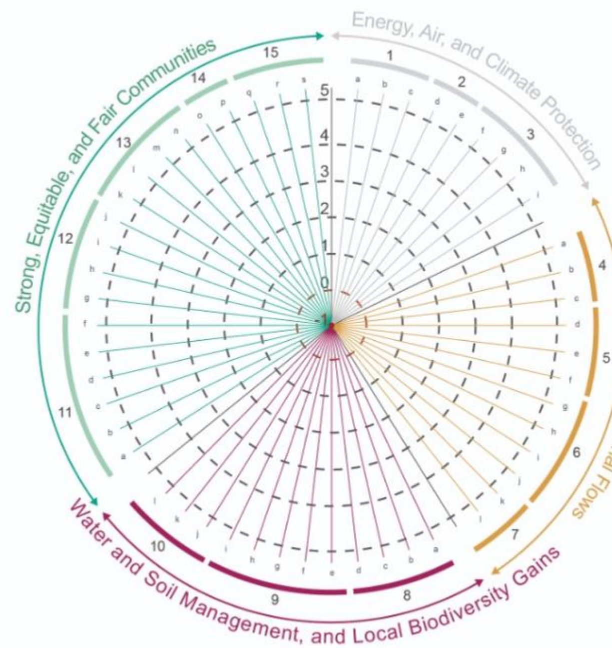
Indicator	benchmark	score
Circular sources - Technical Cycle		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Circular content - Technical Cycle		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Active cycles - Technical Cycle		
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5

Construction Materials Cycles

Indicator	benchmark	score
Circular sources - Construction		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Circular content - Construction		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Active cycles - Construction 1		
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5
Active cycles - Construction 2		
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5

Consumption and Municipal Waste Management

Indicator	benchmark	score
Source separation of materials		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Collection and disposal		
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5



1 Clean and Renewable Energy
2 Healthy Air
3 Urban Comfort and Climate Protection

4 Biological Nutrient Cycle
5 Technical Nutrient Cycle
6 Construction Materials Cycles
7 Consumption and Municipal Waste Management

8 Healthy Water Cycle
9 Resilience and Climate Adaptation
10 Support for Local Biodiversity

11 Governance and Public Participation
12 Equity and Access to Health and Well-being
13 Sociocultural Valorization
14 Added Financial Value
15 Innovation

		Circularity of Healthy Material Flows	
4	a.	Circular sources - Biological Cycle	0
	b.	Circular content - Biological Cycle	0
	c.	Active cycles - Biological Cycle	0
5	d.	Circular sources - Technical Cycle	0
	e.	Circular content - Technical Cycle	0
	f.	Active cycles - Technical Cycle	0
6	g.	Circular sources - Construction	0
	h.	Circular content - Construction	0
	i.	Active cycles - Construction 1	0
	j.	Active cycles - Construction 2	0
7	k	Source separation of materials	0
	l.	Collection and disposal	0

		Energy, Air, and Climate Protection	
1	a.	Circular Sources - Energy	0
	b.	Circular Content - Energy	0
	c.	Active Cycle - Energy	0
2	d.	Air Quality	0
	e.	Greenhouse gas emissions	0
	f.	Acoustic Comfort	0
3	g.	Access to Sunlight	0
	h.	Reducing Heat Island Effect	0
	i.	Renewable Energy in Mass Transportation	0

		Water and Soil Management, and Local Biodiversity Gains	
8	a.	Circular Sources - Water	0
	b.	Circular Content - Water 1	0
	c.	Circular Content - Water 2	0
	d.	Active Cycles - Water	0
9	e.	Mixed-use areas	0
	f.	Productive local green area	0
	g.	Surface soil quality	0
	h.	Recovery of degraded soil	0
	i.	Soil permeability	0
10	j.	Green and blue infrastructure	0
	k	Biodiversity protection area	0
	l.	Green corridors	0

		Strong, Equitable, and Fair Communities	
11	a.	Dissemination of good practices	0
	b.	Educational initiatives	0
	c.	Events for CE (Circular Economy)	0
	d.	New public policies to encourage CE	0
	e.	New partnerships established for synergistic processes	0
	f.	People involved in the recycling process	0
12	g.	Access to potable water supply	0
	h.	Access to sanitation systems	0
	i.	Access to public and pedestrian-oriented mobility and human-powered transportation	0
	j.	Access to green zones and recreational areas	0
13	k	Regional materials	0
	l.	Local techniques	0
	m.	Cultural festivals	0
	n.	Retrofitting of buildings and urban areas revitalization	0
14	o.	New investments to activate CE	0
	p.	New jobs related to CE projects	0
15	q.	Number of patents related to CE projects	0
	r.	New startups working with CE	0
	s.	Research projects addressing CE	0

Figure 26. Performance criteria visualization

Integration with the Pattern Language for Circular Urban Areas

As we reach the culmination of our exploration into the symbiotic relationship between quantitative assessment and qualitative design, it is imperative to underscore the seamless integration of the performance evaluation tool with the pattern language for circular urban areas. The former, a quantitative instrument, aims to measure urban circularity, while the latter offers qualitative insights for urban design enhancement, particularly where metrics indicate the need for improvement. The following sections will delve into the details of this integrated approach.

Subsequent sections introduce the Performance Evaluation Tool for Circular Urban Areas, outlining the four key areas along with their respective categories and indicators. These indicators, primarily adapted from established literature and pre-existing urban evaluation frameworks, have been tailored to suit the context of circular urban areas. Following this, the Pattern Language for Circular Urban Areas is detailed, adhering to a predefined structure and methodology. Additionally, twelve initial patterns are showcased as examples, demonstrating the functionality and application of the pattern language.

5.1.1. *Key area 1: Energy, Air, and Climate Protection*

The Energy, Air, and Climate Protection key area aims to incentivize urban areas to impact energy utilization positively. This involves promoting the adoption of clean, renewable energy sources, reducing energy losses and gaseous emissions, and maintaining energy within high-quality cycles. Ideally, besides fulfilling their energy requirements from renewable sources, these urban areas can also generate surplus energy, which can be shared with local communities or reintegrated into the power grid. Additionally, circular urban areas prioritize responsible emission management to guarantee superior air quality, balance of GHG emissions, and ensure thermal and acoustic comfort for residents. It's crucial to optimize sunlight capture, ensure proper ventilation, and endorse high-quality public transport while encouraging non-motorized mobility.

This key area is assessed across three complementary categories: Clean and Renewable Energy focuses on energy efficiency and clean energy generation, while Healthy Air addresses emission control, and Urban Comfort and Climate Protection investigates comfort, adaptation, and sustainable mobility. These categories are evaluated based on indicators that align with circularity and synergistic benefits requisites, as outlined in Table 7.

5.1.2. *Key area 2: Health and Circularity of Material Flows*

The Health and Circularity of Material Flows key area ensures the continuous circulation of nutrients in healthy systems within biological and technical cycles. This key area encompasses evaluation across four complementary categories: Healthy Biological Nutrient Flow, which involves local food production and organic waste management; Healthy Technical Nutrient Flow, which focuses on materials recirculation from technical production chains; Clean and Circular Construction, which addresses existing building stock maintenance, material dismantling for future cycles, and reusable components; and Consumption and Municipal Waste Management, which deals with waste reduction, household waste separation, and proper disposal. These categories are assessed based on indicators, as outlined in Table 8.

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. On the other hand, integrating 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 significant environmental impacts caused by the current linear model and 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 stock, promoting renovations and adaptations that enhance and prolong their use. Finally, the importance of citizens' conscientious consumption and effective municipal waste management is emphasized through the implementation of information systems and the collection and disposal of these materials.

5.1.3. *Key area 3: Water and Soil Management, and Local Biodiversity Gains*

The Water and Soil Management, and Local Biodiversity Gains key area aims to expand the available area for local biodiversity, revitalize the soil, restore the hydrological functionality of the urban landscape, and improve the population's quality of life. In this context, water and soil are considered precious and shared resources, while providing a favorable environment for local biodiversity.

This key area is segmented into four categories: Healthy Water Cycle, which delves into local water collection, efficient usage, and water recirculation; Climate Resilience and Adaptation, which encompasses nature-based solutions, soil permeability, and land use distribution; and Local Biodiversity Support, which concentrates on creating green spaces, fostering tree growth, encouraging species diversity, and rehabilitating degraded areas. These categories undergo evaluation based on indicators detailed in Table 9.

5.1.4. *Key area 4: Strong, Equitable, and Fair Communities*

Key area 4: Strong, Equitable, and Fair Communities aims to promote equity and accessibility for all their inhabitants and ensure effective public participation and the well-being of the community. Socio-cultural diversity is valued, seeking to add financial value, and stimulating innovation as an intrinsic part of their development vision.

Governance is critical 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.

This key area encompasses six distinct categories. It begins with Governance and Public Participation, highlighting the importance of involving the local population in advancing circular practices through participatory governance. Equity and Accessibility focus on ensuring fair resource distribution and access to essential services for a more equitable society. Health and Well-being address aspects related to community quality of life and health. Sociocultural Valorization involves preserving and appreciating local sociocultural heritage. Added Financial Value examines the financial impact of circular urban practices, while Innovation emphasizes adopting new solutions to address the challenges posed by the prevailing linear economy. Each category undergoes evaluation based on specified indicators outlined in Table 10.

Table 7. Key area 1: Energy, Air, and Climate Protection

Energy, Air, and Climate Protection					
category		indicator	objective	metric	source
Clean and Renewable Energy	a.	**Circular Sources - Energy**	Promoting the use of renewable energy sources	Percentage of renewable energy used / total energy consumption	adapted from C2CPII (2020)
	b.	**Circular Content - Energy**	Advocating for energy efficiency and the use of high-quality energy	Percentage of energy reduction compared to an estimated baseline energy usage for infrastructure (e.g., traffic lights, streetlights, water pumps, and sewage)	adapted from LEED Neighborhood (2018)
	c.	**Active Cycles - Energy**	Maintaining energy in high-quality cycles for extended periods, avoiding energy loss	Energy generation / generation potential	the authors
Healthy Air	d.	**Air Quality**	Enhancing ambient air quality	Percentage of days achieving N1 (good) and N2 (moderate) air quality according to CETESB/CONAMA Resolution No. 491/2018, assessing: inhalable particles (PM10), fine inhalable particles (PM2.5), smoke (FMC), ozone ($O3$), carbon monoxide (CO), nitrogen dioxide ($NO2$), sulfur dioxide ($SO2$)	adapted from CETESB/ CONAMA Resolution nº 491/2018
	e.	**Greenhouse gas emissions**	Controling GHG emissions	$CO2$ balance	the authors
Urban Comfort and Climate Protection	f.	**Acoustic Comfort**	Promoting acoustic comfort	Percentage of the population living in environments with excessive daily noise levels / year	adaptado de iiSBE (2019)
	g.	**Access to Sunlight**	Creating ideal conditions for passive and active solar strategies	Percentage of buildings oriented so that one axis of each qualified building is at least 1.5 times longer than the other, and the longer axis is within 15 degrees of the geographical east-west.	adapted from LEED Neighborhood (2018)
	h.	**Reducing Heat Island Effect**	Mitigate the effects of heat islands in the local area by installing high-reflectance or vegetated roofs	Area of SRI roofs (SRI higher than 29) + Area of greenroofs/ Total roof area	adapted from LEED Neighborhood (2018)
	i.	**Renewable Energy in Mass Transportation**	Encouraging the use of renewable energy for mass transportation	Percentage of trips in mass transportation powered by clean and renewable energy	the authors

Table 8. Key area 2: Circularity of Healthy Material Flows

Circularity of Healthy Material Flows					
category		indicator	objective	metric	source
Biological Nutrient Cycle	a.	**Circular sources - Biological Cycle**	Measure the circularity of material sources	% renewable content	adapted from C2CPII (2020)
	b.	**Circular content - Biological Cycle**	Make the material suitable to be kept in high-quality cycles	% of organic material consumed (produced without pesticides)/ total consumption	adapted from C2CPII (2020)
	c.	**Active cycles - Biological Cycle**	Maintain the material in high-quality cycles for the longest possible time	% of materials being recycled (cascading) / composted	adapted from C2CPII (2020)
Technical Nutrient Cycle	d.	**Circular sources - Technical Cycle**	Measure the circularity of material sources	% of material from reuse, remanufacturing, or recycling	adapted from C2CPII (2020)
	e.	**Circular content - Technical Cycle**	Make the material suitable to be kept in high-quality cycles for the longest possible time	% of non-toxic material (ABC-X list) recyclable or with reuse/remaking possibilities	adapted from C2CPII (2020)
	f.	**Active cycles - Technical Cycle**	Maintain the material in high-quality cycles for the longest possible time	% of material being recycled (in the municipality), reused, or remanufactured	adapted from C2CPII (2020)
Construction Materials Cycles	g.	**Circular sources - Construction**	Measure the circularity of material sources (recycled and/or renewable materials)	% of material from reuse, remanufacturing, recycling, and/or renewable sources	adapted from C2CPII (2020)
	h.	**Circular content - Construction**	Make the material suitable to be kept in high-quality cycles for the longest possible time	% of recyclable, compostable, or reusable/remakable materials	adapted from C2CPII (2020)
	i.	**Active cycles - Construction 1**	Maintain the material in high-quality cycles for the longest possible time	% of construction material being recycled or composted (in the municipality), reused, or remanufactured	adapted from C2CPII (2020)
	j.	**Active cycles - Construction 2**	Adapt and/or renovating existing buildings for new uses	% of existing buildings and structures in the study area being adapted for new uses/building stock	adapted from iisBE (2019)
Consumption and Municipal Waste Management	k.	**Source separation of materials**	Encourage material separation at the source	% of urban waste separated at the source / total waste (volume)	the authors
	l.	**Collection and disposal**	Correctly collecting and disposing of waste	Coverage of the collection and disposal system / total residents	the authors

Table 9. Key area 3: Water and Soil Management, and Local Biodiversity Gains

Water and Soil Management, and Local Biodiversity Gains					
category		indicator	objective	metric	source
Healthy Water Cycle	a.	**Circular Sources - Water**	Measure the circularity of water sources.	% of water collected from "alternative" sources (rainwater harvesting + wastewater treatment) / consumption	adapted from Agudelo-Vera et al. (2012)
	b.	**Circular Content - Water 1**	Make the water flow suitable to be kept in high-quality cycles for as long as possible.	Quality level of locally treated water (e.g., secondary)	the authors
	c.	**Circular Content - Water 2**	Prevent contamination of watercourses.	Presence of hazardous effluents from building operations and adjacent areas	adapted from iiSBE (2019)
	d.	**Active Cycles - Water**	Maintain the water flow in high-quality cycles for as long as possible.	% of building wastewater treated locally	adapted from iiSBE (2019)
Resilience and Climate Adaptation	e.	**Mixed-use areas**	Encourage mixed-use in the study area.	Predominant use share (residential, commercial, etc.) / other uses	the authors
	f.	**Productive local green area**	Increase available area for local agriculture.	Productive area / total area	the authors
	g.	**Surface soil quality**	Make the soil healthy.	Quantity of heavy metals and toxic substances in the soil along with nutrients (e.g., nitrogen and phosphorus)	adapted from Morelli et al. (2013), Forman (2013)
	h.	**Recovery of degraded soil**	Brownfield recovery (contaminated, desertified, and degraded land).	% of recovered contaminated, desertified, and degraded land	the authors
	i.	**Soil permeability**	Encourage permeable soil areas.	% of permeable soil area	the authors
Support for Local Biodiversity	j.	**Green and blue infrastructure**	Restore the hydrological function of the urban landscape, manage stormwater, and reduce the need for additional gray infrastructure.	Contribution of green and blue infrastructure / total infrastructure	adapted from Pelorosso, R., Gobattoni, F., Leone, A.
	k.	**Biodiversity protection area**	Increase available area for local biodiversity development.	Non-urbanized land area with ecological value (which can protect native flora and fauna diversity, like natural green areas and water bodies) / total area	adaptado de iiSBE (2019)
	l.	**Green corridors**	Encourage the continuity of green areas to promote local biodiversity.	Amount of continued green areas over 100m long with local species compatible with land use	adaptado de iiSBE (2019)

Table 10. Key area 4: Strong, Equitable, and Fair Communities

Strong, Equitable, and Fair Communities					
category		indicator	objective	metric	source
Governance and Public Participation	a.	**Dissemination of good practices**	Disseminate good practices for CE	People impacted by good practices (within and outside the community) / total community population	adapted from iisBE (2019)
	b.	**Educational initiatives**	Educate the community about circularity	% of the community impacted with formal education (courses, training, academic and non-academic workshops) for CE	the authors
	c.	**Events for CE (Circular Economy)**	Spread the concept of CE and support existing initiatives	Number of informal events (fairs, exhibitions, etc.) per year	the authors
	d.	**New public policies to encourage CE**	Implement CE policies	Number of policies implemented per year	the authors
	e.	**New partnerships established for synergistic processes**	Create partnerships to generate synergies between stakeholders and flows	Number of partnerships formed per year	the authors
	f.	**People involved in the recycling process**	Engage the community (residents, workers, local students) in CE practices	% of the community involved in circular practices	adapted from CASBEE UDe (2014)/ iisBE (2019)
Equity and Access to Health and Well-being	g.	**Access to potable water supply**	Provide clean water to as many people as possible	% coverage of the public water supply system / total residents	adapted from iiSBE (2019)
	h.	**Access to sanitation systems**	Treat water after use	% coverage of the sanitation system / total residents	adapted from iiSBE (2019)
	i.	**Access to public and pedestrian-oriented mobility and human-powered transportation**	Ensure safe mobility, emphasizing public transportation as the primary means of transport, promoting a pedestrian-oriented environment and human-powered transportation	% of trips by mass transportation, walking, or human-powered transport	adapted from Living Community Challenge (2017)
	j.	**Access to green zones and recreational areas**	Encourage the community to use green and recreational areas	% of residential buildings located within 1km of green public areas and/or recreational areas	adapted from iisBE (2019)
Sociocultural Valorization	k.	**Regional materials**	Foster the local/regional economy	% of materials produced within a 200km radius	the authors
	l.	**Local techniques**	Value techniques from traditional communities and peoples	Number of initiatives using techniques from traditional communities and peoples	the authors
	m.	**Cultural festivals**	Value the culture of traditional communities and peoples	Number of festivals and fairs that value local culture	the authors
	n.	**Retrofitting of buildings and urban areas revitalization**	Promote the revitalization of existing built and cultural landscapes	Number of building retrofits and/or urban area revitalizations / total developments	the authors
Added Financial Value	o.	**New investments to activate CE**	Encourage new investments for CE	Investments in CE projects / total investments per year	the authors
	p.	**New jobs related to CE projects**	Generate new jobs related to CE	New jobs generated with CE / total jobs generated per year	the authors
Innovation	q.	**Number of patents related to CE projects**	Encourage innovation for CE	New patents related to CE projects / new patents per year	the authors
	r.	**New startups working with CE**	Promote the practice of CE solutions	New startups related to CE projects / total new startups per year	the authors
	s.	**Research projects addressing CE**	Promote research in the field of CE	New research related to CE projects / total research in the venture per year	the authors

6. Pattern Language for Circular Urban Areas

Pursuing sustainable urban development has led to exploring various frameworks and methodologies aimed at reducing environmental impact while enhancing the quality of urban life. Among these, the concept of a pattern language as a tool for designing harmonious and sustainable environments has emerged as a powerful approach. This chapter introduces the Pattern Language for Circular Urban Areas, designed to guide urban practitioners to create and transform urban spaces directed to CE principles.

The Pattern Language for Circular Urban Areas can be instrumental in guiding the design and development of circular urban spaces, providing a set of design tools to be transferred and adapted to meet the diverse needs of various urban contexts. It should operate in conjunction with the Performance Evaluation Tool for Circular Urban Areas, ensuring that the principles of urban circularity can be conceptualized, measured, implemented, and optimized. Patterns within this language are crafted to improve the outcomes of the indicators set by the evaluation tool.

The theoretical groundworks of pattern languages are rooted in the pioneering work of Christopher Alexander and his colleagues (Alexander et al., 1977), who introduced the concept in the context of architecture and urban design. Their vision was to create a language of patterns that could address the complex challenges of building environments that are alive and humane. Building on this foundation, the Pattern Language for Circular Urban Areas extends the application of pattern languages to the realm of circular economy within urban settings.

According to Alexander et al. (1977), a pattern language can serve as a guide for the design of urban spaces that are functional, sustainable, and aesthetically pleasing. The authors propose a system of interconnected patterns that can be applied to solve complex problems in a holistic and humanized manner. The authors developed the fundamentals of a pattern language to address recurring problems in our environment. They suggested that a code, which functions as a genetic one, is necessary for creating buildings, constructions, and cities as living structures. Each pattern should describe a problem and, in sequence, outline a solution to that problem, which can be used repeatedly in similar contexts. Hence, the pattern language consists of a network of interconnected patterns or good design practices to solve problems that tend to repeat in a specific field of expertise.

Developing a pattern language promotes designing urban areas and building systems as living systems, which are themselves organized as patterns. These patterns form networks, and the networks shape a pattern language that is constantly being transformed and complemented. And urban systems, like any other nature's ecosystem, are part of a larger interconnected complex unity of different systems and parts, which the author calls 'the *whole'* (Alexander et al., 1977). Hence, the Pattern Language for Circular Urban Areas internalizes 'the *whole'* as a main concept by being inspired by nature's functioning and creating the necessary basis of patterns and patterns' system for circular, regenerative, distributive, and local-oriented urban futures.

6.1. Pattern Language Structure

The structure of Pattern Language for Circular Urban Areas aligns with the configuration of the performance evaluation tool. Both tools embrace the same urban intentions, key areas, and categories, branching into patterns that embody novel design dimensions (pattern language) or indicators (evaluation tool) (Figure 23).

The organization of the pattern language follows as suggested by Alexander et al. (1977), with each pattern functioning as a node within a directed acyclic graph, with edges directing to their consequences. These edges guide urban developers to subsequent patterns at lower levels, establishing a clear hierarchy and sequence for application. This hierarchical structure empowers users to thoroughly address complex urban challenges, ensuring that each solution builds upon the foundation of the previous patterns. Just as an ordinary language equips us with the ability to construct an infinite variety of sentences, the pattern language supports urban developers to create indefinite solutions for buildings, cities, and regions.

While describing circular urban areas, the Pattern Language for Circular Urban Areas is structured to reflect a progression from broad urban intentions to more granular design dimensions as shown in Figure 27. This progression is crucial for translating abstract qualities into tangible actions and outcomes. The structure begins with a pattern describing a vision for ideal circular urban areas followed by the two overarching urban intentions, which then branch out into the four key areas. These key areas further unfold into categories specifically tailored for circular urban areas, leading to an intersection of urban planning principles and CE concepts. Subsequently, these categories give rise to design dimensions. These dimensions are the actionable components of the pattern language, crafted to convert the aspirational intentions of circular urban areas into practical design and operational measures. By doing so, they provide stakeholders with clear guidance on implementing CE within the urban context.

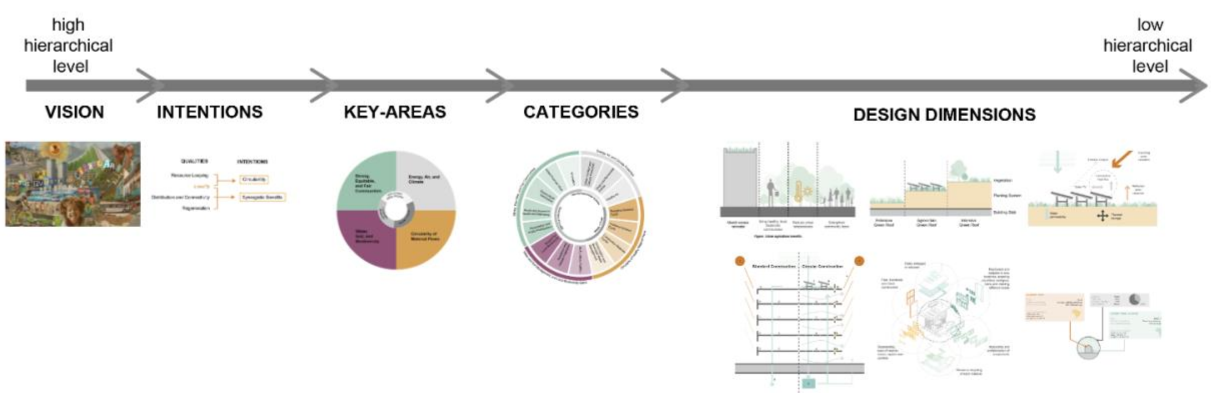


Figure 27. Hierarchical levels of the pattern language.

Figure 28 expresses the organizational structure of the Pattern Language for Circular Urban Areas. The choice of this initial group of design patterns to form the base for the pattern language structure aims to foster essential elements that should be encouraged in projects aimed at circularity, ensuring they are within the scope of urban actors, and simultaneously feasible for implementation in the contemporary urban context. Those patterns were selected based on literature and enriched by contributions from workshop participants. Moreover, recognizing the ever-evolving nature of urban development and the rapid pace of technological change, such structure allows the inclusion of new design patterns as novel needs and opportunities arise.

Finally, the structure of the Pattern Language for Circular Urban Areas is designed to be instructive. It guides urban practitioners through the nuances of working with the interplay between circular urban intentions, key areas, categories, and design dimensions. This guidance allows urban actors to navigate urban circularity's complexities and apply the CE principles effectively within different urban projects.

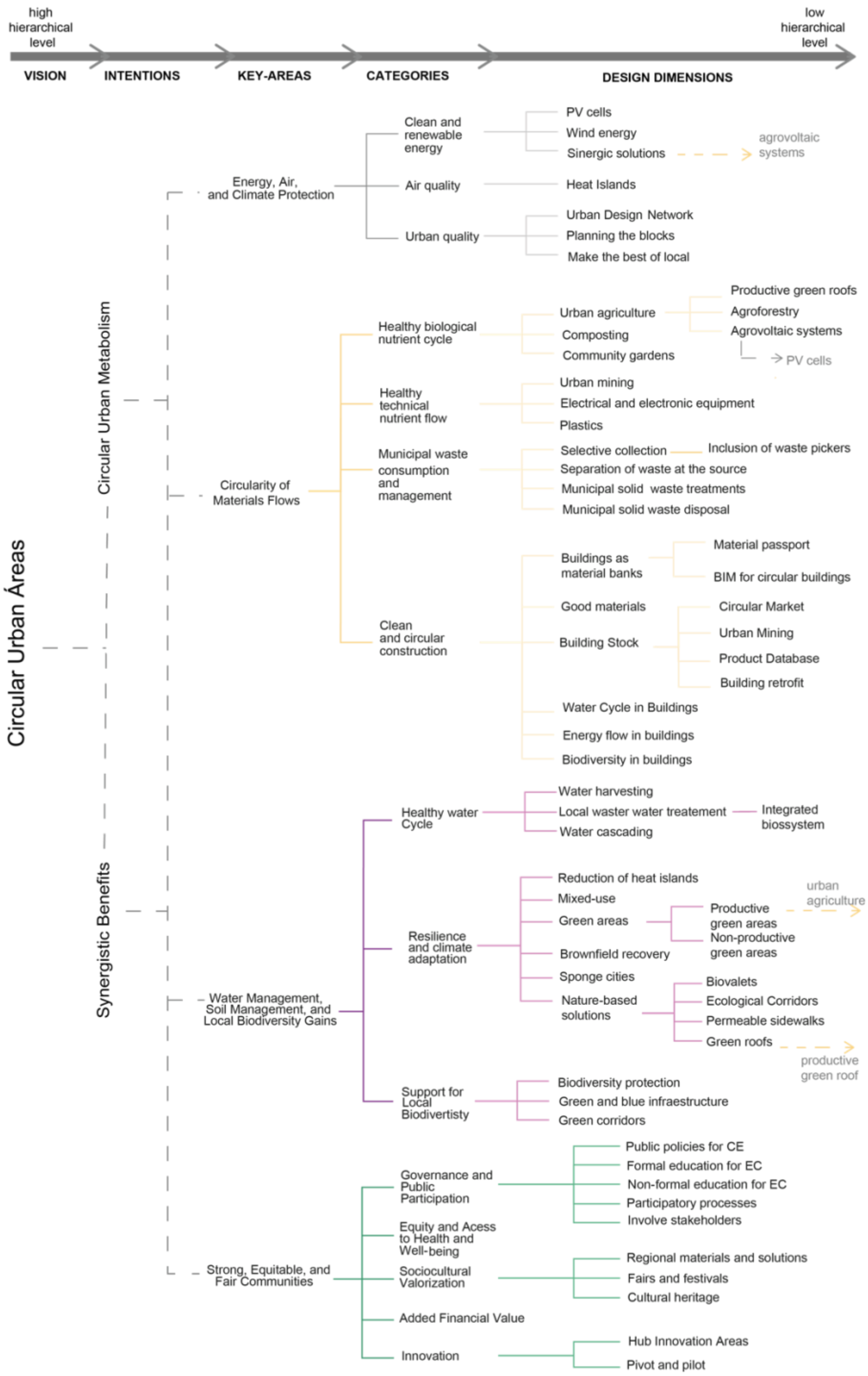


Figure 28. Pattern Language for Circular Urban Area Initial Structure

6.2. Structure of each pattern

Each pattern within the Pattern Language for Circular Urban Areas has been crafted to function within a model analogous to a directed acyclic graph, where each node symbolizes a unique pattern. This deliberate configuration establishes a clear hierarchy among the patterns, delineating the order in which they should be applied and illustrating the cumulative nature of their relationships. The thoughtful assembly of these components ensures that each pattern is both a standalone solution and a connective element within a network of strategies aimed at fostering circularity in urban environments.

Drawing inspiration from Alexander's *Pattern Language* (1977), the pattern structure was simplified and organized with components essential to the efficacy and clarity of the Pattern Language for Circular Urban Areas. The components of each pattern are as follows:

- **Title of the Pattern**: a clear and descriptive heading that encapsulates the essence of the pattern.
- **Upward Pattern Links**: connections to 'higher-level' patterns or key knowledge areas that provide context and support.
- **Three stars (***):** signaling that the problem is beginning.
- **Problem:** a concise statement articulating the urban design challenge or issue the pattern addresses.
- **Action:** specific instructions or strategies that outline how to address the problem.
- **Diagram:** visual representations that illustrate the solution and its components, often accompanied by simple annotations.
- **Three stars (***):** signaling that the main body is finished.
- **Downward Pattern Links:** references to 'lower level' patterns that are necessary to fully realize the main pattern.

6.3. Initial Patterns of the Pattern Language for Circular Urban Areas

Building on the foundational concepts of the Pattern Language for Circular Urban Areas, a series of patterns were crafted to test the efficacy of this structure. Each pattern addresses a distinct aspect of urban design and development, ensuring a holistic approach to circularity. These patterns, beginning with the fundamental concepts of circular urban metabolism and synergic benefits, offer a structured method for tackling the complexities of urban circularity.

In Figure 29, the initial set of 12 patterns, which are located within two pattern strings and presented in red, was developed to test the pattern language's ability to support the development of urban areas towards CE. The first string starts with Circular Urban Areas. It is directed toward the Circularity of Healthy Material Flows and the Biological Nutrient Cycle, followed by patterns that discuss circular strategies within this theme. The second string is also directed toward the Circularity of Healthy Material Flows but focuses on Clean and Circular Construction, detailing design patterns that promote circularity in the built environment.

These pattern strings practically demonstrate how the pattern language operates, showcasing the interconnectedness and strategic approach to fostering circularity in urban environments. Each pattern is a building block in the larger structure, contributing to a comprehensive understanding of how to create sustainable, regenerative urban spaces that are in harmony with the principles of circular urban development. As our research progresses, we will build upon these initial patterns, selecting other pattern strings that will enhance our understanding of systemic thinking and address the primary concerns of circular urban development.

Subsequent pages fully demonstrate the two selected pattern strings, with their numbering following the sequence organized in Figure 29.

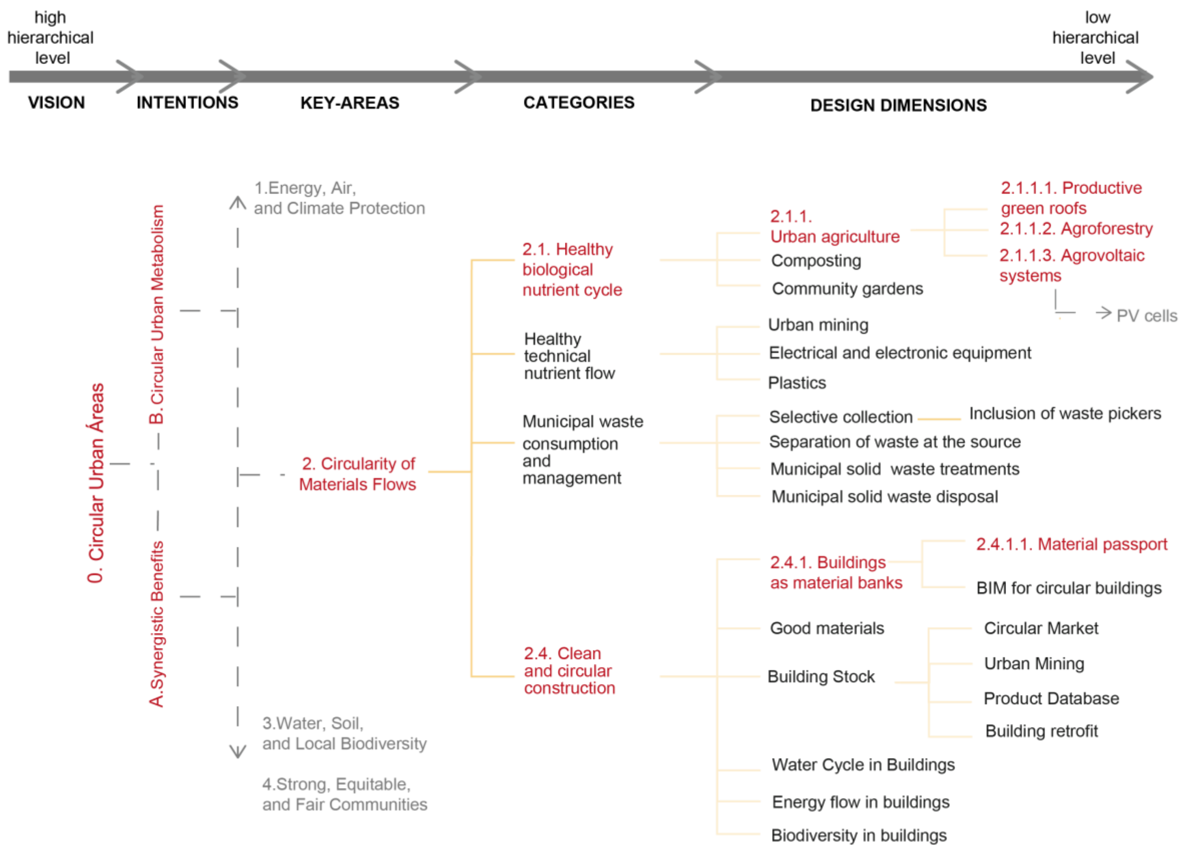


Figure 29. Pattern strings chosen to exemplify the Pattern Language for Circular Urban Areas.

0. Circular Urban Areas

Upward or of key knowledge pattern links: Notion of Regenerative-Adaptive Patterns (Roös, 2021), 'The Whole' (Roös, 2021).

***

Problem:

Humanity has surpassed six of the nine planetary boundaries, endangering ecological stability and human survival. This breach raises the risk of sudden, irreversible environmental changes that could affect global ecosystems and human well-being. The transgressions involve Climate Change, Biosphere Integrity, Land System Change, Biogeochemical Flows of nitrogen and phosphorus, Functional Biosphere Integrity, and Novel Entities like unnatural chemical pollutants and plastics. These lead to biodiversity loss, climate shifts, and resource degradation, impacting crucial ecosystem services (Richardson et al., 2023).

Action:

Transitioning to a circular economy is urban areas means at creating regenerative societies that mimic natural ecosystems, generating positive effects and promoting climate adaptation and system regeneration. Circular urban areas are characterized by Circularity, optimizing energy and recycling nutrients; Regeneration, enhancing biodiversity; Distribution and Connectivity, forming resilient urban-natural networks; and Locality, fostering context-specific solutions that enhance diversity. These principles promote urban development that not only sustains itself but also contributes to planetary regeneration. To evolve from linear to circular urban areas, concentrate on:

1. Implementing circular urban metabolism to optimize resource use, focusing on local, renewable materials, and recirculating resources through continuous nutrient, water and energy cycles.
2. Establishing beneficial synergies that optimize urban elements for circularity, fostering regional positive effects and advancing climate adaptation and ecological regeneration.

Source: Ideia Circular e UCCI, 2022.

***

Downward pattern links: Circular Urbna Metabolsim [A], Synergistic Benefits [B]

A. Circular Urban Metabolism

Upward or of key knowledge pattern links: Circular Urban Areas [0]. Synergistic Benefits [B].

***

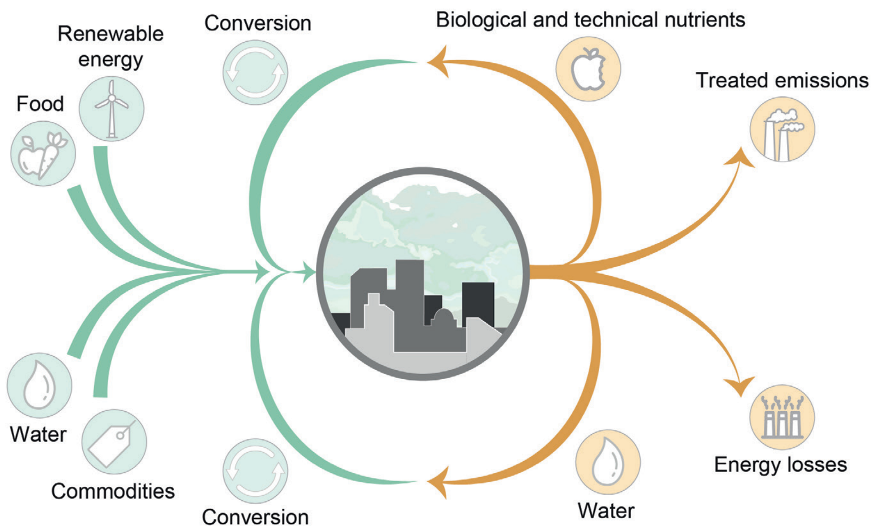
Problem:

Contemporary urban systems operate on a linear "cradle to grave" framework. In this model, industries primarily 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, and the accumulation of waste and pollution of water, air, and land (Lakatos et al., 2021).

Action:

To ensure the continuous high-quality cycle of nutrients, water, and energy, develop effective strategies for the transition from linear to circular urban metabolisms, according to the following steps:

1. Analyze the current situation: Understand the dynamics of the inflows and outflows in your urban area, and set clear goals for their continuous optimization.
2. Optimize the system: Focus on maximizing the efficiency of processes, seeking to optimize the use of resources.
3. Use local and renewable materials: Prioritize the collection and use of locally available resources and from renewable sources.
4. Re-circulate resources: Establish mechanisms that allow the recirculation of resources, prolonging the use of materials.
5. Enhance positive effects: Explore ways to direct positive impacts in each resource cycle, considering energy, water, biological and technical nutrients, construction materials, land use and occupation, and gains in biodiversity.



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Downward pattern links: [1] Energy, Air, and Climate Protection. [2] HHealth and Circularity of Material Flows. [3] Water and Soil Management and Local Biodiversity Gains. [4] Strong, Equitable, and Fair Communities.

B. Synergistic Benefits

Upward or of key knowledge pattern links: Circular Urban Areas [0], Circular Urbna Metabolsim [A],

***

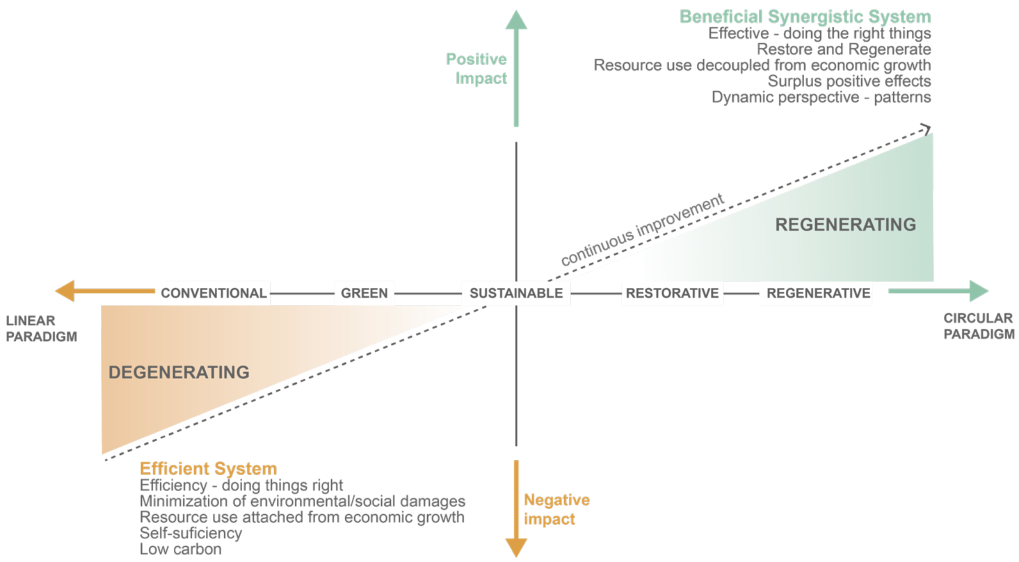
Problem:

With over half of the global population living in urban areas, the ecological footprints of cities have been expanding, covering a large part of the Earth's surface, becoming a serious factor in climate change. The current challenge is no longer limited to creating cities that only reduce impacts and mitigate environmental damage, but to develop truly regenerative cities. Urban areas must ensure that they not only become resource-efficient and low-carbon, but also generate a range of benefits for human well-being and the valorization of ecosystems, including the creation of job opportunities, social and economic inclusion, and the reduction of socio-environmental inequalities, which we call "synergistic benefits".

Action:

When creating solutions for circularity, encourage a surplus of positive effects in the region, so that human activities advance in climate adaptation, restoration, and regeneration of human and ecological systems. Therefore:

1. Instead of just reflecting on strategies to mitigate impacts and reduce environmental damage, develop solutions that export benefits to the community and nature. Focus on quality and not just quantity.
2. Include as many actors as possible who are related to the transition to the Circular Economy, possibly including local government and public participation in decision-making.
3. Develop various distributive solutions, designed to naturally form a distributed network, which can disperse and circulate the created value instead of concentrating it.
4. Work with the possibility of valuing local potentials, such as geographical and territorial characteristics, and socio-cultural aspects.
5. Enable an environment for innovation and to add financial value to the project.



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Downward pattern links: [1] Energy, Air, and Climate Protection. [2] Health and Circularity of Material Flows. [3] Water and Soil Management and Local Biodiversity Gains. [4] Strong, Equitable, and Fair Communities.

2. Circularity of Healthy Material Flows

Upward or of key knowledge pattern links: Circular Urban Metabolism [A]. Synergistic Benefits [B]

***

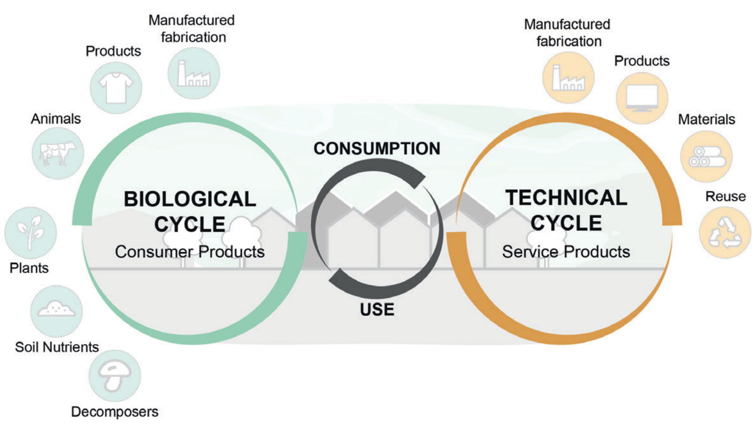
Problem:

When viewing cities from a resource perspective, we tend to see them primarily as consumers of materials and generators of waste. Every day, a significant amount of resources enters an urban area. After being consumed, some flows, such as wastewater or debris, are directed out of the urban system, while others, such as construction materials, food waste, or electronic products, remain internally, constituting urban "stocks". Although certain elements of these urban stocks are often labeled as waste, there is a set of latent resources with the potential to be recovered, recycled, and reused.

Action:

To positively transform the outcomes of human activities, cities can then be seen as reservoirs of these resources, starting with the following steps:

1. Biological and technical cycles: Develop products, technologies, and buildings as "material banks" that should be incorporated into distinct biological and technical cycles. Materials intended for the biosphere should come from renewable sources and be designed to reintegrate as biological nutrients into natural ecosystems. On the other hand, materials intended for the technosphere consist of non-renewable materials and should be designed for continuous circulation, maintaining their value within closed industrial cycles.
2. Civil construction: In the urban context, the construction sector stands out for its high potential for circular transition. New buildings should be designed with the premise of reusing their materials in subsequent cycles, adopting modular and demountable construction systems. In addition, it is essential to extend the existing stock of buildings as much as possible, promoting renovations and adaptations that add value and prolong their use.
3. Promote policies and actions for conscious consumption such as waste separation at the source, its collection and proper disposal, implementation of information systems, and inclusion of social actors in selective collection.
4. Ask yourself for each action: *what happens next?* This continuous reflection on the consequences and impacts of our choices is essential to ensure progress towards a healthier and more circular future.



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Downward pattern links: [2.1] Healthy Biological Nutrient Cycle. [2.2] Healthy Technical Nutrient Cycle. [2.3] Clean and Circular Construction. [2.4] Municipal qaste consumprion and management.

2.1. Healthy Biological Nutrient Cycle

Upward or of key knowledge pattern links: [2] Circularity of Healthy Material Flows

***

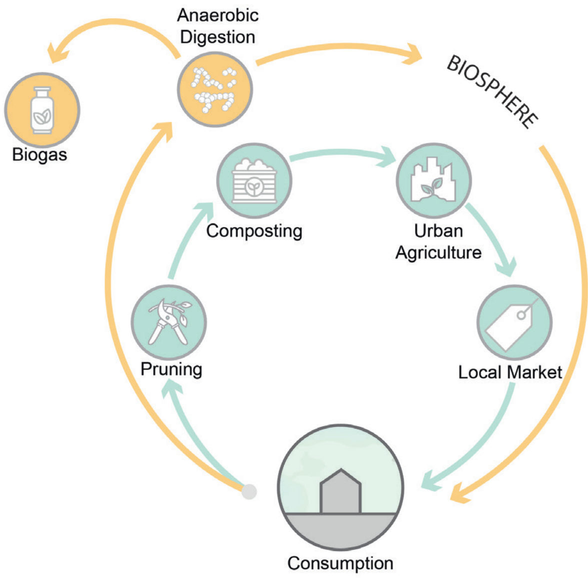
Problem:

Cities, often designed with a focus on efficiency and economic growth, tend to overlook the importance of maintaining and reintegrating organic nutrients into local ecosystems. As a result, we face a disconnection between urban consumption and sustainable food production, leading to the accumulation of organic waste that could be valuable to the biosphere. This failure in the nutrient cycle not only contributes to the increase of landfills but also to the loss of biodiversity and soil degradation.

Action:

The biological nutrient cycle in urban areas is essential to maintain environmental sustainability and promote the bioeconomy. This cycle involves the reintegration of renewable organic materials into natural ecosystems, whether through the valorization of biological waste into new products and biomaterials or by returning these nutrients to the soil as fertilizer, through composting and biodigestion. Adopting practices that allow this reintegration not only minimizes food waste and strengthens local biodiversity but also contributes to carbon capture and improves urban life quality. Efficient management of the biological cycle is, therefore, vital to connect communities with local food production, promoting a more sustainable cultivation approach and proper treatment of organic by-products. Therefore:

1. Implement urban agriculture and composting practices to reintegrate nutrients into the soil and promote ecosystem health, in addition to reusing wood from pruning in local projects.
2. Explore initiatives such as productive landscaping and community gardens, integrating urban areas with sustainable crops, reducing dependence on long-distance foods, and fostering local biodiversity.



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Downward pattern links: [2.1.1] Urban Agriculture. [2.1.2] Composting.

2.1.1. Urban Agriculture

Upward or of key knowledge pattern links: [2.1] Healthy Biological Nutrient Cycle.

***

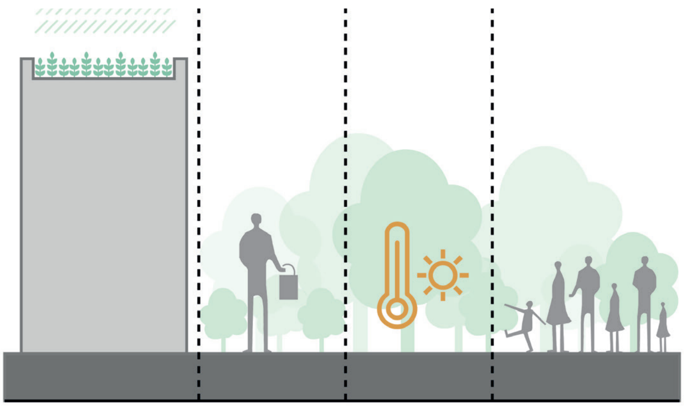
Problem:

The current food production system, developed in intensive monoculture systems to sustain a rapidly growing population, has generated productivity gains at a high cost. Deforestation for the expansion of agricultural lands, along with inadequate livestock and soil management, has resulted in the food industry being responsible for almost 25% of global greenhouse gas emissions (Todoroff, A. 2022). Additionally, the mismanagement of fertilizers has led to the eutrophication of water bodies, while the use of chemical pesticides has degraded the natural resources fundamental to the functioning of the food system. (Robertson-Fall, 2021). Furthermore, data from the UN Environment Programme suggest that one-third of food continues to be lost or wasted each year, demonstrating the inefficiency of the system (Mbow, C., and Rosenzweig, C., 2022).

Action:

Integrating agricultural practices into urban spaces allows to urban citizens to use local organic waste as inputs for cultivation, thereby closing the nutrient cycle. This approach provides a local source of healthy food while transforms urban spaces into greener and more resilient environments, contributing to the creation of self-sufficient and ecologically conscious communities. Furthermore, the proximity between producers and consumers in urban agriculture reduces the need for extensive and complex distribution systems, minimizing food waste and decreasing the environmental footprint associated with transportation. Therefore:

1. Work on urban agriculture in its various forms: in community gardens, green roofs, productive landscaping, agroforestry, food production on urban fringes, among others.
2. Link urban agriculture to composting processes and the reuse of urban wood prunings, reintroducing nutrients to the biosphere.
3. Involve the community in urban agriculture projects, promoting not just food production but also education and food perception, as well as a sense of belonging and community cohesion.



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Downward pattern links: [2.1.1.1] Productive green roofs. [2.1.1.2] Agrofloresty Systems. [2.1.1.3] Agrovoltaic systems.

2.1.1.1 Productive green roofs

Upward or of key knowledge pattern links: [2.1.1] Urban Agriculture.

***

Problem:

In the heart of urban centers, where the scarcity of arable land poses a significant challenge to food security and sustainability, the innovative solution of productive rooftop presents itself as a beacon of hope. The problem of limited green spaces and the increasing distance between food production and consumption are pressing concerns in rapidly urbanizing areas. Traditional green roofs have served as a stepping stone, providing environmental benefits and enhancing urban aesthetics. However, they fall short in addressing the urgent need for local food production and the reintegration of natural cycles within cityscapes.

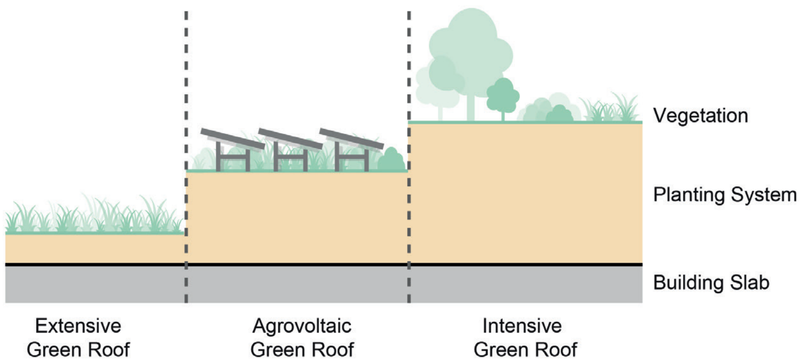
Action:

Implement urban rooftops as productive resources as rooftop farming has been emerging as a distinctive alternative to conventional green roofs. While both approaches involve vegetation atop buildings, rooftop farming goes beyond the aesthetic and environmental benefits of green roofs by actively cultivating crops for food production. Rooftop farming transforms otherwise underutilized spaces into vibrant hubs of agricultural activity, contributing to local food resilience and circularity.

Three primary types of productive green roofs—extensive, intensive, and agrovoltaic —highlight the diverse approaches within this field (Calheiros & Stefanakis, 2021).

- Extensive green roofs typically feature low-maintenance vegetation like sedums, optimizing environmental benefits with minimal input.
- Intensive green roofs, on the other hand, involve more complex and diverse plantings, resembling traditional gardens, allowing for a wider range of crops.
- Agrovoltaic roofs integrate solar panels with agriculture, creating a symbiotic relationship that maximizes energy production while fostering crop growth.

The choice between these variations reflects a nuanced decision-making process, considering factors such as available space, resource inputs, and the desired balance between food production and environmental services.



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Downward pattern links: [2.1.1.1.2] Agrovoltaic systems.

2.1.1.2. Agroforestry Systems

Upward or of key knowledge pattern links: [2.1.1] Urban Agriculture.

***

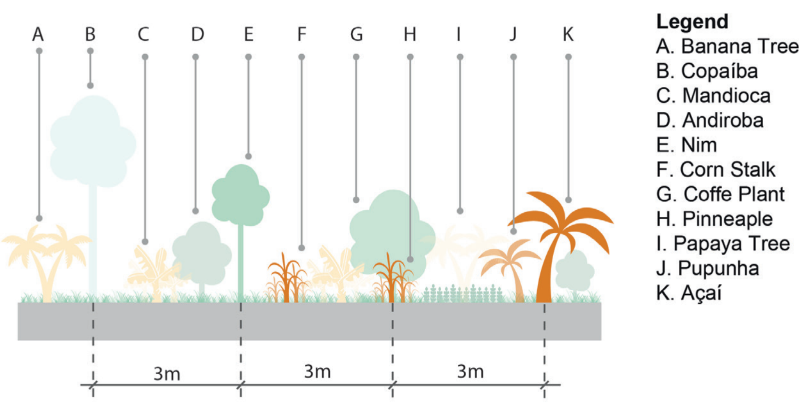
Problem:

Urban areas face significant environmental, social, and economic challenges due to rapid urbanization, which leads to the loss of green spaces, biodiversity, and natural habitats. This transformation results in increased temperatures due to the urban heat island effect, water cycle disruption causing flooding and pollution, and a disconnection between residents and nature, impacting mental health and community cohesion. Economically, cities become dependent on distant food sources and resources, increasing their vulnerability to supply chain disruptions and contributing to climate change. Urban agroforestry systems present a solution by revitalizing urban landscapes, improving ecological conditions, and fostering sustainable local economies.

Action:

Implement Agroforestry Systems in urban contexts. These systems represent an agricultural approach inspired by the natural dynamics of ecosystems untouched by human intervention, aligning with the laws of nature. This method seeks to enhance cultivation conditions without resorting to genetic alterations or the addition of petrochemical substances commonly found in traditional monocultures. In agroforestry, plants are grown in consortium, arranged in parallel lines, and intermixing different species in terms of size and characteristics, aiming for optimal land use and the preservation and reintroduction of native species (Andrade, 2019).

The primary strategy is to accelerate natural succession through practices such as selective weeding, removing mature pioneer plants, and pruning trees and shrubs to provide nutrients to the soil. The parts removed from the plants that are not marketable return to the soil with the intention of strengthening the compost. Unlike conventional practices, external chemical controllers are not used, and insects and organisms are seen as indicators of deficiencies in the system, assisting producers in understanding the cultivation needs. This approach, by respecting natural principles, strengthens and regenerates soil health in an integrated manner (Andrade, 2019).



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Downward pattern links: ...

2.1.1.3. Agrovoltaic Systems

Upward or of key knowledge pattern links: [2.1.1] Urban Agriculture. [1.1] Clean and Renewable Energy

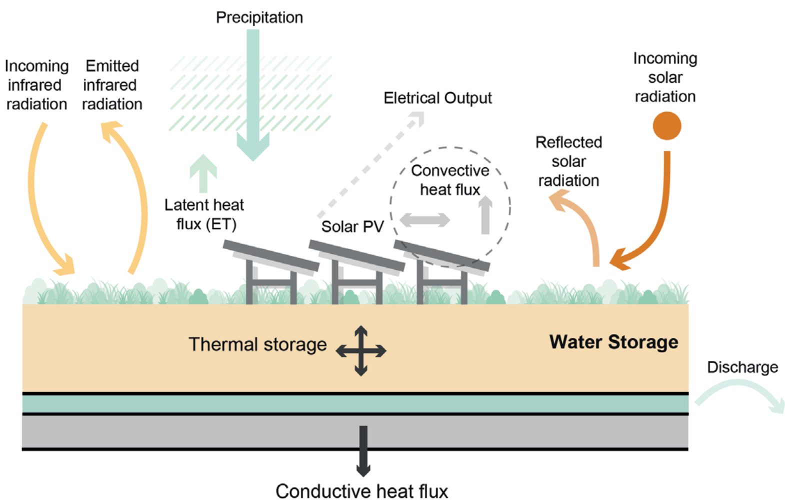
***

Problem:

Urban areas face challenges including increasing demand for energy and food, loss of green spaces and biodiversity, and rising temperatures due to the urban heat island effect. Urban expansion often leads to soil sealing, exacerbating the risk of flooding and water pollution. Moreover, reliance on distant sources for food and energy makes cities vulnerable to supply chain disruptions and contributes to greenhouse gas emissions. The lack of integration between urban development and sustainable agricultural practices exacerbates these issues, challenging cities' ability to provide resources efficiently and sustainably to their growing populations.

Action:

Agrovoltaic systems represent an innovative convergence of solar photovoltaic energy development and agriculture on the same land area, a promising solution for modern urban challenges. In urban environments, these systems can be implemented at ground level, above community gardens, or on green rooftops, optimizing both vertical and horizontal space. The installation of solar panels over cultivation areas creates a more controlled agricultural environment, protecting plants from excessive sun exposure while simultaneously generating renewable energy. The interaction between photovoltaic cells and vegetation is beneficial, as plants help cool the panels, enhancing their efficiency in electricity generation. Moreover, green rooftops equipped with agrovoltaics can mitigate urban stormwater runoff, contribute to lowering city temperatures, save building energy, and encourage biodiversity. Through the dual use of land, agrovoltaic systems maximize available resources, allowing the energy produced to be used directly in agricultural operations or fed into the local power grid. This virtuous cycle of food and energy production not only contributes to the resilience and autonomy of urban communities but also offers an integrated strategy to address food security, energy sustainability, and environmental challenges in cities (Agrovoltaic, 2024).



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Downward pattern links: [1.1.3] Sinergic solutions.

2.4. Clean and Circular Construction

Upward or of key knowledge pattern links: [2] Circularity of Healthy Material Flows

***

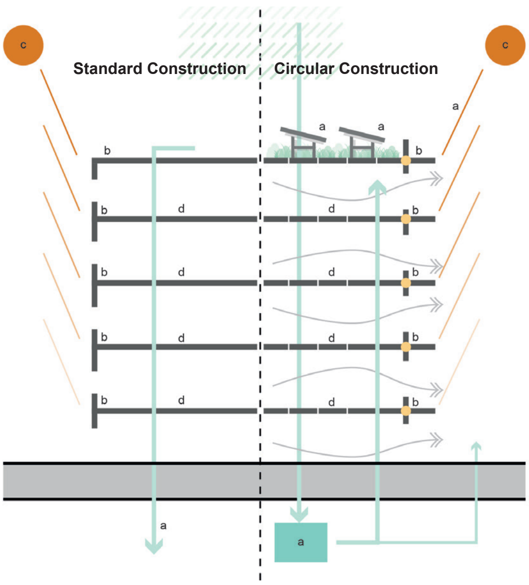
Problem:

Only 9% of the economy is considered circular, with less than 10% of the 92.8 billion tonnes of materials from production processes being recirculated (Circle Economy, 2019). Nearly half of this massive consumption (42.4 billion tonnes/year) is attributed to the construction and maintenance of houses, highways, and infrastructure. In the Brazilian context, civil construction is particularly impactful, accounting for the consumption of 75% of natural resources, 12% of potable water, and 50% of electricity (MMA; CBCS; PNUMA, 2014). The country generates approximately 84 million cubic meters of construction and demolition waste annually, representing 50% to 70% of the mass of solid urban waste in Brazil (Ministério do Meio Ambiente, n.d.)

Action:

Design and construct circular buildings. A circular building is one that is designed, constructed, operated, maintained, and dismantled in a manner consistent with the principles of the circular economy.

'What next?' This should be the guiding question for a project of clean and circular construction. As an alternative to the linear system that generates pollution and resource waste, circular constructions are inspired by nature, where waste is nutrients, solar energy is captured in abundance, and diversity is celebrated. Thus, such construction does not generate waste, while natural resources and healthy materials circulate within their biological and technical spheres. The construction system is prefabricated and modular, enabling quick and clean construction, as well as future expansions, reductions, dismantlings, and the reuse of its materials in new industrial cycles. The project also optimizes the capture of renewable resources and fosters harmony with natural cycles, landscape, and biodiversity. Resources such as water, energy, biological nutrients, and construction materials are designed to be indefinitely reused, creating a healthy, circular, and regenerative place.



Standart Construction
a. Resource disposal
b. Isolated building
c. Non-use of solar energy
d. Construction with non-reusable resources

Clean and Circular Construction
a. Use of natural resources
b. Integration and exchanges with the environment
c. Energy from the sun is captured in abundance
d. Prefabricated and modular construction system

***

Downward pattern links: [2.4.1] Building as Material Banks.

2.4.1. Building as material banks

Upward or of key knowledge pattern links: [2.4] Clean and Circular Construction

***

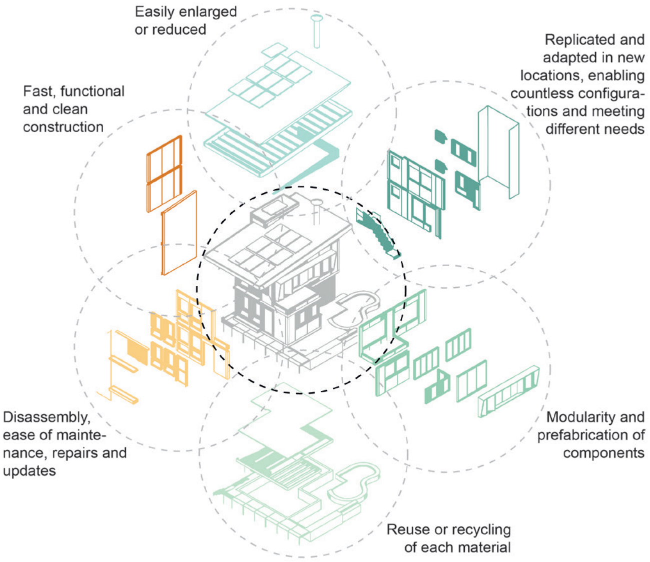
Problem:

The construction sector faces significant problems related to high natural resource consumption, intensive waste generation, and long construction periods, which negatively impact the environment and economic efficiency. These challenges are exacerbated by traditional construction practices that often result in excess materials wasted and the need to transport large quantities of resources to construction sites, contributing to greenhouse gas emissions. Moreover, the extended nature of traditional construction projects can lead to significant delays and an increase in operational costs, affecting the sustainability and economic viability of projects. These problems highlight the urgent need for innovation and change in construction practices to meet the growing requirements for sustainability and efficiency in the sector.

Action:

Plan buildings as material banks: each material has its value, recovered, and reinserted into biological or technical cycles when its use is no longer needed. Each item is designed to be reused in new constructions, new products, or to return to nature. Planning, modularity, and prefabrication of components allow for rapid, functional, and clean construction. The aim is to generate no waste at all, optimizing physical resources and construction time.

In addition to the modularity of the systems, buildings should be designed to be possibly disassembled, facilitating maintenance, repairs, and updates, and allowing for the reuse or recycling of each material. The construction avoids using glues and adhesives, opting for fittings and screws, allowing infinite combinations to adapt spaces to the needs of its users. It can be easily expanded or reduced, or disassembled and completely reused as housing or inputs for new product cycles. These characteristics also allow the project to be replicated and adapted in new locations, enabling numerous configurations and meeting different needs.



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Downward pattern links: [2.4.1.1] Material passports

2.4.1.1. Material Passports

Upward or of key knowledge pattern links: [2.4.1] Building as Material Banks

***

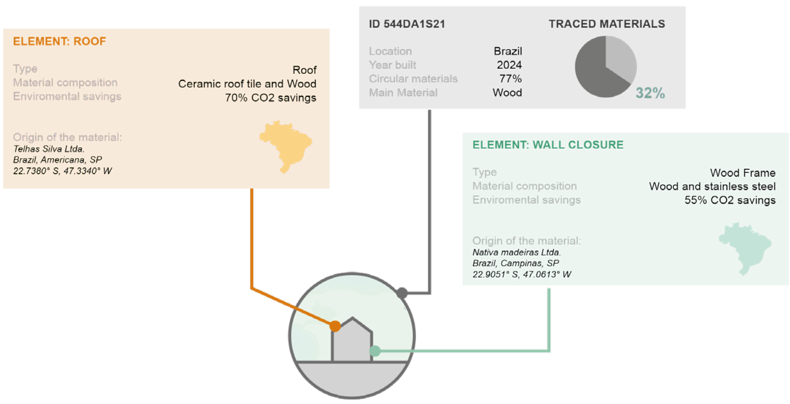
Problem:

Implementing the reuse and recycling of building materials often runs into the absence of efficient systems for the prior identification and cataloging of these materials. This gap in material management often results in the improper disposal of these resources as waste, compromising the potential for their recovery. Additionally, the lack of prior material identification makes the processes of removal and disposal at the end of a building's life not only more costly but also significantly reduces the possibility of recovering these materials. The absence of a detailed inventory of the materials contained in a structure makes it difficult to carry out efficient, safe, and sustainable demolition and renovation practices, increasing the risks associated with these procedures.

Action:

Create passports for materials, construction systems, and buildings. The circular material passport functions similarly to a conventional passport, which records essential personal information. This tool, however, accurately details the material composition of buildings. These records, usually available on digital platforms, provide a complete overview of the materials, products, and components used, not only facilitating identification but also efficient recovery of these resources at the end of the construction's life cycle. This process eliminates the need to discard or incinerate valuable materials, favoring their reuse or recycling in future demolition or renovation projects (Göswein et al., 2022).

Moreover, the circular material passport offers a reliable and standardized database, which organizes and stores vital information, giving a unique identity to each product, and consequently, attributing intrinsic value to it. This approach allows for the tracking of materials throughout the entire supply chain, creating a faithful record of the composition and carbon footprint of buildings through digital product passports. In this way, it not only facilitates the recovery of materials but also provides crucial information for maintenance, recovery, reuse, and recycling of the same. The accumulation of these individual records can culminate in the creation of a collective Construction Materials Passport, marking significant progress in resource management and the consolidation of the circular economy in the construction industry (Göswein et al., 2022).



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Downward pattern links: ...

7. Applying to the case study: HIDS and Argentina Farm

The Framework to Transition Urban Areas Towards a CE was applied to the case study of Argentina Farm, establishing a basis for this analysis. Situated next to the "Zeferino Vaz" Unicamp Campus in Campinas, São Paulo, Brazil, this farm, once developed, will be incorporated and managed by the university. Additionally, the area is under development to become an integral part of the forthcoming International Hub for Sustainable Development (HIDS).

The case study analysis considered the guidelines and regulations applicable to the university (Unicamp) and the campus (Zeferino Vaz), including municipal and state regulations, including topics like governance strategies, accessibility to public and educational services, purchasing, and innovation. These guidelines are equally pertinent to Argentina Farm, as they are subject to the same administration. In addition, the research adapted energy consumption, materials, food, and waste management from the Zeferino Vaz Campus data, adjusted proportionally to the number of users at Argentina Farm, reflecting the current practices and consumption of the campus.

Furthermore, the Sustainable Campus Project, a partnership between Unicamp and CPFL Energia, aimed at enhancing the campus energy infrastructure and, through the study and development of new technologies, improving teaching and research to transform Unicamp into the largest Living Lab for Energy Sustainability in Latin America, was also incorporated into the analysis (Silva, 2023). This project derived energy generation and food production estimates based on the agrovoltaic system's proposed design at Argentina Farm.

Lastly, the analysis incorporated the guidelines from the HIDS Masterplan, as developed by KRIHS (2022). As a result, the study considers a population of 10,551 individuals. This number encompasses both the employment opportunities created through technological innovations and the public sector positions located near the farm, as outlined in the Masterplan. This population figure serves as the basis for all further calculations and assessments.

The HIDS Masterplan adopted five main strategies for developing HIDS scenarios: creating a multi-functional city with a harmonious balance of workspaces, educational areas, and leisure zones centered around a core that brings together innovation activities, business hubs, and research centers; providing a model of compact and sustainable development with mid-level density and mixed land use; connecting the HIDS road network with highways and surrounding plots, while conserving the existing green network; and preserving the natural ecosystem through a variability of green spaces, such as parks, trails, and, open squares, and environmental preservation areas (KRIHS, 2022).

The proposal entails the perimeter occupation of blocks with intermediate density in residential areas, suggesting buildings of 10 to 15 stories to accommodate an average of 300 people per hectare. Mixed-use within buildings is proposed, with an equitable distribution among residential, commercial, service, social housing, and community facilities. For other usage typologies, buildings of 5 to 7 stories are proposed, with utilization coefficients ranging from 2 to 3 (KRIHS, 2022; Noronha, 2023). Despite the Masterplan indicating mixed-use within the HIDS, residential and commercial areas are deliberately situated outside the Fazenda Argentina zone, where, due to its public characteristics, only institutional purposes are permissible. Essential functions such as innovation hubs and other public facilities integral to the HIDS will be strategically located within the Argentina Farm area (KRIHS, 2022).

The following sections present the main results for each indicator of the framework, complemented by the calculation memorandum when necessary. This examination aims to assess Argentina Farm's current performance in terms of CE and identify opportunities for improvement and innovation that can be replicated in other urban areas.

7.1. Energy, Air, and Climate Protection

Clean and Renewable Energy

Table 11. Results for the category of Clean and Renewable Energy

	Indicator	Objective	Metric	Result
a.	**Circular Sources - Energy**	Promote the use of renewable energy sources	Percentage of renewable energy used / total energy consumption	165%
b.	**Circular Content - Energy**	Advocate for energy efficiency and the use of high-quality energy	Percentage of energy reduction compared to an estimated baseline energy usage for infrastructure (e.g., traffic lights, streetlights, water pumps, and sewage)	1,8%
c.	**Active Cycle - Energy**	Encourage the use of the highest-quality energy for as long as possible	Percentage of onsite renewable production spent in electric power / total renewable electricity production	100%

a) Circular Sources – Energy

The *Circular Sources – Energy* indicator compares local renewable energy production and total energy consumption. The production was estimated by the number of agrovoltaic modules and their production, as planned in the Sustainable Campus Project (L. C. P. da Silva, 2023). The energy consumption at Argentina Farm is determined by the expected number of users, calculated proportionally based on the current per capita consumption at the Zeferino Vaz Campus. The result showed highly positive results, with a rate of 165%, which indicates that the agrovoltaic system will be able to fully cover the energy needs through renewable sources while producing a significant energy surplus.

Description of Calculations

- Current energy consumption at Zeferino Vaz Campus per user = 1.58 MWh/year (annual average of electricity bills - from 09/01/2018 to 09/01/2019)(CPFL Energia.)
- Agrovoltaic area = 9.3 ha (L. C. P. da Silva, 2023)
- Number of modules planned for Argentina Farm= 46.000 modules (L. C. P. da Silva, 2023)
- PV current production in Zeferino Campus per module = 0.75 MWh/year (L. C. P. da Silva, 2023)

- PV Efficiency of agrovoltaic (compared to standard PV systems) = 80% (Agrovoltaic, 2024)

$$Energy\ Production\ (agrovoltaic) = \text{number of modules x module energy production} = 46.000 \text{ x } 0{,}75 \text{ x } 0{,}80 = 27.600 \text{ MWh/ year}$$

$$Energy\ Consumption\ (BAU) = \text{current consumption per user x number of users} = 1{,}58 \text{ x } 10.551 = 16.670{,}58 \text{ MWh/ year}$$

$$Circular\ source\ (energy) = \frac{\text{renewable energy produced}}{\text{total energy consumption}} = \frac{27.600}{16.670{,}58} = 165\%$$

b) Circular Content - Energy

For the *Circular Content - Energy* indicator, the energy consumption reduction was based on the project for energy efficiency in areas external to buildings, such as lighting, traffic lights, water pumps, and sewage systems. However, the Sustainable Campus Project (L. C. P. da Silva, 2023) only foresees reduction for the lighting system.

Calculations considered that LED bulbs achieve a 60% reduction in consumption compared to fluorescent bulbs (Mario et al., 2015), which represents the Business as Usual (BAU) scenario on the Campus (L. C. P. da Silva, 2023). Furthermore, it was estimated that the consumption of external public lighting accounts for 3% of the campus's total energy consumption, a figure proportional to the expenditure on public lighting in Brazil (Acosta, 2022).

As a result, Argentina Farm achieved a 1,8% rate for the *Energy Circular Content*. This modest result is due to having informationonly the project for energy efficiency in public lighting in areas external to buildings. It highlights the need for a more comprehensive implementation of energy efficiency practices in other parts of the urban infrastructure, such as traffic lights, water pumps, and sewage systems. On the other hand, this low rate can also be explained by the format of the collected data, which represents the total consumption without specific details on the consumption by buildings or different uses within the campus and does not distinguish between the consumption of external areas and that of buildings, which tend to represent a proportionally much more significant portion of the total consumption.

Description of Calculations

- LED energy consumption reduction (compared to fluorescent bulbs - BAU) = 60% (Mario et al., 2015)
- Fazenda Argentina total energy consumption (BAU scenario) = 16.670,58 MWh/year
- Average proportions of energy consumption related to public lighting in Brazil = 3% (Acosta, 2022)

$$External\ lighting\ consumption\ (BAU)\ in\ Fazenda\ Argentina = 16.670{,}58 * 0{,}03 = 500{,}12\ \text{MWh/ ano}$$

$$New\ external\ lighting\ \ consumptio\ in\ Fazenda\ Argentina = 500{,}12 * 0{,}40 = 200{,}05\ \text{MWh/ ano}$$

$$New\ energy\ consumptio\ in\ Fazenda\ Argentina = 16.670{,}58 - (500{,}12 - 200{,}05) = 16.370{,}51\ \text{MWh/ ano}$$

$$Circular\ content(energy) = \frac{\text{consumption reduction}}{\text{total energy consumption}} = \frac{(500{,}12 - 200{,}05)}{16.370{,}51} = 1{,}8\%$$

c) Active Cycle - Energy

The *Active Cycle - Energy* indicator reflects an efficiency of 100% in the use of onsite renewable energy production for electricity, meaning that all renewable energy produced at the university is utilized in its highest quality, and the transmission lost is minized.

Healthy Air

Table 12. Results for category of Healthy Air

	Indicator	Objective	Metric	Result
d.	**Air Quality**	Enhance ambient air quality	Percentage of days achieving N1 (good) and N2 (moderate) air quality according to CETESB/CONAMA Resolution No. 491/2018, assessing: inhalable particles (PM10), fine inhalable particles (PM2.5), smoke (FMC), ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2)	Information not available
e.	**Greenhouse gas emissions**	Balance of CO2	Percentage of buildings oriented so that one axis of each qualified building is at least 1.5 times longer than the other, and the longer axis is within 15 degrees of the geographical east-west.	Information not available

d) Air Quality

There is a significant information gap for the *Air Quality* indicator at Argentina Farm. This research has not found specific data on air quality in the area or records of measurements made by CETESB in the Barão Geraldo district. This lack of data prevents a direct assessment of the current state of air quality in the region and a comparison with the standards established by CETESB/CONAMA (Governo do Brasil, 2018).

e) Greenhouse gas emission

No specific records or directives related to the control of greenhouse gas emissions exist for the university or the Fazenda Argentina project. This absence highlights a need for improvement and development within the topic.

Urban Comfort and Climate Protection

Table 13. Results for Category of Urban Comfort and Climate Protection

	Indicator	Objective	Metric	Result
f.	**Optimize Solar input**	Create ideal conditions for passive and active solar strategies, and landscape quality	Percentage of buildings oriented so that one axis of each qualified building is at least 1.5 times longer than the other, and the longer axis is within 15 degrees of the geographical east-west.	0%
g.	**Reducing Heat Island Effect**	Mitigate the effects of heat islands in the local area by installing high-reflectance or vegetated roofs	Area of SRI roofs (SRI higher than 29) + Area of greenroofs/ Total roof area	20%
h.	**Renewable Energy in Mass Transportation**	Encourage the use of renewable energy for mass transportation	Percentage of trips in mass transportation powered by clean and renewable energy	Under consideration

f) Optimize Solar Input

The *Optimize Solar Input* indicator aims to maximize solar utilization in buildings by orienting them to create ideal conditions for passive solar strategies. However, insufficient information was available to calculate specific results for this indicator. The DEPI/CSUS (Executive Board of Integrated Planning of Unicamp/ Sustainability Division Coordination) 2023 guidelines (Dalbelo, 2023) emphasize the importance of ensuring the right to sunlight and the visual quality of the urban landscape and optimizing solar input. Nevertheless, the KRIHS Masterplan (KRIHS, 2022) does not present a study that justifies the design of the plots aiming to optimize the potential for sunlight or shading, leaving the indicator with 0% compliance.

g) Reducing Heat Island Effect

The *Reducing Heat Island Effect* indicator encourages using vegetative and high-reflectance materials in coverage areas. The HIDS Masterplan (KRIHS, 2022) guideline recommends at least 20% green cover on building rooftops. This result indicates an initial effort to deal with the heat island effect while highlighting the need to expand these practices to larger areas.

h) Renewable Energy in Mass Transportation

The *Renewable Energy in Mass Transportation* metric focuses on the percentage of mass transportation trips powered by clean and renewable energy. The HIDS Masterplan (KRIHS,

2022) includes guidelines such as the establishment of electric BRT circulation networks, the construction of personal mobility routes using electric devices, and indicating studies for mobility with green hydrogen buses. Despite these guidelines and studies indicating a direction for using renewable energies in mass transportation, more detail and sizing of the projects are needed to ensure a quantitative assessment of this indicator.

7.2. Circularity of Healthy Material Flows

Biological Nutrient Cycle

Table 14. Results for the category of Biological Nutrient Cycle

	Indicator	Objective	Metric	Result
a.	**Circular Sources – Biological Cycle**	Measure the circularity of material sources	% renewable content cycling	100%
b.	**Circular Content - Biological Cycle**	Make the material suitable to be kept in high-quality cycles	% of organic material consumed (produced without pesticides)/ total consumption	183%
c.	**Active Cycle - Biological Cycle**	Maintain the material in high-quality cycles for the longest possible time	% of biological materials cascading / total material biological +hybrid output	20%

a) Circular sources - Biological Cycle

For the *Circular Source—Biological Cycle* indicator, the study implied that local food production at the case study site would be conducted without the use of synthetic fertilizers, resulting in 100% of the material sources circulating as biological nutrients.

b) Circular content - Biological Cycle

The *Circular Content—Biological Cycle* indicator measures the area's ability to consume as much organic (without synthetic fertilizers) as possible. The calculation estimated the food production onsite, pesticide-free, over the total consumption of meals. For the calculations, the whole area of the photovoltaic system was considered covered with organic tomato plantations. In addition, the meal consumption was adjusted by the number of expected users at Argentina Farm, based on the current individual consumption of the Zeferino Vaz Campus.

The indicator in the case study resulted in an index of 183%, demonstrating the viability of the Argentina Farm to be self-sufficient in terms of food production and suggesting a significant potential surplus that could be distributed or commercialized. However, regulations or guidelines considering organic food in cafeterias have yet to be established, expressing the need to review this theme within the university community.

Calculation Description

Food Consumption at Argentina Farm (C)

- Current consumption in the Zeferino Vaz Campus cafeterias per user: 0.05 t/year (Prefeitura da Unicamp. Diretoria de Alimentação do Campus, 2019)

- Number of users at Argentina Farm = 10.551 people

$$\text{Food consumption at Argentina Farm} = \text{number of users x consumption per user} = 10.551 \text{ x } 0.05 = 509.04 \text{ t/year}$$

Organic Food Production at Argentina Farm (P)

- Annual average productivity of organic tomatoes in Brazil = 80 t/year/ha (Morales et al., 2019)
- Agrovoltaic area = 9.3ha (L. C. P. da Silva, 2023)

$$Organic\ Food\ production\ at\ Argentina\ Farm = \text{Annual average productivity of organic tomatoes x Agrovoltaic area} = 744 \text{ t/year}$$

Circular content – Biological Cycle

$$Circular\ content\ (biological) = \%\ of\ organic\ food\ consumed\ (produced\ without\ pesticides) / total\ consumption = \frac{744}{509.04} = 183\%$$

c) Active Cycles - Biological Cycle

For the Active Cycle – Biological Cycle indicator, Argentina Farm recorded a result of 23%. This value reflects the proportion of biological materials cascading, compared to those mixed with other materials and directed to municipal landfills. These materials, such as tree pruning and garden waste, are directed to manufacturing wood pellets, composting, or gardening. Although the percentage of 23% indicates that there is room for improvement in looping biological nutrients, it also shows an initial commitment to managing biological outputs and their maintenance in high-quality cycles.

Calculations Description

- cascade = tree pruning = 788,66 t / ano Prefeitura Unicamp. Diretoria de Limpeza Urbana, 2019)
- material sent to landfill = 2.600 t/ano (Prefeitura Unicamp. Diretoria de Limpeza Urbana, 2019)

$$Total\ output = \text{cascade} + \text{material sent to landfill} = 788{,}66 + 2.600 = 3.388{,}66\ \text{t/year}$$

$$Active\ cycles\ (biological) = \frac{\text{cascade}}{\text{total output}} = \frac{788{,}66}{3.388{,}66} = 23\%$$

Technical Nutrient Cycle

Table 15. Results for category of Technical Nutrient Cycle

	Indicator	Objective	Metric	Result
d.	**Circular Sources – Technical Cycle**	Measure the circularity of material sources	% of material from reuse, remanufacturing, or recycling	information not available
e.	**Circular Content - Technical Cycle**	Make the material suitable to be kept in high-quality cycles	% of non-toxic material (ABC-X list) recyclable or with reuse, or remaking possibilities	information not available
f.	**Active Cycle - Technical Cycle**	Maintain the material in high-quality cycles for the longest possible time	% of material being recycled, reused, or remanufactured	9%

d) Circular sources - Tehcnical Cycle

Regarding maintaining materials in high-quality cycles, there is a need for more information and policies related to the recyclability and potential for reuse or remanufacturing of the materials and products acquired on Campus. A clear strategy to ensure the acquisition of non-toxic, easily recyclable, or reusable materials is needed to ensure Unicamp's ability to promote a robust circular economy in the technical cycle. Therefore, developing and implementing guidelines that prioritize these key areas in future purchases is imperative, ensuring that technical materials can circulate in continuous and healthy cycles.

e) Circular Content – Technical Cycle

The *Active Cycle - Technical Cycle* indicator showed a result of 9%, which indicates that only a small fraction of the technical materials is currently recycled, reused, or remanufactured in the case study. This percentage, derived from the comparison between the materials sent for recycling and the total waste generated, reflects the urgent need to improve technical waste management on campus. Although recycling is already an adopted practice, it is evident that more comprehensive and effective strategies are needed to increase technical materials' recirculation rate significantly.

f) Active Cycle - Technical Cycle

The *Active Cycle - Technical Cycle* indicator showed a result of 9%, which indicates that only a small fraction of the technical materials is currently recycled, reused, or remanufactured at the case study. This percentage, derived from the comparison between the materials sent for recycling and the total waste generated, reflects the urgent need to improve the management of technical waste on campus. Although recycling is already an adopted practice, it is evident that more comprehensive and effective strategies are needed to significantly increase the rate of recirculation of technical materials.

Calculations description:

- Materials destined for recycling = 249,2 t/year (Diretoria de Limpeza Urbana. Prefeitura Unicamp, 2019)

- Materials sent to landfill = 2.600 t/year (Diretoria de Limpeza Urbana. Prefeitura Unicamp, 2019)

$$Active\ cycles\ (technical) = \frac{\text{recycling}}{\text{total output}} = \frac{249{,}2}{(2.600 + 249{,}2)} = 9\%$$

Construction Material Cycle

Table 16. Results for category of Construction Material Cycle

	Indicator	Objective	Metric	Result
g.	**Circular Sources – Construction**	Measure the circularity of material sources (recycled and/or renewable materials)	% of material from reuse, remanufacturing, recycling, and/or renewable sources	0- no policies were found
h.	**Circular Content - Construction**	Make the material suitable to be kept in high-quality cycles for the longest possible time	% of recyclable, compostable, or reusable/remakable materials	0- no policies were found
i.	**Active Cycle – Construction 1**	Maintain the material in high-quality cycles for the longest possible time	% of construction material being recycled or composted, reused, or remanufactured	0- no policies were found
j.	**Active Cycle – Construction 2**	Adapt and/or renovate existing buildings for new uses	% of existing buildings and structures in the study area being adapted for new uses/building stock	0- no policies were found

g) Circular Sources – Construction

The analysis of the *Circular Sources – Construction* indicator at the case study reveals a scenario where the circularity of construction materials remains largely unexplored and undocumented. The absence of a declaration about the origin of the materials used in the university's constructions, combined with the lack of specific guidelines for the incorporation of recycled, reusable, or remanufactured materials in new acquisitions, points to a significant opportunity for advancement. This situation underscores the importance of establishing clear policies that promote the use of construction materials from circular sources, thereby contributing to the reduction of reliance on virgin resources and minimizing the environmental impact associated with construction activities.

h) Circular Content - Construction

Regarding the *Circular Content - Construction* indicator, there is also a clear lack of strategies aimed at selecting materials and construction systems that facilitate their subsequent disassembly and reinsertion into new productive cycles. The absence of guidelines that encourage the use of recyclable, compostable, or reusable/remodelable materials in construction reflects a still limited vision of the circular management of material resources. Implementing practices that prioritize these attributes from the design stage can significantly extend the lifespan of construction materials and strengthen the CE in the sector.

i) Active Cycle – Construction 1

For the *Active Cycle – Construction 1* indicator, the absence of studies on the destination of construction waste and the lack of guidelines for the management of such waste at the university indicate a critical area that requires immediate attention. The construction debris is all mixed up and sent to municipal landfill. Effective management of construction waste, which includes recycling, reuse, and remanufacturing of materials, is essential for reducing the volume of waste sent to landfills and for resource conservation.

j) Active Cycle – Construction 2

Regarding the *Active Cycle – Construction 2* indicator, the study could not reach any information on the adaptation or renovation of existing buildings for new uses. Although there is constant maintenance and adaptation of buildings on campus, adopting a more proactive approach in identifying opportunities for building adaptation can extend the lifespan of existing structures and contribute to reducing the demand for new construction materials, aligning building management practices with the principles of the CE.

Consumption and Municipal Waste Management

Table 17. Consumption and Municipal Waste Management

	Indicator	Objective	Metric	Result
k.	**Source separation of materials**	Encourage material separation at the source	% of urban waste separated at the source / total waste (mass)	100%
l.	**Collection and disposal**	Correctly collecting and disposing of waste	Coverage of the collection and disposal system / total users	100%

k) Source Separation of Materials

The *Source Separation of Materials* indicator shows a source rate of 100%. This achievement is attributed to the implementation of 150 selective collection points spread throughout the campus, covering both academic units and common areas. The Campus Urban Cleaning Directorate affirmed that all collected materials are properly separated at the source and directed to appropriate destinations (Prefeitura Unicamp.Diretoria de Limpeza Urbana, 2019).

l) Collection and Disposal

The *Collection and Disposal* indicator also presents a positive result, with 100% coverage in the waste collection and disposal system. The Campus Urban Cleaning Directorate states that all waste produced is correctly separated at the source and collected and disposed of appropriately (Prefeitura da Unicamp. Diretoria de Limpeza Urbana do Campus, 2019).

7.3. Water and Soil Management, and Local Biodiversity Gains

Healthy Water Cycle

Table 18. Results for category of Healthy Water Cycle

	indicator	Objective	Metric	Result
a.	**Circular Source – Water**	Measure the circularity of water sources	% of water collected from "alternative" sources (rainwater harvesting + wastewater treatment) / consumption	50%
b.	**Circular Content – Water 1**	Make the water flow suitable to be kept in high-quality cycles for the longest possible time	Quality level of locally treated water (e.g., secondary)	0- no policies were found
c.	**Circular Content – Water 2**	Promote water system efficiency	Presence of hazardous effluents from building operations and adjacent areas	0- no policies were found

d.	**Active Cycle – Water**	% of building wastewater treated locally	% of building wastewater treated locally	0- under consideration

a) Circular Source – water

The result of the *Circular Source – Water* indicator was based on the guideline from DEPI/CSUS (Dalbelo, 2023), which recommends harvesting rainwater for reuse in at least 50% of the total area of impermeable surfaces, such as roofs and built structures. This strategy aims to maximize water efficiency and minimize environmental impact by reducing the need for potable water for secondary activities.

In addition, the farm's Master Plan emphasizes the need to incorporate rainwater harvesting systems into public office buildings located at the pilot project site. Such systems should collect rainwater from both roofs and the ground, store it in underground tanks, and use it for various non-potable purposes, including supplying fountains, irrigating gardens, and flushing toilets (KRIHS, 2022).

b) Circular Content – Water 1

The *Circular Content - Water 1* indicator's main objective is to optimize the water flow, keeping the water in high-quality cycles for as long as possible. The metric used to assess this goal is the level of quality of locally treated water, considering, for example, secondary treatment as a reference standard. However, there has yet to be a forecast or implementation of local water treatment or systematic monitoring of effluents. Conducting such studies is essential to identify the presence of hazardous substances and develop effective strategies to mitigate the contamination of watercourses. This result highlights a significant gap in water resource management practices, suggesting a critical area for future development and investment to achieve the desired water conservation standards within the university.

c) Circular Content - Water 2

The primary goal of the *Circular Content—Water 2* indicator is to enhance the water system's efficiency. This involves reducing water losses throughout the distribution network and during consumption by end-users, thereby ensuring that water resources are utilized more effectively and sustainably. The metric used to assess this objective is the quantification of water loss in both distribution and consumption.

As a result, policies or measures were not found to be in place at Fazenda Argentina that specifically address water loss in distribution and consumption. This lack of policies underscores the urgent need to develop and implement targeted strategies to mitigate water loss by establishing comprehensive policies and practices that monitor, report, and reduce water loss.

d) Active Cycle – Water

The *Active Cycle – Water* indicator focuses on the percentage of wastewater from buildings treated on site. Its goal is to quantify the success of initiatives by assessing effectviness in water resource management through water treatment and reuse practices. Currently under review, the implementation of a sewage treatment system, as recommended by the DEPI/CSUS guidelines (Dalbelo, 2023), aims to allow the reuse of the generated wastewater, highlighting the university's commitment to these practices.

Resilience and Climate Adaptation

Table 19. Results for category of Resilience and Climate Adaptation

	Indicator	Objective	Metric	Result
e.	Mixed-use areas	Encourage mixed-use in the study area	Predominant use share (residential, commercial, etc.) / other uses	17%
f.	Productive local green area	Increase available area for local agriculture	Productive area / total area	7%
g.	Surface soil quality	Make the soil healthy	Quantity of heavy metals and toxic substances in the soil along with nutrients (e.g., nitrogen and phosphorus)	0

h.	Recovery of degraded soil	Brownfield recovery (contaminated, desertified, and degraded land)	% of recovered contaminated, desertified, and degraded land	does not apply to the area
i.	Soil permeability	Encourage permeable soil areas	% of permeable soil area	60%

e) Mixed-use areas

Within the context of climate resilience and adaptation, the *Mixed-Use Areas* indicator stands out as an essential pillar to foster diversification in the functions performed by the areas under analysis. The metric used to evaluate this indicator is the proportion between the predominant use in the area and the variety of other uses present, according to HIDS Masterplan (KRIHS, 2022). This resulted a number of 17%, with residential use being the most frequent, and expressing a high-level of diversity within land use.

Although the guideline for the Argentina Farm area favors the construction of buildings focused on innovation and public use, the calculation addressed the need for a more comprehensive analysis that encompassed the entire extent of the HIDS area. This approach allowed for a broader understanding of the context in which the project is situated, highlighting the residential predominance.

Calculations Description

$$Mixed\ use = \frac{\text{area of predominant use}}{\text{total area (HIDS)}} = \frac{870.234}{5.252.266} = 17\%$$

f) Productive local green area

The *Productive Local Green Area* indicator aims to expand the space available for local agriculture, thereby creating a greener and more productive landscape close to consumption. The metric used to measure the success of this indicator is the percentage of the area that can be allocated to local agriculture, having achieved a result of 17%, demonstrating a high percentage of land used for food production. The calculation resulted from the proportion of the area designated for the agrovoltaic system in the Sustainable Campus Project (L. C. P. da Silva, 2023) about the total area of Argentina Farm.

Calculations Description

$$Productive\ area = \frac{\text{agrovoltaic system}}{\text{total area (Fazenda Argentina)}} = \frac{9{,}3\text{ha}}{140ha} = 17\%$$

g) Surface Soil Quality

The *Surface Soil Quality* indicator aims to ensure the health of the soil, a crucial element for the health of ecosystems and agriculture. The metric adopted to evaluate this indicator focuses on quantifying heavy metals and toxic substances present in the soil. The results obtained, as disclosed in the geotechnical and hydrogeological report, recommended by the Interamerican Development Bank (Carbono Zero Consultoria Ambiental, 2022), indicate an absence of contaminants in the soil of Argentina Farm.

h) Brownfield Recovery

The *Brownfield Recovery* indicator plays a crucial role in environmental restoration efforts, focusing specifically on the recovery of brownfield areas, which are those contaminated, desertified, or degraded. This indicator does not apply to the area of Argentina Farm, as there are no degraded areas on the site.

i) Soil permeability

The *Soil Permeability* indicator is designed to encourage the preservation of permeable soil areas, which are essential for maintaining the natural water cycle, minimizing surface runoff, and promoting water infiltration into the subsoil. This indicator is particularly important because permeable soils play a crucial role in recharging aquifers, reducing the risk of flooding, and filtering contaminants.

The DEPI/CSUS Office (Dalbelo, 2023) establishes a clear guideline that the maximum rate of soil impermeabilization on the land in new developments should be 40%. This implies that, to comply with these guidelines, at least 60% of the total land area must maintain its permeability capacity, thus allowing water infiltration and contributing to ecological balance and water sustainability.

Support for Local Biodiversity

Table 20. Results for category of Support for Local Biodiversity

	Indicator	Objective	Metric	Result
j.	Green and blue infrastructure	Restore the hydrological function of the urban landscape, manage stormwater, and reduce the need for additional gray infrastructure.	Contribution of green and blue infrastructure / total infrastructure	0-no policies were found
k.	Biodiversity protection area	Increase available area for local biodiversity development.	Non-urbanized land area with ecological value (which can protect native flora and fauna diversity, like natural green areas and water bodies) / total area	18%
l.	Green corridors	Encourage the continuity of green areas to promote local biodiversity.	Amount of continued green areas over 100m long with local species compatible with land use	13

j) Green and Blue Infrastructure

The assessment of the *Green and Blue Infrastructure* indicator under the *Local Biodiversity Support* category highlights the importance of integrating natural and aquatic elements into urban and landscape planning to restore the hydrological function of the urban landscape. This goal aims to efficiently manage stormwater and reduce surface runoff, while minimizing the dependence on additional gray infrastructure, such as drainage and treatment systems, which are more costly and have a greater environmental impact.

The proposed metric aims to quantify the proportion of such natural and aquatic elements in relation to the total infrastructure of the area under analysis, to understand how much green and blue infrastructure is being integrated into urban development and planning practices. As a result, no policies were found indicating a lack of initiatives or specific policies aimed at implementing green and blue infrastructure in the project.

k) Biodiversity Protection Area

The analysis of the *Biodiversity Protection Area* indicator focuses on increasing areas available for the development of local biodiversity, which is fundamental for the conservation of native flora and fauna, as well as contributing to the maintenance of essential ecosystem services. The metric used allows quantifying the proportion of the territory that is being effectively designated for biodiversity conservation in opposition to urban expansion and other land uses that may compromise the ecological value of areas.

The 18% result indicates that a significant portion of the territory under analysis will be composed of non-urbanized areas with recognized ecological value, including ecological corridors, forest restoration areas, wildlife crossings, and green corridors, as described by Dalbelo (2023) and allocated in the Masterplan (KRIHS, 2022).

Calculations Description

$$Biodiversity\ protection\ area = \frac{\text{protection area}}{\text{total area (Fazenda Argentina)}} = \frac{25{,}38\text{ha}}{140ha} = 18\%$$

l) Green Corridors

The *Green Corridors* indicator aims to promote the continuity of green areas, intending to support local biodiversity. The metric used is the amount of continuous green areas, more than 100 meters long, that use local species compatible with land use. In the Masterplan project developed by KRIHS (2022), a total of 1,309 linear meters of green corridors were identified in the project Autocad file, representing a high-level of concern regarding this indicator.

7.4. Strong, Equitable, and Fair Communities

Governance and Public Participation

Table 21. Results for category of Governance and Public Participation

	Indicator	Objective	Metric	Result
a.	Dissemination of good practices	Disseminate good practices for CE: Circularity of Nutrients, Water, and Energy and Biodiversity Gains.	People impacted by good practices (within and outside the community) / total community population	0-no policies were found
b.	Educational initiatives	Educate the community about circularity	% of the community impacted with formal education (courses, training, academic and non-academic workshops) for CE	0-no information were found
c.	Events for CE	Spread the concept of CE and support existing initiatives	Number of informal events (fairs, exhibitions, etc.) per year	0-no policies were found
d.	New public policies to encourage CE	Implement CE policies	Number of policies implemented per year	3
e.	New partnerships established for synergistic processes	Create partnerships to generate synergies between stakeholders and flows	Number of partnerships formed per year	0-no policies were found
f.	People involved in the recycling process	Engage the community (residents, workers, local students) in CE practices	% of the community involved in circular practices	0-no information were found

a) Dissemination of good practices

The initiative to disseminate good practices related to the CE, focusing on the circularity of nutrients, water, energy, and biodiversity gains, did not yield results at the case study. No specific policies were identified as implemented to achieve this goal. This indicates a significant area of opportunity for the development and implementation of strategies that can effectively disseminate these essential practices, both within and outside the local community, to promote the CE.

b) Educational Initiatives

Although the study could not find specific information about the number of participants in educational initiatives, CEUCI (Center for Studies on Urbanization for Knowledge and Innovation) promotes workshops with the university community to explore synergies within its programs (CEUCI, 2022). Furthermore, the existence of a technical chamber for environmental management (DEPI, 2024) and an executive board for human rights at Unicamp (Diretoria Executiva de Direitos

Humanos da Unicamp, [s.d.]) with thematic groups focused on accessibility, gender, and harassment, suggests a commitment to education on various topics. These initiatives reflect an effort to raise community awareness on topics that are adjacent to CE, although they do not focus solely on this subject.

c) Events for Circular Economy

In the context of Unicamp, no informal events, such as fairs and exhibitions, aimed at disseminating the concept of the CE and supporting existing initiatives were identified. This absence suggests a significant gap in promoting understanding and community engagement with the principles of the CE, underlining the need for more robust efforts to integrate these concepts into future community's daily life.

d) New Public Policies to Encourage CE

In 2023, Argentina Farm implemented three important policies to encourage themes related to the CE: Guidelines for Sustainable Buildings in DEPI/CSUS (Dalbelo, 2023) a thematic management plan focused on sustainable resource management. These policies represent significant steps in the commitment to sustainability and indicate notable progress in integrating a number of CE related practices into local management and planning, although they do not focus solely on this subject.

e) New Partnerships Established for Synergistic Processes

No information was found on new partnerships established to generate synergies between stakeholders and flow management at the university or at Argentina Farm.

f) Community Involvement in the Recycling Process

No information was found on community involvement in circular practices. This result highlights a critical area that requires attention and development, aiming to engage local workers, and students in CE activities, which is fundamental to creating medium and long-term engagement on the topic.

Equity and Access to Health and Well-being

Table 22. Results for category of Equity and Access to Health and Well-being.

	Indicator	Objective	Metric	Result
g.	Access to potable water supply	Provide clean water to as many people as possible	% coverage of the public water supply system / total residents	100%
h.	Access to sanitation systems	Treat water after use	% coverage of the sanitation system / total residents	92,6%
i.	Access to public and pedestrian-oriented mobility and human-powered transportation	Ensure safe mobility, emphasizing public transportation as the primary means of transport, promoting a pedestrian-oriented environment and human-powered transportation	% of trips by mass transportation, walking, or human-powered transport	under consideration
i.	Access to green zones and recreational areas	Encourage residents to use green and recreational areas	% of residential buildings located within 1km of green public areas and/or recreational areas	does not apply to the area

g) Access to Drinking Water Supply

At Argentina Farm, located in the municipality of Campinas, a milestone of 100% of the population having access to drinking water was achieved, as indicated by SANASA Campinas (2024). This ensures that all citizens, including the Argentina Farm users, will have access to clean and safe water for consumption and daily use.

h) Access to Sanitation Systems

Access to sanitation systems in Campinas also demonstrates a strong commitment to public health, with 92.6% of the population having access to treated sewage, according to 2022 data from SANASA Campinas (2024). This high percentage of basic sanitation coverage is crucial for preventing water-related diseases, promoting a cleaner and healthier environment for the community. Despite the success, there is still room for improvement, aiming to achieve 100% coverage and ensure that all residents enjoy adequate sanitary conditions.

i) Access to Public and Pedestrian-Oriented Mobility

The indicator of access to public and pedestrian-oriented mobility in Argentina Farm, under the guidance of the HIDS Masterplan (KRIHS, 2022), reveals an innovative approach committed to urban sustainable mobility. The strategy outlined by the plan emphasizes safety and ease of mobility, prioritizing public transport as the main means of locomotion and promoting an environment favorable to pedestrians and human-powered transport. Although detailed information about the quantity and type of trips expected at Argentina Farm is not available, the plan encourages the promotion of active mobility, the prioritization of public transport, and the reduction of private car use.

Key policies established for the HIDS public transport plan include: Expansion of the LRT Line; Establishment of Electric BRT Circulation Networks; and Construction of Personal Mobility Routes, which include electric unicycles, electric scooters, and electric bicycles, which have been incorporated into the HIDS district's public transportation plan to increase accessibility in areas neglected by public transportation service or areas with walking difficulties due to inclines (KRIHS, 2022).

j) Access to Green Zones and Recreational Areas

In the context of Argentina Farm, the applicability of metrics related to access to green zones and recreational areas does not directly apply, due to the absence of planned residential areas within the area in question.

Sociocultural Valorization

Table 23. Results for category of Sociocultural Valorization

	Indicator	Objective	Metric	Result
k.	Regional materials	Foster the local/regional economy	% of materials produced within a 200km radius	10%
l.	Local techniques	Value techniques from traditional communities and peoples	Number of initiatives using techniques from traditional communities and peoples	0-no information were found
m.	Cultural festivals	Value the culture of traditional communities and peoples	Number of festivals and fairs that value local culture	0-no information were found
n.	Retrofitting of buildings and urban areas revitalization	Promote the revitalization of existing built and cultural landscapes	Number of building retrofits and/or urban area revitalizations / total developments	0

k) Regional Materials

The valorization of regional materials at Argentina Farm represents a noteworthy yet modest step towards nurturing the local and regional economy. The adherence to DEPI/CSUS (2023) guidelines, which highlight the use of at least 10% of materials produced within a 200km radius, is a commendable metric, but it is far from sufficient. While this outcome signals a preliminary dedication to local development and the use of regional material resources in construction and infrastructure maintenance, it is imperative to recognize that this is just an initial measure. Much more extensive efforts are needed to truly capitalize on the potential benefits of regional material utilization.

l) Local Techniques

Applying and appreciating techniques from traditional communities at Argentina Farm or university is still a field without concrete data. The need for more information about initiatives that use such techniques suggests an opportunity to grow and integrate this ancestral knowledge into the region's development and construction processes.

m) Cultural Festivals

Currently, there are no guidelines for developing festivals and fairs that value the culture of communities and traditional peoples in the university. The creation and support of these events can serve as powerful tools for strengthening local identity and providing spaces for exchange, learning, and appreciation of the diverse cultural expressions in the region.

n) Retrofit of Buildings and Revitalization of Urban Areas

The revitalization of existing buildings and cultural landscapes at the Fazenda Argentina is not a reality, as demonstrated by the absence of retrofit projects for buildings or urban revitalizations within the specified area. Although there is a project for the transformation of the Pau D'Alho and Anhumas Farms into the House of Ancestral Knowledge in the HIDS area, it is located outside Argentina Farm; thus, it was not considered in the assessment.

Added Financial Value

Table 24. Results for category of Added Financial Value

	Indicator	Objective	Metric	Result
o.	New investments to activate CE	Encourage new investments for CE	Investments in CE projects / total investments per year	0-no information were found
p.	New jobs related to CE projects	Generate new jobs related to CE	New jobs generated with CE / total jobs generated per year	0-no information were found

o) New Investments to Activate the Circular Economy

Specific information was not found that allows for a quantitative analysis regarding attracting new investments to activate CE in the university. This lack of data indicates a gap in the documentation or realization of investments directed towards CE projects. The absence of such information suggests the need to develop strategies focused on encouraging investment in CE.

p) New Jobs Related to Circular Economy Projects

No information was also found regarding the creation of new jobs related to CE projects at Argentina Farm or at the university. The absence of records on new jobs generated in this context highlights the importance of implementing and documenting initiatives aligning CE practices' goals with employment growth and innovation in the sector.

Innovation

Table 25. Results for category of Innovation

	Indicator	Objective	Metric	Result
q.	Number of patents related to CE projects	Encourage innovation for CE	New patents related to CE projects / new patents per year	0-no information were found
r.	New startups working with CE	Promote the practice of CE solutions	New startups related to CE projects / total new startups per year	9%
s.	Research projects addressing CE	Promote research in the field of CE	New research related to CE projects / total research in the venture per year	0-no information were found

q) Number of Patents Related to Circular Economy Projects

In 2023, the Unicamp community generated a total of 100 new patents, indicating a vibrant environment of innovation (Inova, 2023). However, the lack of specific information on how many of these patents are directly linked to the CE points to a gap in the integration and identification of circular-focused innovation. This result suggests the need for more effective mechanisms to track and encourage technological development specific to the CE, aiming to maximize the potential for innovation in circular practices.

r) New Startups Working with Circular Economy

In the startup sphere, the information that 9% of startups are directed towards sustainability solutions (Inova, 2023) reflects a growing interest and commitment to the practice of sustainable solutions. This data is particularly relevant as startups often represent the forefront of innovation, bringing new ideas and business models that can be crucial for the transition to circular practices. The involvement of startups in sustainable solutions is indicates that environmental awareness is gaining ground in the entrepreneurial ecosystem, enhancing the development of technologies and services that favor innovation for themes frequently related to CE.

s) Research Projects Addressing the Circular Economy

Regarding the promotion of research in the field of the Circular Economy, there was a noted lack of information on new research projects related to CE, which indicates that, despite the presence of innovation and interest in sustainability, there is a critical need to foster more research directed explicity towards the CE. This gap in the documentation or existence of research projects focused on CE highlights the importance of strategies and policies that encourage scientific investigation and technological development in this area.

7.5. Performance Criteria Results

To conclude the analysis of the proposed framework, the evaluation of the case study has provided practical parameters for assessing typical urban design practices. The results of each category and indicator obtained from the study were compared with recognized excellence practices in the field, aiming to quantify and establish a benchmark for the success of their implementation. This comparison allows setting future targets for Fazenda Argentina, aligned with its strategic objectives.

Figure 30 illustrates a landscape where a select number of indicators reach a high level of circularity, such as the generation of renewable energy, food production, waste management, and access to public services like water and sanitation systems. However, these isolated instances of excellence are set against a backdrop where most current practices fail to meet the envisioned benchmarks for a genuine CE, highlighting a vast expanse of untapped potential for improvement.

To demonstrate the practical use of the performance criteria, specific scales were developed for each indicator within their categories and applied to the case study results. To illustrate how the performance criteria was developed, Table 26 details the outcomes of the Circularity of Healthy Material Flows key area. The result expresses a diverse range of performance levels, shedding light on both commendable achievements and areas requiring focused enhancement:

- In the Biological Nutrient Cycle category, the result was 4.33 points, on a scale ranging from -1 to 5, indicating a practice close to excellence.
- In the Technical Nutrient Cycle category, the results were negative for the subcategories of circular source and circular content due to the absence of information or guidelines, resulting in a performance coefficient of -0.67.
- In the Construction Materials Cycle category, information was not available, leading to a score of -1, which suggests the need for immediate attention and corrective action.
- In Consumption and Municipal Waste Management, the score was 5, reflecting the effectiveness in the collection and proper disposal of materials in the case study.

- The final result for the Circularity of Healthy Material Flows is 1.92, based on a weighted average. It shows that although actions have been taken towards circular strategies, there is still room to improve the outcomes across various indicators within this key area.

To maintain the relevance and efficacy of the performance scale as a catalyst for the continuous improvement of CE principles in urban areas, it is essential to undertake regular reviews and make necessary adjustments. This will ensure that the scale accurately reflects evolving urban practices and directing towards a more circular urban future.

1 Clean and Renewable Energy
2 Healthy Air
3 Urban Comfort and Climate Protection

4 Biological Nutrient Cycle
5 Technical Nutrient Cycle
6 Construction Materials Cycles
7 Consumption and Municipal Waste Management

8 Healthy Water Cycle
9 Resilience and Climate Adaptation
10 Support for Local Biodiversity

11 Governance and Public Participation
12 Equity and Access to Health and Well-being
13 Sociocultural Valorization
14 Added Financial Value
15 Innovation

		Circularity of Healthy Material Flows	
4	a.	Circular sources - Biological Cycle	5
	b.	Circular content - Biological Cycle	5
	c.	Active cycles - Biological Cycle	3
5	d.	Circular sources - Technical Cycle	-1
	e.	Circular content - Technical Cycle	-1
	f.	Active cycles - Technical Cycle	0
6	g.	Circular sources - Construction	-1
	h.	Circular content - Construction	-1
	i.	Active cycles - Construction 1	-1
	j.	Active cycles - Construction 2	-1
7	k	Source separation of materials	5
	l.	Collection and disposal	5

		Water and Soil Management, and Local Biodiversity Gains	
8	a.	Circular Sources - Water	3
	b.	Circular Content - Water 1	-1
	c.	Circular Content - Water 2	-1
	d.	Active Cycles - Water	-1
9	e.	Mixed-use areas	3
	f.	Productive local green area	3
	g.	Surface soil quality	-1
	h.	Recovery of degraded soil	-1
	i.	Soil permeability	5
10	j.	Green and blue infrastructure	-1
	k	Biodiversity protection area	5
	l.	Green corridors	3

		Energy, Air, and Climate Protection	
1	a.	Circular Sources - Energy	5
	b.	Circular Content - Energy	0
	c.	Active Cycle - Energy	5
2	d.	Air Quality	-1
	e.	Greenhouse gas emissions	-1
3	f.	Acoustic Comfort	3
	g.	Access to Sunlight	-1
	h.	Reducing Heat Island Effect	0
	i.	Renewable Energy in Mass Transportation	0

		Strong, Equitable, and Fair Communities	
11	a.	Dissemination of good practices	-1
	b.	Educational initiatives	-1
	c.	Events for CE (Circular Economy)	-1
	d.	New public policies to encourage CE	-1
	e.	New partnerships established for synergistic processes	-1
	f.	People involved in the recycling process	-1
12	g.	Access to potable water supply	5
	h.	Access to sanitation systems	3
	i.	Access to public and pedestrian-oriented mobility and human-powered transportation	0
	j.	Access to green zones and recreational areas	-1
13	k	Regional materials	0
	l.	Local techniques	-1
	m.	Cultural festivals	-1
	n.	Retrofitting of buildings and urban areas revitalization	-1
14	o.	New investments to activate CE	-1
	p.	New jobs related to CE projects	-1
15	q.	Number of patents related to CE projects	-1
	r.	New startups working with CE	0
	s.	Research projects addressing CE	-1

Figure 30. Performance Scale applied to Argentina Farm.

Table 26. Performance Criteria applied to the Circularity of Healthy Material Flows category.

Circularity of Healthy Material Flows

Biological Nutrient Cycle		
Circular sources - Biological Cycle		
	Performance benchmark	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**100%**	**5**
Circular content - Biological Cycle		
	Performance benchmark	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 100 %	3
Best practice	> 100%	5
Argentina Farm	**206%**	**5**
Active cycles - Biological Cycle		
	Performance benchmark	Score
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5
Argentina Farm	**23%**	**3**
Total Argentina Farm		**4,33**

Technical Nutrient Cycle		
Circular sources - Technical Cycle		
	Performance	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**0%**	**-1**
Circular content - Technical Cycle		
	Performance	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**0%**	**-1**
Active cycles - Technical Cycle		
	Performance	Score
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5
Argentina Farm	**9%**	**0**
Total Argentina Farm		**-0,67**

Construction Materials Cycles		
Circular sources - Construction		
	Performance benchmark	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**0%**	**-1**
Circular content - Construction		
	Performance benchmark	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**0%**	**-1**
Active cycles - Construction 1		
	Performance benchmark	Score
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5
Argentina Farm	**0%**	**-1**
Active cycles - Construction 2		
	Performance benchmark	Score
Negative	< 0%	-1
Minimum practice	1% - 20%	0
Good Practice	20% - 50%	3
Best practice	> 50%	5
Argentina Farm	**0%**	**-1**
Total Argentina Farm		**-1,00**

Consumption and Municipal Waste Management		
Source separation of materials		
	Performance	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**100%**	**5**
Collection and disposal	100%	5
	Performance	Score
Negative	< 20%	-1
Minimum practice	20% - 50%	0
Good Practice	50% - 80 %	3
Best practice	> 80%	5
Argentina Farm	**100%**	**5**
Total Argentina Farm		**5,00**

Total Circularity of Healthy Material Flows	**1,92**

7.6. Recommendations for Argentina Farm

When applying the Framework to Transition Urban Areas towards a CE to the case study, practices exemplifying excellence in circularity were identified, such as the generation of renewable energy and food production, indicative of an innovative campus aligned with the principles of the CE. Nevertheless, the analysis also brought to light that numerous areas within current practices do not meet the anticipated standards for a CE. This contrast highlights an urgent call for definitive guidance and robust support mechanisms to catalyze continuous improvement for comprehensive strategies towards this transition. By pinpointing these areas of deficiency, stakeholders can direct their efforts more effectively, crafting targeted strategies that bridge the gap between current practices and the ideal model.

For instance, the project shows itself to be exemplary in terms of renewable energy sources, with production exceeding consumption due to the implementation of agrovoltaic systems. This system can ensure that this surplus continues to benefit the area and possibly neighboring communities, contributing to regional energy sustainability. However, while the results in reducing energy consumption are a start, there is room for significant improvements. The project should consider implementing energy efficiency measures across all infrastructure.

The case study also demonstrates strong adherence to the principles of the CE with respect to the biological nutrient cycle. The ability to produce more food than necessary for internal consumption offers opportunities for the distribution of high-quality food to other areas or for commercialization, promoting economic benefits as well. However, the *Active Cycles* indicator shows that there is still significant potential to improve the reuse of biological waste. Strategies such as expanding composting programs, integrating regenerative agriculture practices, and developing new uses for organic waste can help increase the percentage of recirculation of biological nutrients.

Regarding the technical cycle, the framework demonstrated an absence of clear and transparent guidelines that encourage the acquisition of materials from reuse, remanufacturing, or recycling.

The lack of a statement about the origin and specific content of the materials acquired by the university in new purchases highlights an opportunity to strengthen the CE on campus. Furthermore, the *Active Cycle* indicator result has implied that only a small fraction of technical materials is currently being destined to recycling, reuse, or remanufacturing, reflecting the need for actions to encourage the reinsertion of these materials into future cycles.

Similarly, strategies aimed at choosing materials and construction systems that facilitate their subsequent disassembly and reinsertion into new production cycles are absent. It is essential to implement practices that prioritize the choice to prolong the lifespan of construction materials and strengthen the CE in the construction sector. In addition, the university should adopt a more proactive approach in identifying opportunities for the adaptation of buildings in further uses, extending their lifespan, and reducing the demand for new construction materials.

On the other hand, municipal waste management on campus effectively separates waste at the source and properly disposes of it. This separation ensures that recyclable materials are diverted from landfills and that all campus users, regardless of their location, have access to waste management services.

Regarding *Climate Adaptation and Resilience*, the Argentina Farm Masterplan already projects a significant percentage of its area dedicated to biodiversity. The existence of green corridors is a positive starting point. To improve, Argentina Farm could expand these corridors, connect habitat fragments, and create a more robust network of green spaces that facilitate the movement of fauna and flora, increasing ecological resilience.

The HIDS Masterplan also demonstrates an initial commitment to efficient water management through rainwater harvesting in Fazenda Argentina. To further improve, the area could expand the capacity for rainwater capture and storage and explore other sources of non-potable water for secondary use. Additional measures could be implemented, such as ecological restoration programs, enhancement of the requirement for green and high-reflectance roofs, and policies for water conservation.

The absence of policies in the indicators of *Circular Content – Water 1* points to the need to develop strategies to optimize water use and prevent contamination of water resources. Argentina Farm could invest in on-site water treatment technologies, such as purification and recycling systems, and in sustainable management practices to protect local watercourses. Moreover, considering a local sewage treatment system is a positive step. The effective implementation of this system will allow Argentina Farm to treat and reuse wastewater, closing the water loop locally.

The *Governance and Public Participation* category highlights the importance of participatory and collaborative governance with the local community in promoting circular practices. However, the study suggests that this category is underrepresented, indicating that there is significant room for improvement of implementation of new policies and community inclusion to implement the CE on campus. On the other hand, the *Equity and Access to Health and Well-being* category addresses the fair distribution of resources and accessibility to essential services. For instance, access to potable water reached 100%, and access to sanitation systems reached 92.60%, reflecting a commitment to public health in the municipality of Campinas.

Sociocultural Valorization involves the preservation of local resources and heritage. There is a guideline for the use of 10% regional materials within the university purchases, indicating an initial modest effort to foster the local and regional economy. Furthermore, there is no information on the valorization of local techniques or the holding of cultural festivals, suggesting opportunities for greater engagement and appreciation of local culture.

The results obtained in the case study reveal a favorable scenario regarding the innovation strategies adopted by the university, particularly in the increase of sustainable initiatives that can be related to the CE approach. This growth indicates a rising awareness and an effort to incorporate more sustainable practices into the academic environment. However, despite these positive advancements, the integration of the CE as a structural and fundamental element in the case study's overall strategy has not yet been fully realized. This suggests that, although there is recognition of the importance and value of sustainable practices and CE, adopting these principles at a structural and comprehensive level requires a more profound commitment of existing structures to ensure that CE becomes a central pillar in Fazenda Argentina's mission and operation.

The pattern language and the performance evaluation tool can further enhance the CE at Argentina Farm. Using the examples of the patterns developed in Section 5, Argentina Farm can guide the improvement of implementing CE in the construction sector and the biological cycle. These patterns can provide actionable guidance on selecting materials and construction systems that are modular, easily disassembled, and reusable while refining its organic waste management, expanding composting programs, and optimizing regenerative agriculture practices. Applying such measures can help improve the results in the performance evaluation system.

8. Discussion

This study demonstrates that a framework based on the Cradle to Cradle (C2C) principles can effectively establish a robust foundation for directing urban areas in the transition towards a circular economy (CE). The holistic approach of C2C, which seeks to replicate the functioning of natural systems in urban environments, is a distinctive characteristic of the CE and confers on the framework a prominent role as a driver of CE in urban areas. Thus, the research provides a practical foundation for shaping CE to urban development, culminating in creating a comprehensive methodological framework that harmonizes qualitative and quantitative measures.

The proposed 'Framework to Transition Urban Areas Towards a CE' identifies opportunities and directs strategies while directing public policies formulation, standardizing processes, and measuring progress toward urban circularity. By providing structured design patterns and a set of indicators, the framework can empower decision-makers to implement circular practices strategically, assessing their impact and effectiveness in the urban context. Hence, the research contributes to the field of urban development and planning in light of the CE by proposing a guide that can assist design, planning, and management of urban areas that aspire to circularity, presenting a practical tool that is potentially replicable and adaptable to different urban contexts.

Through conceptualizing circular urban areas, carried out through a bibliographic review and practical adaptation of these concepts into a framework that would express quantitative and qualitative circular urban features, the research advances the understanding of what constitutes applying CE into urban areas. The work has delineated four essential circular urban qualities: Resource Looping, Regeneration, Distribution and Connectivity, and Locality. These qualities underpin identifying two core intentions: Circularity and Synergistic Benefits. Together, these elements define the essence of circular urban areas, emphasizing the emulation and integration of natural cycles within urban systems.

The framework consists of four circular urban key areas and fifteen categories encompassing these circular urban qualities and intentions. The key areas and categories are ramified in two complementary tools: the Performance Evaluation Tool and the Pattern Language for Circular Urban Areas, which support a dynamic and cyclic quantitative and qualitative analysis. The Performance Evaluation Tool provides a concrete means of assessing the implementation of circular design standards and their impact on promoting circularity in urban areas. In parallel, the Pattern Language guides the design and implementation of project practices that are in harmony with CE principles. The Performance Evaluation Tool, more than a single evaluation tool, acts as a source of feedback, providing data that supports the continuous evolution of the Pattern Language. This interaction between the tools establishes a dynamic cycle of learning and refinement, which is fundamental to the materialization of CE in urban areas.

The successful application of these tools in the case study demonstrates the ability of the C2C approach to synthesize a subject of such complexity and facilitate the communication of crucial information for decision-making. C2C established clear connections between principles, concepts, key areas, categories, indicators, and design patterns and their potential applications in urban projects, highlighting the model's ability to develop a holistic and integrated approach. This structure ensures that all elements, from energy production to waste and water management and public governance, are contemplated and enhanced, aiming to transition towards a benefic CE. Furthermore, the framework has acted as a guide to determine the status of the case study in terms of CE and has expressed its capacity to direct the future development of the project.

The framework's performance in the case study illustrates the transformative potential of CE principles applied systematically and integrated into urban areas. In some respects, the Argentina Farm project has been remarkably ahead of *business as usual* in similar developments. This is the case with the *Circular Sources – Energy* indicator, which achieved a rate of 165% renewable energy used in total consumption, and the *Circular Content - Biological Cycle*, which reached 183% in food production compared to its consumption. These results highlight the energy and food self-sufficiency of Argentina Farm and underline the potential of positively contributing to the broader energy network and community, generating synergistic benefits that go beyond its self-sufficiency.

Although Argentina Farm has achieved remarkable performance in terms of energy and food production, other important categories, such as *the Technical Nutrient Cycle*, *Construction Materials Cycles*, and *Governance and Public Participation*, have shown unsatisfactory or only marginal results. This modesty in results can be partially explained by the pioneering character and the complexity of the implemented framework, which comprises a range of challenging details and indicators. Additionally, Unicamp, especially HIDS — the innovation hub encompassing Argentina Farm and serving as a model for sustainable and innovative practices — still faces considerable barriers in these specific domains of the CE. The absence of more significant advances in these categories indicates the urgency of developing focused strategies to overcome the detected gaps.

The pattern language can be a valuable instrument for improving these poorly evaluated categories as an integral part of the framework. It offers a practical guide for implementing actions and tools to strengthen these deficient areas. In particular, effective governance is crucial for the success of the CE in the case study, as it establishes the necessary policies and processes for a smooth transition. Equally important is public participation, which can promote awareness of the CE concept and ensure that all stakeholders are aligned and committed to the long-term vision of the CE. The adoption of these patterns can, therefore, play a fundamental role in realizing the full potential of the CE at Argentina Farm.

In turn, the performance evaluation tool, which was designed to assess and monitor the performance of ongoing processes, can catalyze the continuous optimization of CE implementation at Argentina Farm. Employing the performance scale that quantifies the success of existing initiatives allows for identifying the thriving areas and those that need adjustments or innovations to improve results. With this analysis, urban practitioners can implement targeted strategies to enhance each aspect of the system, promoting a culture of continuous improvement. The performance evaluation tool can guide the constant evolution of processes, ensuring that the case study and other projects move towards the practice and improvement of the CE.

Observing the application of the assessment tool at the Argentina Farm, it became clear that working with a project that has yet to be realized presents its own intricacies. The scarcity of concrete data and the lack of detailed guidelines for some categories forced us to rely on still vague plans and future guidelines, policies, and strategies. This dependence on theoretical information and projections places us in front of an analysis that is, by nature, speculative since the project is still awaiting execution, and we do not know for sure when or if it will be concretized.

Hence, the estimated nature of the calculations, which are based on a planning stage and not on tangible operations, highlights the limitations of the case study application. The uncertainty accompanying Argentina Farm's unbuilt project represents a variable we must recognize and manage carefully. The current estimates are a valuable starting point, but they must be adjusted as the project develops and new information becomes available. Therefore, closely following the development of Argentina Farm is crucial, as it offers a unique opportunity for continuous optimization of the tool. With the project's progress, it is possible to iterate and refine the framework as we incorporate the lessons learned.

On the other hand, the integration of performance assessment tools and design patterns at the project's inception has showed to be a cornerstone of circular development. By incorporating these tools from the initial phases, the developers of Argentina Farm can establish clear and measurable goals for circularity from the outset. This allows for a proactive, rather than reactive, approach to the incorporation of circular practices, ensuring that design and construction decisions are aligned with the project's long-term goals. Moreover, the early integration of these tools can facilitate the identification of synergy opportunities and the optimization of systems, resulting in cost savings and operational efficiency.

Also, it is essential to recognize the necessity of applying and testing the framework in various case studies as a critical step forward, particularly in already operational projects. This approach enables the calibration of the performance scale and the refinement of the assessment tool. Moreover, by analyzing the framework's performance across diverse socioeconomic, climatic, and cultural conditions, we can identify universal patterns of success and adapt strategies to meet specific local needs. Subsequently, developing and documenting additional patterns derived from observed good practices in different contexts can facilitate the adoption of CE solutions by other cities and regions. By sharing knowledge and experiences, we can accelerate the transition to more circular practices on a global scale, allowing various urban communities to benefit from tested and proven approaches.

An additional issue that arose is that, although the implementation of the framework at Argentina Farm has proven its usefulness in mapping the degree of integration of CE principles in the project in relation to reference practices, the effective adoption of many of the strategies demanded in day-to-day operations still seems distant, which reflects on the difficulty of obtaining information for many of the proposed indicators and categories. The framework proved quite complex, covering a wide range of indicators and categories spanning various action areas. Therefore, applying the framework fully at once is challenging, and it becomes crucial to identify where to start this process. Three distinct approaches stand out when pondering the ideal starting point for this implementation, each with its implications and benefits.

The first approach is to treat all indicators with equal weight by improving all indicators and categories slightly simultaneously. This strategy assumes uniformity in the importance of each aspect of the CE, ensuring a balanced and comprehensive approach. However, this methodology may not reflect each urban context's nuances and specific priorities. By assigning the same weight to all indicators, one may neglect areas that require more urgent attention or offer opportunities for more significant impact.

The second approach is to start with what is considered most important or with the most significant potential according to local stakeholders. This strategy is highly adaptive and stakeholder-centered, reflecting local priorities and ensuring that interventions are aligned with the community's needs and expectations. By focusing on the areas of greatest importance to stakeholders, the framework can gain greater acceptance and engagement, which is crucial for the long-term success of CE initiatives.

The third and perhaps most strategic approach is to focus on planetary boundaries. This perspective recognizes the urgency of addressing the most pressing environmental challenges we face as a global society. By prioritizing actions that have the most significant impact on maintaining the stability and resilience of the Earth system, we can preferentially address critical issues such as climate change, biodiversity loss, and sustainable resource use.

Regardless of the selected options, we recommend managing the implementation of the framework through a phased process, which implies prioritizing solutions that have the most significant potential impact or that are more feasible to be executed in the short term, as well as those that are essential for the specific context of the enterprise. In the case of Argentina Farm, categories such as energy and food production emerge as priorities, given their importance for impacting environmental pressures and the potential to generate significant results. Strategic incentives should target these categories and adopting design patterns can facilitate the effective implementation of relevant indicators yet to be addressed within these categories.

To establish an effective phasing of circular actions, we suggest starting with stakeholders' development of an inspiring vision that clearly articulates the transformative effects that CE can create. Argentina Farm, for example, can be imagined as a model of CE, where plenty of spaces exist for biodiversity and community life, renewable sources fully provide energy, water is captured and treated locally, and nutrients are fully composted, recycled, or reused.

With this inspiring vision as a guide, the subsequent step is the creation of a CE Implementation Plan, which outlines the phasing of practical and tangible measures to transform the established vision into reality. Given that urban areas are, by nature, dynamic entities characterized by constant movement and change, this challenges the perception of viewing them as unified, static systems. The dynamic nature of urban areas necessitates a shift from static diagnostics to more fluid and adaptable frameworks. Hence, the implementation plan should define specific areas of focus, similar to leverage points, that can drive significant change. Identifying these leverage points involves a comprehensive understanding of each urban areas' subsystems and their interactions. By analyzing patterns within resource flows, and areas of inefficiency, stakeholders can identify strategic areas where interventions would yield the most substantial benefits.

According to the selected leverage points, the strategic plan will delineate the purposes and goals, select precise indicators to measure progress, define significant milestones, and set deadlines for each process phase. The CE plan should foster a virtuous cycle of continuous improvement, incorporating qualitative objectives, such as the enrichment of biodiversity and the promotion of ecological awareness, and establishing quantifiable goals supported by established indicators with well-defined timelines. Examples of these goals may be to achieve 100% composting within a decade and to increase energy efficiency by 50% within five years.

Through this phasing outlined in the CE Implementation Plan, resources and efforts can be managed more efficiently, ensuring that each step constructively contributes to the overall goal of circularity. This approach enables continuous adjustments and improvements based on the results and lessons of each phase. Over time, it also allows for integrating other categories and solutions, expanding the framework's scope and the complexity of circularity strategies.

In this context, supporting ongoing CE projects and communicating the successes achieved are ways to maintain momentum and community engagement. Multisectoral involvement is vital for achieving a unified vision and plan implementation. Collaboration among different internal and external stakeholders becomes crucial. Events, local fairs, and social media campaigns are excellent tools for this purpose. In addition, open sections, dialogue tables, public consultations, and workshops, like those already happening at CEUCI, are effective methods for achieving shared governance and creating a joint vision of the transition towards a CE.

Developers should also apply continuous improvement to the framework itself, enhancing the tools and methods used to assess and guide progress. Creating new patterns exemplifies how to gather collective knowledge to raise valuable insights in a common language, which facilitates the communication and implementation of circular practices. Developers should continuously expand and refine these patterns, incorporating new findings, innovations, and user feedback. By doing this, the pattern language evolves into a living, adaptable, and increasingly rich tool that reflects the evolution of thought and practice in a circular economy.

Similarly, the evaluation tool must be flexible and adaptable, balancing each region's specific variables, development of new technologies, and emerging possibilities. As Argentina Farm and other circular ventures advance, developers must adjust the evaluation tool to reflect context and technological capabilities changes. There is a virtuous cycle between the pattern language and the evaluation tool: as one evolves, it informs and improves the other, resulting in a more robust and practical approach to the implementation and monitoring of circular systems. This iterative and collaborative process is essential to ensure that the circular economy framework remains relevant and effective in promoting circular practices.

The assessment of urban systems requires metrics that are not only appropriate but also effective in directing focus to what truly matters. Drawing from existing literature, it becomes evident that some traditional indicators may fall short in capturing the complexities of urban dynamics. In the next phase of this research, it is essential to reflect on and refine the raised set of indicators to ensure they effectively evaluate the quality and relevance within the context of urban subsystems. When identifying leverage points and monitoring points, urban areas can optimize existing assessments and stablish benchmarks for its improvement, ensuring that metrics remain aligned with the overarching goals of circularity.

Another important consideration within the proposed framework is that urban mobility issues are distributed across various categories, such as energy, emissions, accessibility, and equality. However, for the next phases of this study, it is more effective to treat mobility as a separate category due to its fundamental importance in urban dynamics and the unique set of challenges and opportunities it presents. By adopting a systemic approach, the need to consider mobility within the broader context of urban connections and dynamicity becomes evident. Mobility not only influences but is also influenced by various urban subsystems, being crucial for promoting systemic change. By examining mobility from this perspective, cities can develop strategies that not only address emissions and energy use but also enhance connectivity and adaptability, contributing to a more integrated and circular urban environment.

In summary, this study contributes to the existing literature and the practice of CE in urban planning by providing practical insights and a framework for action. It expands current knowledge by exploring the practical application of C2C principles in urban areas and structuring an assessment and design framework that reciprocally addresses quantitative and qualitative criteria for urban areas' transit towards a CE.

The Argentina Farm case study exemplifies the transformative potential of embedding CE concepts in urban settings. It demonstrates the viability, benefits, and challenges of such an integration and showcases the tangible outcomes that can be achieved through strategic implementation. Besides, the study underscores the importance of a phased approach in rolling out circular strategies, which is integral to crafting an adaptable and responsive CE framework.

This approach emphasizes the necessity of iterative refinement, where continuous improvement, the expansion of established patterns, and the dynamic adaptation of the evaluation tool are essential for the success and replicability of the model. In essence, the research delineates a clear trajectory for urban development that harmonizes with CE principles, offering a guiding light for future endeavors to foster circular urban ecosystems.

Finally, this research enriches the literature and practice of urban planning from the perspective of the CE, providing practical insights and establishing a well-defined action framework. It goes beyond pre-existing knowledge by concretely applying the C2C principles in the urban context and developing an assessment and design framework that harmoniously integrates quantitative and qualitative criteria. This bidimensional approach is essential for the successful development of urban projects that align with the ideals of CE.

By documenting the process and the results of the assessment in the case study of Argentina Farm, the study offers a valuable resource for academics and professionals interested in the theme of transiting urban areas towards a CE. It also serves as a starting point for future discussions on how to improve assessment tools combined with design processes to meet the needs of circular urban projects. Therefore, the study sheds light on possible practical paths for implementing such concepts while establishing a starting point for future reflections and debates on enhancements in assessment tools and design processes, aiming to meet the specific demands of urban projects seeking circularity.

9. Conclusion and research continuity

The central purpose of this research was to develop a comprehensive design and evaluation framework rooted in the C2C principles aimed at assisting urban developers in transitioning urban areas towards a CE. To achieve this goal, we began with an in-depth exploration of the critical concepts for applying the CE in the urban context. The literature review conducted identified various existing approaches to circular urban practices. It became evident that while the four essential circular qualities—Resource Looping Regeneration, Distribution and Connectivity, and Locality—were often discussed separately in the literature, their true potential is unlocked only when considered interconnected. This research underscores the necessity of treating these qualities not as isolated elements but as parts of a synergistic ensemble that must be addressed collectively to confront the complexity of the CE transition within urban areas.

Moreover, all the emerging concepts emphasize the importance of understanding and replicating nature's functioning, which has proven to be a critical factor in achieving the dynamics of CE in urban systems. Integrating these qualities into a unified framework is crucial for successfully emulating natural systems within urban environments. By doing so, we pave the way for urban areas to adopt circular principles while thriving as interconnected, resilient, and adaptive systems harmonizing with the CE model.

The ‘Framework to Transition Urban Areas Towards a Circular Economy’ is based on the Cradle to Cradle principles, drawing inspiration from natural processes. Although adjustments were needed to manage urban complexities, C2C principles, and product certification criteria have provided a solid foundation for applying CE in the urban context. Therefore, the proposed framework would benefit from incorporating the successful practices of product assessment and certification following the C2C certification standard for industrial products and establishing a connection for its application on an urban scale. To encompass the complexity of the CE in urban areas, requirements, and performance indicators from other approaches were also included in the framework, facilitating the engagement of various stakeholders to address the challenges of CE implementation.

Thus, the C2C principles and key areas were adapted to the urban scale, resulting in four key areas and fifteen categories, and transformed into two complementary tools that became the framework foundation: a performance evaluation tool and a pattern language. The first will measure the performance of the proposed requirements, with quantitative indicators for each category. The second will guide the design and planning of circular urban areas and the dissemination of good practices, transferring the framework and adapting it to different urban contexts and needs through qualitative design patterns and dimensions.

The calibration of the framework through expert consultations via a questionnaire and workshop, coupled with testing it in the case study of Argentina Farm, were crucial steps for consolidating the proposed tool. Engaging with urban practitioners facilitated the structuring of communication and the refinement of specific categories, indicators, and design patterns. Additionally, applying the framework in the case study provided an in-depth evaluation of the performance tool, revealing how the project incorporates CE practices and whether these practices align or diverge from the best practices expected for circularity in each category. Moreover, this process has demonstrated how the design patterns can reinforce similar projects and support their replication in future projects.

As a microcosm of urban innovation, Argentina Farm provided an ideal testing ground for the framework. Analyzing the framework's application in the case study demonstrates how the framework works in practice. By recording the assessment methodology and the results achieved, the study presents a practical example that can be examined and used as a reference for future projects. It extends existing knowledge by demonstrating the effective implementation of circular strategies, emphasizing tangible benefits, and showing how to overcome challenges.

On the other hand, the difficulty in obtaining complete information for all indicators underscored the importance of promoting greater transparency and integrating CE-related data in the case study. Additionally, the complexity that follows the implementation of the CE in urban development indicates the need for ongoing dialogue among stakeholders to refine and adjust the framework according to local specificities. It also suggests the importance of adopting strategies such as phased planning and continuous improvement of processes and outcomes.

The study highlights the challenges and opportunities associated with implementing circular strategies. Challenges include the need for interdisciplinary collaboration, aligning policies and regulations, data collection and transparency, and overcoming economic and technological barriers. Opportunities, in turn, include the potential for innovation, the creation of green jobs, the strengthening of community resilience and biodiversity, and the promotion of a healthier and more livable urban environment.

Creating a replicable and adaptable framework represents advancing the academic literature on CE in urban areas. The holistic structure that combines the performance evaluation tool and the pattern language offers an integrated approach that can be applied in various urban contexts with specific characteristics and challenges. With its ability to assess the implementation of CE standards and their impact on promoting circularity, the performance evaluation tool provides a quantitative means of measuring progress. Ensuring that CE goals are set, achieved, and maintained over time is essential. Yet, the pattern language is a qualitative guide for design and implementation practices, offering a common language that can be shared among different disciplines and stakeholders.

The study deepens the understanding of circular strategies, offering a detailed view of integrating the CE principles, particularly C2C, into urban contexts. By emphasizing the importance of replicating natural cycles within urban systems, the study promotes a symbiosis between the built environment and natural ecosystems, establishing a vital balance for urban regeneration. This approach establishes a theoretical foundation for the CE in urban areas. At the same time, it paves the way for continuous improvement, where each stage of urban development is an opportunity to enhance circular practices.

In addition to its academic value, the framework serves as a practical tool for professionals involved in urban planning and development. By providing a clear structure and measurable indicators, the framework facilitates informed decision-making and the implementation of strategies that promote the CE. Concurrently, the pattern language serves as a roadmap for the design and execution of project practices, ensuring that design and construction choices align with the long-term goals of one's enterprise. These elements, working together, establish a continuous process of learning and evolution, which is fundamental for realizing urban spaces that follow the principles of the CE.

In summary, the developed Framework for Urban Areas to Transition Towards a CE is a step towards circular practices, and its application in the case study of Argentina Farm demonstrates the transformative potential that the CE brings to urban development. By advancing the understanding and application of circular practices, we can inspire a wave of transformation towards more circular urban areas. The Argentina Farm project can inspire urban development by adopting a CE vision, positively influencing circularity, regeneration, connectivity, and local and regional sustainability. However, this study goes beyond indicating the path for Argentina Farm; it can contribute for enabling a future where urban areas worldwide thrive in harmony with the natural environment by contributing to urban regeneration.

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Annexes

Annex 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 31).

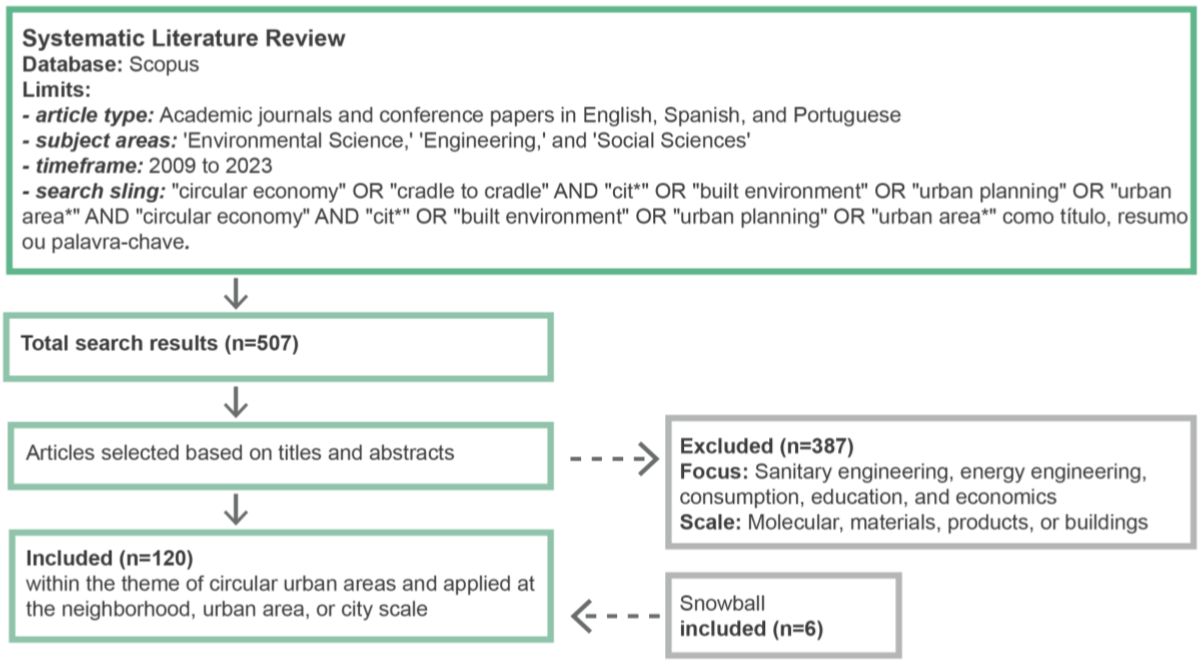

Figure 31. Systematic Literature Review Protocol

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 (Table 2). 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 (Table 3): two institutional documents that outline the strategy for implementing CE in two pioneering cities - Amsterdam (Gemeente Amsterdam, 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-Habitat, 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 and Braungart, 2010).

Table 27. Selected articles from the SLR, separated according to conceptual emphases.

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 cities 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	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.

Table 28. Articles collected using the 'snowball' technique

SNOW BALL		
Numbering (within sample)	**Title**	**Author(s)**
120	Amsterdam Circular 2020-2025 Strategy	GEMEENTE AMSTERDAM (2020)
121	Cities and climate change	UN-HABITAT (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)

Annex B - Articles According to Resource Flow

Table 29. 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.

Annex C - Questionnaire

Questionário sobre um *framework* de aplicação de Economia Circular em Áreas Urbanas

Introdução

Atualmente, mais de metade da população global reside em áreas urbanas, que ocupam apenas 3% da superfície terrestre. No entanto, essas áreas urbanas são responsáveis por aproximadamente 75% das emissões globais de gases de efeito estufa, bem como uma proporção semelhante no consumo de recursos e na produção de resíduos[1]. Isso destaca o impacto significativo que as cidades têm no consumo de recursos, na geração de resíduos e na poluição em escala global, mas também ressalta o potencial transformador que possuem em direção a um futuro mais circular.

Nossas escolhas relacionadas a questões urbanas, como a produção de alimentos, o uso de materiais de construção, o saneamento, o transporte e a energia, têm repercussões diretas nos serviços ecossistêmicos e nas mudanças climáticas. Além disso, essas escolhas afetam consideravelmente os aspectos sociais e econômicos, uma vez que as áreas mais desfavorecidas frequentemente são as mais vulneráveis e com menor acesso a serviços e infraestrutura ambiental e urbana.

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[1] UNITED NATIONS. **World population in cities.** 2018. Disponível em: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html. Acesso em: 9/5/2021.

Nesse contexto, a economia circular (EC) tem ganhado destaque como um paradigma econômico-ambiental a ser buscado pela humanidade. O conceito de áreas urbanas circulares está se tornando mais claro, indo além da gestão de resíduos e da eficiência dos sistemas, direcionando-se para a redução de entradas de recursos externos e a promoção de ciclos internos de recursos. Isso implica mudanças significativas no uso do solo e na regulamentação pública. Tais áreas urbanas devem adotar os princípios da economia circular em todas as suas dimensões, planejando suas funções de maneira regenerativa, com a máxima utilização de recursos locais, retenção do valor dos materiais e produtos, recuperação de nutrientes para novos ciclos produtivos e aprimoramento das condições dos recursos naturais e da biodiversidade.

A transição para áreas urbanas circulares requer a colaboração de diversas partes interessadas e camadas da sociedade. No entanto, ainda não existe uma definição única para "áreas urbanas circulares" nem um *framework* abrangente para medir o desempenho e orientar melhorias dos processos[2].

Neste contexto, este trabalho tem como objetivo resumir o conceito de áreas urbanas circulares, estabelecendo possíveis critérios, categorias e indicadores, a fim de simplificar e direcionar a avaliação das informações necessárias para a tomada de decisões, e contribuir para a capacitação dos gestores urbanos, fornecendo-lhes ferramentas para projetar e otimizar sistemas urbanos inspirados na abordagem de economia circular.

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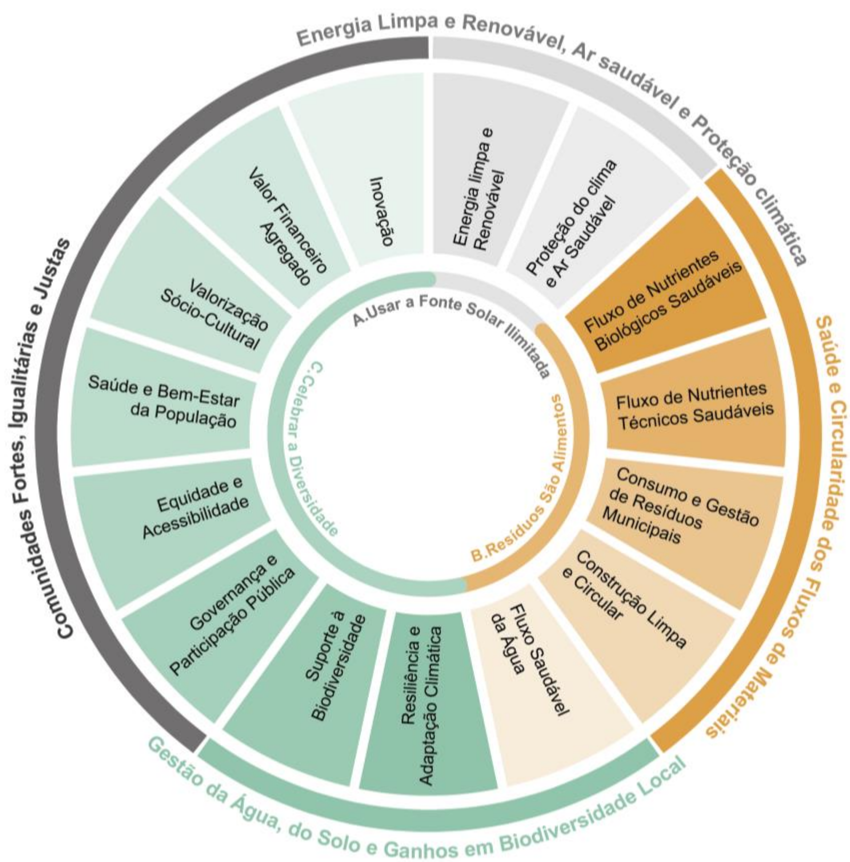
[2] BÎRGOVAN, A. L. et al. How Should We Measure ? A Review of Circular Cities Indicators. **International Journal of Environmental Research and Public Health**, v. 19, n. 9, p. 5177, 2022. DOI: https://doi.org/10.3390/ijerph19095177

Critérios de Economia Circular em Áreas Urbanas:

Dado a diversidade de aspectos envolvidos na promoção de áreas urbanas circulares, é fundamental iniciar o processo reconhecendo os diferentes critérios, categorias e indicadores relevantes. Nesse sentido, estamos atualmente delineando quatro critérios fundamentais, subdivididos em quinze categorias, juntamente com seus respectivos indicadores. O objetivo deste questionário é obter validação e avaliar a importância desses critérios, categorias e indicadores junto a especialistas em áreas de relevância. Isso permitirá futuramente direcionar os esforços de gestores e planejadores urbanos na implementação da economia circular nas áreas urbanas.

Foram estabelecidos quatro critérios, divididos em quinze categorias para abarcar a economia circular em áreas urbanas:



CRITÉRIO	OBJETIVOS
Energia Limpa e Renovável, Ar saudável e Proteção climática	Áreas urbanas circulares têm o potencial de exercer um impacto benéfico no abastecimento de energia ao promover o uso de fontes de energia limpa e renovável, ao evitar perdas energéticas e emissões de poluentes gasosos, e ao manter a energia em ciclos de alta qualidade. Em um cenário ideal, estas áreas urbanas podem não apenas atender às suas próprias necessidades energéticas a partir de fontes limpas e renováveis, mas também exceder este consumo, disponibilizando o excedente para as comunidades locais ou reintegrando-o à rede elétrica. Adicionalmente, áreas urbanas circulares devem priorizar a gestão responsável das emissões de poluentes, garantindo a manutenção de uma alta qualidade do ar, e conforto térmico e acústico para seus habitantes. Torna-se fundamental otimizar a captação de luz solar, assegurar uma ventilação adequada, além de promover sistemas de transporte público de alta qualidade e fomentar a mobilidade a pé.
Saúde e Circularidade dos Fluxos de Materiais	Áreas urbanas circulares devem assegurar a circulação contínua de nutrientes em sistemas saudáveis dentro de ciclos biológicos e técnicos. Para isto, ressalta-se a importância do consumo consciente dos cidadãos e a efetiva gestão municipal de resíduos, com a implementação de sistemas de informação, coleta e destinação desses materiais. Fomentar o fluxo de nutrientes biológicos saudáveis nas áreas urbanas implica em devolver estes nutrientes de maneira apropriada ao solo, criando valor a partir de resíduos orgânicos sólidos e minimizando o desperdício de alimentos. Estas ações estão associadas à redução das distâncias percorridas na produção de alimentos de qualidade e à inclusão da população, incentivando a sua participação em outros setores da bioeconomia. A integração de áreas urbanas na EC também engloba os fluxos de materiais relacionados ao ciclo técnico, uma vez que as cidades são as maiores consumidoras de produtos industriais. As áreas urbanas podem implementar e facilitar sistemas de reutilização, reparo, remanufatura e reciclagem de produtos e materiais técnicos. Destaca-se, ainda, o potencial do setor da construção civil, que tem grandes impactos ambientais causados pelo modelo linear atual, mas também amplas possibilidades regenerativas para a transição circular. Os novos edifícios devem ser concebidos com a premissa do reaproveitamento de seus materiais em ciclos posteriores. Isto implica na adoção de sistemas construtivos modulares e desmontáveis, possibilitando a reutilização de componentes em novos projetos. Além disto, é fundamental estender ao máximo o estoque existente de edifícios, promovendo reformas e adaptações que valorizem e prolonguem seu uso.
Gestão da Água e do Solo e Ganhos em Biodiversidade Local	Este critério tem como objetivos expandir a área disponível para a biodiversidade local, revitalizar o solo, restaurar a funcionalidade hidrológica da paisagem urbana e aprimorar a qualidade de vida da população. Neste contexto, a água e o solo são considerados recursos preciosos e compartilhados. O uso misto do solo, soluções baseadas na natureza e a recuperação de áreas degradadas são ferramentas que promovem resiliência e adaptação às mudanças climáticas, enquanto proporcionam um ambiente propício para a biodiversidade local. Para garantir um fluxo saudável de água, é fundamental adotar práticas como a captação de água da chuva, a prevenção da contaminação da água e o tratamento de efluentes.
Comunidades Fortes, Igualitárias e Justas	Comunidades em áreas urbanas circulares devem estar comprometidas com a promoção da equidade e acessibilidade para todos os seus habitantes, a garantia de participação pública efetiva e o bem-estar da comunidade como um todo. A diversidade sociocultural que as compõe deve ser valorizada, buscando agregar valor financeiro e estimulando a inovação como parte intrínseca de sua visão de desenvolvimento. A governança desempenha um papel fundamental na promoção destes princípios e na garantia de que as políticas, regulamentos e ações urbanas estejam alinhados com a construção da EC em comunidades fortes, igualitárias e justas. Uma governança robusta pode ajudar a traduzir estas intenções em práticas eficazes, assegurando a participação democrática, a distribuição equitativa de recursos e o cumprimento dos princípios de igualdade e justiça em todas as áreas da vida urbana.

Na sua opinião, qual é a importância de cada um dos quatro critérios propostos para a implementação e prática de economia circular em áreas urbanas?

- Energia Limpa e Renovável, Ar saudável e Proteção climática
- Saúde e Circularidade dos Fluxos de Materiais
- Gestão da Água e do Solo e Ganhos em Biodiversidade Local
- Comunidades Fortes, Igualitárias e Justas

Você gostaria de compartilhar algum comentário ou sugestão em relação à proposta dos critérios e categorias para áreas urbanas circulares?

Critério 1: Energia Limpa e Renovável, Ar saudável e Proteção climática

O critério Energia Limpa e Renovável, Ar saudável e Proteção climática está sendo avaliado em duas categorias complementares:

ENERGIA LIMPA E RENOVÁVEL, AR SAUDÁVEL E PROTEÇÃO CLIMÁTICA	
CATEGORIA	**OBJETIVOS**
Energia Limpa e Renovável	trabalhar a eficiência energética e geração de energia proveniente de fontes limpas e renováveis
Proteção do Clima e Ar Saudável	controlar emissões e incentivar a mobilidade sustentável

Na sua opinião, qual é a importância de cada uma das categorias propostas para a implementação e prática de economia circular em áreas urbanas?

- Energia Limpa e Renovável,
- Proteção do Clima e Ar Saudável.

Para a avaliação do Critério 1:Energia Limpa e Renovável, Ar saudável e Proteção climática, a categoria Energia Limpa e Renovável foi dividida em três indicadores e a de Proteção do Clima e Ar Saudável foi dividida em outros seis indicadores conforme tabela a seguir:

Energia Limpa e Renovável, Ar saudável e Proteção climática				
		indicador	**objetivo**	**métrica**
Energia Limpa e Renovável	**a.**	Fontes Circulares - Energia	incentivar o uso de fontes de energia renovável	% energia energia renovável utilizada/ consumo energia total
	b.	Conteúdo circular - Energia	incentivar o uso de energia da mais alta qualidade pelo maior tempo possível	% energia elétrica onsite/ eletricidade renovável total
	c.	Ciclos ativos - Energia	manter a energia em ciclos de alta qualidade o maior tempo possível, evitar perda de energia	geração de energia/ potencial de geração
Proteção do Clima e Ar Saudável	**d.**	Qualidade do ar	promover a qualidade do ar ambiente - Ozônio (O3), monóxido de carbono (CO) e poluição por material particulado (PM10)	% Número de dias que não excedem os limites diários de Ozônio (O3), monóxido de carbono (CO) e poluição por material particulado (PM10) em um ano
	e.	Conforto acústico	promover conforto acústico	% da população vivendo em ambientes com nível de ruído excessivo diário/ ano
	f.	Orientação solar (quadras e edifícios)	reduzir a a necessidade de resfriamento/ aquecimento e melhorar o conforto térmico através da orientação dos edifícios e quadras	% de sombra dos edifícios
	g.	Redução de ilhas de calor	estimar os efeitos de ilhas de calor na área local, e identificar fatores causais relevantes	aumento da temperatura local durante o verão/ano
	h.	Energia renovável no transporte de massa	incentivar a energia renovável para o transporte de massa	% das viagens em transporte de massa movidos à energia limpa e renovável
	i.	Poluições noturna	reduzir a poluição noturna na área do projeto	densidade de potência instalada (watts/m2)

Na sua opinião, qual é a importância de cada um dos indicadores propostos para a implementação e prática de economia circular em áreas urbanas?

Você gostaria de compartilhar algum comentário ou sugestão em relação ao quadro proposto (categorias e indicadores) para Critério 1: Energia Limpa e Renovável, Ar saudável e Proteção climática?

Critério 2: Saúde e Circularidade dos Fluxos de Materiais

O critério Saúde e Circularidade dos Fluxos de Materiais está sendo avaliado em duas categorias complementares:

SAÚDE E CIRCULARIDADE DOS FLUXOS DE MATERIAIS	
CATEGORIA	**OBJETIVOS**
Circularidade dos Fluxos de Nutrientes Biológicos Saudáveis	estimular a produção local de alimentos e gestão de resíduos orgânicos
Circularidade dos Fluxos Nutrientes Técnicos Saudáveis	trabalhar a recirculação de materiais provenientes de cadeias produtivas da esfera técnica
Circularidade dos Fluxos da Construção Civil	incentivar a manutenção e o reuso do estoque existente de edifícios, bem como o desmembramento de sistemas construtivos, componentes e materiais projetados para futuros ciclos
Consumo e Gestão de Resíduos Municipais	promover a redução de consumo para a não geração de resíduos, a separação de resíduos domésticos e a sua destinação

Na sua opinião, qual é a importância de cada uma das categorias propostas para a implementação e prática de economia circular em áreas urbanas?

- Circularidade de Fluxos de Nutrientes Biológicos Saudáveis
- Circularidade de Fluxos de Nutrientes Técnicos Saudáveis
- Circularidade de fluxos da Construção Civil
- Consumo e Gestão de Resíduos Municipais

Para a avaliação Critério 2: Saúde e Circularidade dos Fluxos de Materiais, as categorias Circularidade de Fluxos de Nutrientes Biológicos Saudáveis, Circularidade de Fluxos de Nutrientes Técnicos Saudáveis, Circularidade de fluxos da Construção Civil e Consumo e Gestão de Resíduos Municipais foram divididas nos indicadores conforme tabela a seguir:

Saúde e Circularidade dos Fluxos de Materiais				
		indicador	objetivo	métrica
Circularidade de Fluxos de Nutrientes Biológicos Saudáveis	a.	Fontes circulares - Ciclo Biológico	medir a circularidade das fontes dos materiais	% conteúdo renovável
	b.	Conteúdo circular - Ciclo Biológico	tornar o material adequado para ser mantido em ciclos de alta qualidade pelo maior tempo possível	% da produção de materiais orgânicos (produzidos sem pesticidas)
	c.	Ciclos ativos - Ciclo Biológico	manter o material em ciclos de alta qualidade o maior tempo possível	% de materiais sendo reciclado/ compostado
Circularidade de Fluxos de Nutrientes Técnicos Saudáveis	d.	Fontes Circulares - Ciclo Técnico	medir a circularidade das fontes dos materiais	% de material provindo de reuso, remanufatura ou reciclado
	e.	Conteúdo circular- Ciclo Técnico	tornar o material adequado para ser mantido em ciclos de alta qualidade pelo maior tempo possível	% de material reciclável ou com possibilidades de reuso ou remanufatura
	f.	Ciclos ativos - Ciclo Técnico	manter o material em ciclos de alta qualidade o maior tempo possível	% de material sendo reciclado (no município), reutilizado ou remanufaturado
Circularidade de fluxos da Construção Ci	g.	Fontes circulares - Construção	medir a circularidade das fontes dos materiais (materiais reciclados e/ou renováveis)	% de material provindo de reuso, remanufatura, reciclado e/ou de fontes renováveis
	h.	Conteúdo circular - Construção	tornar o material adequado para ser mantido em ciclos de alta qualidade pelo maior tempo possível	% de materiais recicláveis, compostáveis ou com possibilidades de reuso ou remanufatura
	i.	Ciclos ativos - Construção 1	manter o material em ciclos de alta qualidade o maior tempo possível	% de material de construção sendo reciclada ou compostada (no município), reutilizada ou remanufaturada
	j.	Ciclos ativos - Construção 2	adaptar e/ou renovar edifícios existentes para novos usos	% de edifícios e estruturas existentes na área de estudo sendo adaptadas a novos usos/ estoque de edificações
Consumo e Gestão de Resíduos Municipais:	k.	Separação de materiais na fonte	incentivar a separação de materiais na fonte	% de resíduos urbanos separados na fonte / total de resíduos (volume)
	l.	Coleta e destinação	coletar e destinar os corretamente os resíduos	% cobertura do sistema de coleta e destinação/total de residentes

Na sua opinião, qual é a importância de cada um dos indicadores propostos para a implementação e prática de economia circular em áreas urbanas?

Você gostaria de compartilhar algum comentário ou sugestão em relação ao quadro proposto (categorias e indicadores) para Critério 2: Saúde e Circularidade dos Fluxos de Materiais?

Critério 3: Gestão da Água e do Solo e Ganhos Em Biodiversidade Local

O Critério 3: Gestão da Água e do Solo e Ganhos Em Biodiversidade Local está sendo avaliado em duas categorias complementares:

GESTÃO DA ÁGUA E DO SOLO E GANHOS EM BIODIVERSIDADE LOCAL	
CATEGORIA	**OBJETIVOS**
Circularidade dos Fluxos de Água Saudável	estimular a captação local, ao uso eficiente e recirculação saudável da água
Resiliência e Adaptação Climática	promover soluções baseadas na natureza, permeabilidade do solo e distribuição do uso do solo
Suporte à Biodiversidade Local	incentivar a implantação de áreas verdes e árvores, a diversidade de espécies e a recuperação de áreas degradadas

Na sua opinião, qual é a importância de cada uma das categorias propostas para a implementação e prática de economia circular em áreas urbanas?

- Circularidade dos Fluxos de Água Saudável
- Resiliência e Adaptação Climática
- Suporte à Biodiversidade Local

Para a avaliação do Critério 3: Gestão da Água e do Solo e Ganhos Em Biodiversidade Local está sendo avaliado em duas categorias complementares as categorias Circularidade dos Fluxos de Água Saudável, Resiliência e Adaptação Climática, Suporte à Biodiversidade Local foram divididas nos indicadores conforme tabela a seguir:

Gestão da Água e do Solo e Ganhos em Biodiversidade Local				
		indicador	objetivo	métrica
Circularidade dos Fluxos de Água Saudável	a.	Fontes Circulares - Água	medir a circularidade das fontes de água	% da água coletada de fontes "alternativas" (captação chuva+ tratamento água residual)/ consumo
	b.	Conteúdo circular - Água 1	tornar o fluxo de água adequado para ser mantido em ciclos de alta qualidade pelo maior tempo possível.	nível de qualidade da água tratada localmente (ex. secundário)
	c.	Conteúdo circular - Água 2	prevenir a contaminação dos cursos d'agua	presença de efluentes perigosos de operações das edificações e áreas adjacentes
	d.	Ciclos ativos - Água	manter o material em ciclos de alta qualidade o maior tempo possível	% de água residual dos edifícios tratada localmente
Resiliência e Adaptação Climática	e.	Áreas de uso misto	incentivar o uso misto da área de estudo	parcela de uso predominante (residencial, comercial, etc.)/ outros usos
	f.	Área verde produtiva local	aumentar a área disponível para agricultura local	Área produtiva/ área total
	g.	Qualidade superficial do solo	tornar o solo saudável	quantidade de metais pesados e substâncias tóxicas no solo e com nutrientes (ex. nitrogênio e fósforo)
	h.	Recuperação de solo degradado	recuperação de brownfield (terrenos contaminados, desertificados e degradados)	% de terrenos contaminados, desertificados e degradados que foram recuperados
Suporte à Biodiversidade Local	i.	Infraestrutura verde e azul	restaurar a função hidrológica da paisagem urbana, gerenciar águas pluviais e reduzir a necessidade de infraestrutura cinza adicional	contribuição infraestrutura verde e azul/infraestrutura total
	j.	Área de proteção de biodiversidade	aumentar a área disponível para o desenvolvimento da biodiversidade local	Área de terreno não urbanizado com valor ecológico (que podem proteger a diversidade da fauna e flora nativas, como área verdes naturais e corpos hídricos) / área total
	k.	Corredores verdes	favorecer a continuidade de áreas verdes para promover a biodiversidade local	quantidade de áreas verdes continuadas com mais de 100m de comprimento

Na sua opinião, qual é a importância de cada um dos indicadores propostos para a implementação e prática de economia circular em áreas urbanas?

Você gostaria de compartilhar algum comentário ou sugestão em relação ao quadro proposto (categorias e indicadores) para o Critério 3: Gestão da Água e do Solo e Ganhos Em Biodiversidade Local?

Critério 4: Comunidades Fortes, Igualitárias e Justas

O Critério 4: Comunidades Fortes, Igualitárias e Justas está sendo avaliado em duas categorias complementares:

COMUNIDADES FORTES, IGUALITÁRIAS E JUSTAS	
CATEGORIA	**OBJETIVOS**
Governança e Participação Pública	promover a governança participativa e a colaboração da população local na promoção de práticas circulares
Equidade e Acessibilidade	gerar uma distribuição justa de recursos e acessibilidade a serviços essenciais para garantir uma sociedade mais igualitária
Saúde e Bem-Estar da População	trabalhar aspectos relacionados à qualidade de vida e à saúde da comunidade
Valorização Sociocultural	valorizar e a preservar a herança sociocultural local
Valor Financeiro Agregado	estimular financeiramente das práticas urbanas circulares
Inovação	introdução de novas soluções para enfrentar os desafios da economia linear vigente

Na sua opinião, qual é a importância de cada uma das categorias propostas para a implementação e prática de economia circular em áreas urbanas?

- Governança e Participação Pública
- Equidade e Acessibilidade
- Saúde e Bem-Estar da População
- Valorização Sociocultural
- Valor Financeiro Agregado
- Inovação

Para avaliar o Critério 4: Comunidades Fortes, Igualitárias e Justas, as categorias Governança e Participação Pública, Equidade e Acessibilidade, Saúde e Bem-Estar da População, Valorização Sociocultural, Valor Financeiro Agregado e Inovação foram divididas em indicadores conforme tabela a seguir:

Comunidades Fortes, Igualitárias e Justas				
Governança e Participação Pública	a.	Disseminação de boas práticas	disseminar as boas práticas de EC (circularidade de fluxos de nutrientes, água, energia e ganhos de biodiversidade)	pessoas impactadas pelas boas práticas (dentro e fora da comunidade) em ciclos técnicos/ total da comunidade
	b.	Iniciativas educacionais	educar a comunidade para a circularidade	% da comunidade impactada com educação para EC em ciclos biológicos
	c.	Novas políticas públicas para incentivar a EC	implementar políticas de EC	número de políticas implementadas/ ano
	d.	Novas parcerias firmadas para processos sinérgicos	criar parcerias para gerar sinergias entre atores e fluxos	número de parcerias firmadas/ ano
	e.	Pessoas envolvidas no processo de ciclagem	envolver a comunidade (residentes, trabalhadores, estudantes locais) em práticas de EC	% da comunidade envolvida em práticas circulares
Equidade e Acessibilidade	f.	Novos empregos relacionados aos projetos de EC	gerar novos empregos relacionados à EC para a produção de energia limpa e clima saudável	novos empregos gerados com projetos vinculados à EC/ ano
	g.	Acesso ao abastecimento de água potável	fornecer água limpa para o maior número de pessoas	% cobertura do sistema público municipal de abastecimento de água/total de residentes
	h.	Acesso ao sistemas de esgotamento sanitário	tratar a água após o uso	% cobertura do sistema de esgotamento sanitário/total de residentes
Saúde e Bem-Estar da População	i.	Acesso à mobilidade pública e orientada a pedestres e transporte de tração humana	garantir a mobilidade segura, com ênfase no transporte público como o principal meio de deslocamento, promover um ambiente orientado para pedestres e adequado ao transporte de tração humana	% das viagens em transporte de massa, a pé ou com transportes de tração humana
	j.	Acesso à zonas verdes e áreas de lazer	estimular o uso de áreas verdes e de lazer pela comunidade	% de edifícios residenciais localizados a menos de 1km de áreas públicas verdes e/ou áreas de lazer
Valorização Sociocultural	k.	Materiais regionais	incentivar a economia local/ regional	% de materiais produzidosem um raio de 200km
	l.	Retrofit de edifícios e revitalização de áreas urbanas	promover a revitalização de áreas construídas existentes	número de retrofit de edifícios e/ou revitalização de áreas urbanas / total de empreendimentos
Valor Financeiro Agregado	m.	Novos investimentos para ativar a EC	estimular a captação de novos investimentos para a EC	investimentos em projetos de EC / total de investimentos por ano
	n.	Novos empregos relacionados aos projetos de EC	gerar novos empregos relacionados à EC em ciclos biológicos	novos empregos gerados com EC / total de empregos gerados por ano
Inovação	o.	número de patentes relacionadas aos projetos de EC	incentivar a inovação para a EC	novas patentes relacionadas aos projetos de EC / novas patentes por ano
	p.	novas startups trabalhando com EC	estimular a prática de soluções para a EC	novas startups relacionadas aos projetos de EC / total de novas startups por ano
	q.	projetos de pesquisa abordando EC	promover pesquisa na área de EC	novas pesquisas relacionadas aos projetos de EC / total de pesquisas no empreendimento por ano

Na sua opinião, qual é a importância de cada um dos indicadores propostos para a implementação e prática de economia circular em áreas urbanas?

Você gostaria de compartilhar algum comentário ou sugestão em relação ao quadro proposto (categorias e indicadores) para o Critério 4: Comunidades Fortes, Igualitárias e Justas?

Você quer adicionar algum comentário ou sugestão geral para a pesquisa?

Muito obrigada por participar da pesquisa e pelo seu tempo!
Sua contribuição adicionará informações valiosas sobre o tópico e ajudará a desenvolver melhores soluções para o framework de áreas urbanas circulares. Suas respostas serão mantidas em sigilo e garantirei que seus dados sejam usados apenas para fins desta pesquisa.
Se você deseja receber um resumo dos resultados da pesquisa depois que o estudo for concluído ou tiver quaisquer comentários adiciona, por favor, entre em contato com as pesquisadoras pelo e-mail lea.gejer@gmail.com.

Mais uma vez, obrigado pela sua participação e valiosa contribuição.

Léa Gejer.

Annex D – Draft version of initial patterns

Four initial patterns were crafted as a draft version to be discussed during the workshop phase. These patterns area illustrated in the following pages, each representing one of the four key areas:

- Clean and Renewable Energy, Healthy Air and Climate Protection,
- Health and Circularity of Material Flows
- Water and Soil Management and Gains in Local Biodiversity,
- Strong, Equitable, and Just Communities.

3. Energia Limpa e Renovável, Ar saudável e Proteção climática

Links acendentes: [1] Circularidade: Metabolismo Urbano Circular; [2] Benefícios Sinérgicos

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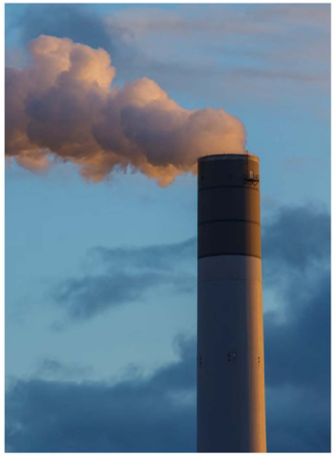


Foto: Peter Werkman para Unsplash

Problema:

A produção de energia está intrinsecamente ligada à emissão de gases de efeito estufa, desempenhando um papel fundamental nas mudanças climáticas e no aquecimento global. A relação entre o ciclo de energia e o ciclo do carbono deve-se à necessidade de capturar o carbono para reinseri-lo em ciclos subsequentes. A energia renovável desempenha um papel crucial na substituição de fontes de energia baseadas em combustíveis fósseis, que são os principais emissores de carbono. Isso ocorre porque as fontes de energia fóssil liberam grandes quantidades de carbono na forma gasosa, tornando a captação e reintegração desse carbono em ciclos futuros desafiadora. Assim, quaisquer modificações na quantidade e na composição da energia gerada influenciam o equilíbrio de carbono na atmosfera, desempenhando um papel direto na transformação do clima global.

O que fazer:

Áreas urbanas circulares têm o potencial de exercer um impacto benéfico no abastecimento de energia ao promover o uso de fontes de energia limpa e renovável, ao evitar perdas energéticas e emissões de poluentes gasosos, e ao manter a energia em ciclos de alta qualidade. Em um cenário ideal, essas áreas urbanas podem não apenas atender às suas próprias necessidades energéticas a partir de fontes limpas e renováveis, mas também exceder esse consumo, disponibilizando o excedente para as comunidades locais ou reintegrando-o à rede elétrica.

Além disso, as áreas urbanas circulares devem priorizar a gestão responsável das emissões de poluentes, garantindo a manutenção de uma alta qualidade do ar, e conforto térmico e acústico para seus habitantes. É fundamental otimizar a captação de luz solar, assegurar uma ventilação adequada, além de promover sistemas de transporte público de alta qualidade e fomentar a mobilidade a pé.

Como fazer:

Passo 1: Avaliação do Potencial Local
- Compreenda a orientação solar e padrões de vento.
- Analise a radiação solar, temperatura, e disponibilidade de resíduos de calor e biomassa.
- Estude o sistema de mobilidade local.

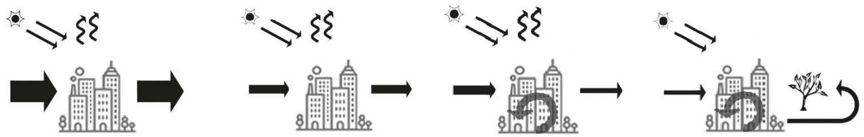
Passo 2: Estabelecimento de Metas Claras
- Defina metas iniciais e progressivas, como redução de consumo, adoção de fontes renováveis, melhoria da qualidade do ar e dos sistemas de transporte.

Passo 3: Análise do Cenário Atual
- Determine a quantidade e qualidade de energia atualmente consumida e suas emissões.
- Analise o tipo e fontes de energia utilizadas e a proporção atual de energia renovável.
- Avalie a qualidade do ar no local.

Passo 4: Otimização do Sistema
- Verifique e reduza a demanda de energia.
- Considere sistemas passivos para ventilação e iluminação, e estratégias de economia de energia.
- Avalie possibilidades de otimização do transporte público e de modos de transporte não motorizados.

Passo 5: Energias Renováveis e Reutilização de Fluxos Locais
- Projete e implemente sistemas passivos, de forma a manter a qualidade energética, além de produzir energia no local.
- Planeje melhorias nos sistemas de transporte no curto, médio e longo prazos.
- Escolha um sistema de geração eficaz de energia e analise a viabilidade financeira.

Passo 6: Busca por Benefícios Sinérgicos
- Explore possibilidades de geração excedente e exportação.
- Crie estratégias de melhoria contínua.
- Dissemine boas práticas, eduque a comunidade e atraia investimentos e empregos no setor.



1. Avaliação do Potencial
2. Definição de metas

3. Análise do Cenário Atual
4. Otimização do Sistema (redução de entradas e saídas)

5. Energias Renováveis e Reutilização de Fluxos Locais

6. Benefícios Sinérgicos

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Links descendentes: [7] Energia Limpa e Renovável. [8] Proteção do Clima e Ar Saudável.

4. Saúde e Circularidade dos Fluxos de Materiais

Links acendentes: [1] Circularidade: Metabolismo Urbano Circular; [2] Benefícios Sinérgicos

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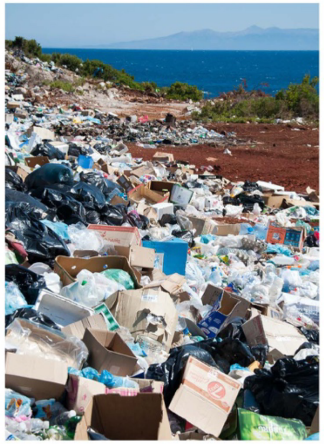


Foto: Antoine Giret para Unsplash

Problema:
Os sistemas urbanos contemporâneos operam com base em uma estrutura linear “do berço ao túmulo”. Nesse modelo, as indústrias produzem principalmente materiais e produtos não renováveis para consumo e descarte rápido, resultando no esgotamento de recursos naturais, bem como no acúmulo de resíduos e na poluição da água, ar e terra (Lakatos et al., 2021). Segundo estudo da Circle Economy (2019), apenas 9% da economia é considerada circular, com menos de 10% dos 92,8 bilhões de toneladas de materiais dos processos produtivos sendo recirculados. Quase metade desse consumo massivo (42,4 bilhões de toneladas/ano) é atribuída à construção e manutenção de casas, rodovias e infraestrutura.

No contexto brasileiro, a construção civil é particularmente impactante, sendo responsável pelo consumo de 75% dos recursos naturais, 12% da água potável e 50% da eletricidade (CBCS, 2018). O país gera aproximadamente 84 milhões de metros cúbicos de resíduos de construção civil e demolição anualmente (SINIR, s.d.), representando de 50% a 70% da massa dos resíduos sólidos urbanos no Brasil (IPEA, 2012).

O que fazer:
Ao observar as cidades sob a ótica dos recursos, tendemos a enxergá-las principalmente como consumidoras de materiais e geradoras de resíduos. Diariamente, uma quantidade significativa de recursos adentra uma área urbana. Depois de consumidos, alguns fluxos, como águas residuais ou detritos, são direcionados para fora do sistema urbano, enquanto outros, como materiais de construção, resíduos de alimentos ou produtos eletrônicos, permanecem internamente, constituindo “estoques” urbanos.

Embora certos elementos desses estoques urbanos frequentemente sejam rotulados como resíduos, existe um conjunto de recursos latentes com potencial de serem recuperados, reciclados e reutilizados. As cidades podem então serem vistas como reservatórios destes recursos, transformando positivamente os resultados das atividades humanas.

Como fazer:

1. **Compreenda a distinção entre os ciclos biológico e técnico:** Desenvolva produtos, tecnologias e edifícios como “bancos de materiais” que devem ser incorporados em ciclos biológicos e técnicos distintos. Materiais destinados à biosfera devem provir de fontes renováveis e ser projetados para reintegrar como nutrientes biológicos nos ecossistemas naturais. Já materiais destinados à tecnosfera, consistem em materiais não renováveis, e devem ser projetados para uma circulação contínua, mantendo seu valor dentro de ciclos industriais fechados.

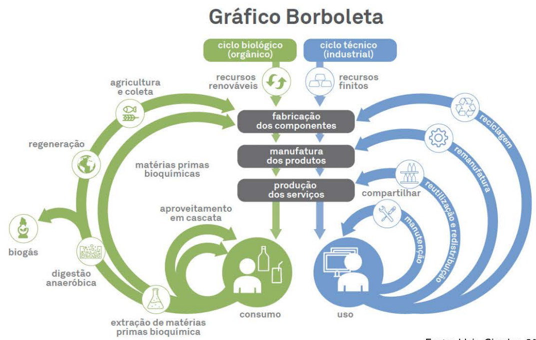
2. Gerencie o ciclo biológico: Implemente sistemas que reintegrem nutrientes de maneira apropriada ao solo. Isso pode incluir práticas como agricultura urbana, compostagem urbana e reutilização de madeira de poda. Essas ações contribuem para produzir alimentos saudáveis, reduzir as distâncias percorridas no seu consumo e incentivar a participação da população em diversos setores da bioeconomia.

3. Gerencie o ciclo técnico: A integração de áreas urbanas na EC também engloba fluxos de materiais técnicos, já que as cidades são as maiores consumidoras de produtos industriais. Nutrientes técnicos, como metais e plásticos, podem circular de forma contínua em sistemas industriais fechados se forem projetados com essa finalidade. As áreas urbanas podem facilitar a implementação de sistemas de reutilização, reparo, remanufatura e reciclagem de produtos e materiais técnicos.

5. Construção civil: No contexto urbano, o setor da construção civil destaca-se pelo alto potencial para a transição circular. Novos edifícios devem ser projetados com a premissa do reaproveitamento de seus materiais em ciclos posteriores, adotando sistemas construtivos modulares e desmontáveis. Além disso, é fundamental estender ao máximo o estoque existente de edifícios, promovendo reformas e adaptações que valorizem e prolonguem seu uso.

6. Promova políticas e ações para o consumo consciente: como a separação de resíduos na fonte e a implementação de sistemas de informação, coleta seletiva e destinação apropriada desses materiais. Essas ações visam criar uma cultura de responsabilidade ambiental e maximizar a efetividade na utilização de produtos e na ciclagem dos recursos urbanos.

7. E, para cada ação que você tomar, é essencial se questionar: o que acontece a seguir? Esta reflexão contínua sobre as consequências e os impactos de nossas escolhas é fundamental para garantir o progresso em direção a um futuro mais saudável e circular.



Fonte: Ideia Circular, 2022, adapatdo de Fundação Ellen Macarthur, 2013.

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Links descendentes: [9] Fluxo de nutrientes biológicos saudáveis. [10] Fluxo de nutrientes técnicos saudáveis [11] Construção limpa e circular. [12] Consumo e gestão de resíduos municipais.

5. Gestão da Água, do Solo e Ganhos em Biodiversidade Local

Links acendentes: [1] Circularidade: Metabolismo Urbano Circular; [2] Benefícios Sinérgicos

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Foto: Zetong Li para Unsplash

Problema:
No atual paradigma linear, a sociedade humana age como se suas atividades e comportamentos estivessem desconectados da natureza, resultando na interrupção dos ciclos naturais que perpetuam a reciclagem de elementos essenciais, como carbono, oxigênio, água, nitrogênio e fósforo. As atividades industriais e urbanas consomem excessivamente esses recursos, transformando-os em produtos de consumo efêmero e liberando resíduos no ambiente, gerando poluição em diversas formas e desorganizando os ecossistemas locais (Raworth, 2017).

Por exemplo, o uso de fertilizantes produzidos a partir de nitrogênio e fósforo em áreas agrícolas resulta no escoamento excessivo desses elementos para cursos d'água, como o esgoto urbano. Além disso, o escoamento de águas pluviais carrega metais pesados, substâncias tóxicas e patógenos das superfícies urbanas para corpos d'água, aumentando os níveis de poluição. Em algumas áreas urbanas, esgotos domésticos são despejados em valas ou córregos a céu aberto, elevando a presença de bactérias patogênicas. Em outras regiões, os esgotos são direcionados a sistemas de tratamento centralizados, mas ainda assim resíduos patogênicos e outros poluentes persistem nos cursos d'água (Forman, 2013). A poluição da água é uma das principais causas de morte por doenças, especialmente em países em desenvolvimento, de acordo com as Nações Unidas (s.d.).

Outro exemplo é a interação incomum entre diferentes espécies, incluindo os humanos, como a manipulação e o comércio de animais selvagens, juntamente com a destruição de seus habitats naturais, pode desencadear pandemias regionais e globais. Doenças transmitidas por animais, como artrópodes, roedores e animais domésticos, apresentam uma grande diversidade e constituem uma preocupação significativa para a saúde humana nas cidades (Forman, 2013).

O que fazer:
Nesse contexto, a água e o solo são considerados recursos preciosos e compartilhados. O uso misto do solo, a revitalização de áreas urbanas degradadas, a expansão de áreas disponíveis para a biodiversidade local, a promoção de soluções baseadas na natureza e a restauração da funcionalidade hidrológica da paisagem urbana são estratégias cruciais para promover resiliência e adaptação às mudanças climáticas, enquanto proporcionam um ambiente propício para a biodiversidade local.

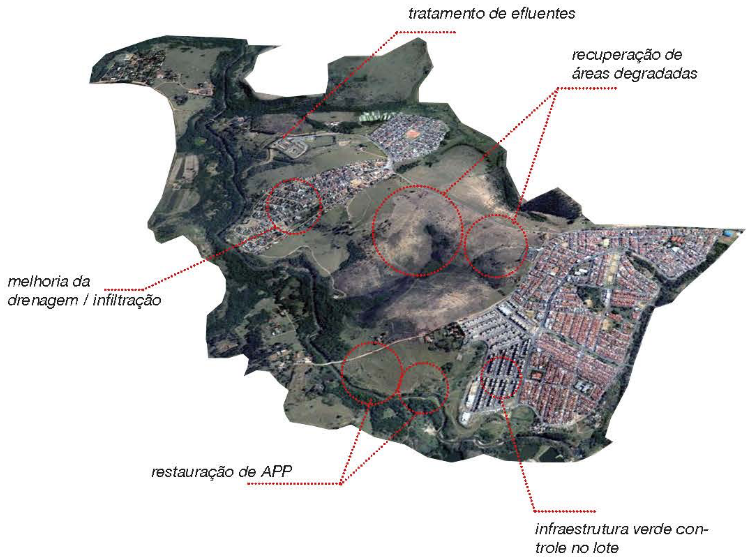
Como fazer:

1. Inicie com uma análise detalhada da sua área de estudo, abrangendo tanto a saúde humana quanto a dos ecossistemas. Concentre-se em três áreas-chave do ambiente urbano:

- Gestão das águas urbanas
- Integração com sistemas naturais
- Uso do solo e sua ocupação

2. Desenvolva estratégias de curto, médio e longo prazos que abordem as seguintes dimensões:

- Garanta um Fluxo Saudável da Água: incluindo medidas de captação local e uso eficiente dos recursos hídricos.
- Promova a Resiliência e Adaptação Climática, incorporando soluções baseadas na natureza, a melhoria da permeabilidade do solo e um planejamento adequado para a ocupação do solo.
- Apoie a Biodiversidade Local, implementando áreas verdes, fomentando a diversidade de espécies e trabalhando na recuperação de áreas degradadas.



Fonte imagem: Google Earth, 2023.

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Links descendentes: [13] Fluxo saudável da água. [14] Resiliência e adaptação climática. [15] Suporte à biodiversidade local.

6. Comunidades Fortes, Igualitárias e Justas

Links acendentes: [1] Circularidade: Metabolismo Urbano Circular; [2] Benefícios Sinérgicos

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Foto: Richard Cordones para Unsplash

Problema:
A economia circular é um movimento que tem evoluído dinamicamente nas últimas décadas, envolvendo diversos atores e setores da sociedade, como fundações, governos, empresas e organizações da sociedade civil em todo o mundo. Essa abordagem busca enfrentar os desafios apresentados pelas crises ecológicas, econômicas e sociais que a humanidade enfrenta. A EC propõe um novo relacionamento com nossos bens e materiais, com o objetivo de economizar recursos e energia, promover a criação de negócios e empregos locais e contribuir para a regeneração dos sistemas naturais (Ideia Circular, 2022). No entanto, a transição para uma economia circular propõe uma mudança significativa no status quo, tornando-se uma abordagem complexa que abarca diversas dimensões urbanas e necessita da participação de todos os setores da sociedade.

Além disso, a urbanização tem crescido de forma acelerada, concentrada e desordenada, especialmente em países emergentes. Como os fenômenos sociais têm uma expressão espacial, as condições urbanas tornaram-se fatores que contribuem para a reprodução das desigualdades sociais e raciais. Nesse contexto, os recursos naturais tornaram-se elementos valiosos, muitas vezes vinculados a disputas sociais e urbanas (CAMARA, 2014)

Concomitantemente ao aumento das vulnerabilidades sociais, produziu-se o fenômeno da "cidade informal", em que uma série de estruturas formais e informais complexas e populações periféricas surgiram em grande parte das áreas urbanas de países emergentes. Essas áreas, em sua maioria compostas por loteamentos clandestinos, favelas e construções autoconstruídas sem planejamento institucional, resultaram em relações legais e territoriais irregulares, criando disparidades significativas no acesso a serviços urbanos, como moradia, saneamento, emprego, transporte, contato com a natureza e resiliência climática (ROLNIK; CYMBALISTA, 2000). O desafio – em especial aos países emergentes - reside em criar sistemas e regulamentações que também alcancem essa população, conectando esses territórios periféricos às áreas urbanas formais e estruturadas.

O que fazer:
Nesse contexto de desenvolvimento historicamente desigual, as decisões de planejamento urbano e uso do solo devem não apenas apoiar a valorização ambiental, mas também enfrentar as injustiças socioambientais reproduzidas no espaço urbano. Portanto, as soluções circulares devem ser planejadas de forma a beneficiar todas as classes sociais e garantir espaços adaptativos e resilientes. Isso implica em adotar uma abordagem sistêmica para questões urbanas que aproveite ao máximo os recursos locais, como água e energia, promova a produção local de alimentos e melhore a qualidade de vida em áreas informais, fornecendo serviços essenciais, como saneamento básico, áreas verdes, transporte público e moradia.

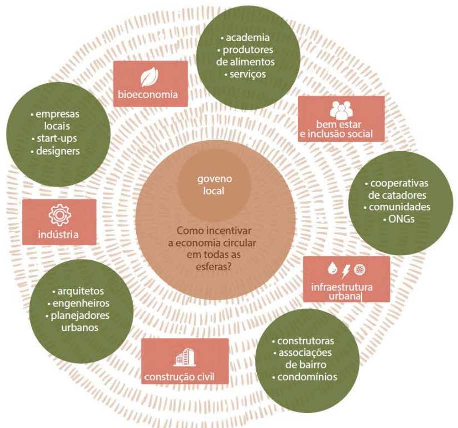
Como fazer:

1. Abordagem unificada
A visão de economia circular deve ser adotada pela cidade como um todo, promovendo uma abordagem unificada do governo que envolva diversas entidades responsáveis pela formulação de politicas de economia circular. A transição para a EC deve abranger várias secretarias, agências e departamentos municipais relevantes e ser validada externamente por meio da participação da sociedade civil, incluindo empresas, associações, comunidades e universidades, por meio de sessões abertas, mesas de diálogo e consultas públicas. A educação também desempenha um papel crucial para o sucesso da transição, capacitando as pessoas a compreender os princípios da economia circular, promovendo a conscientização e o engajamento da comunidade, contribuindo

2. Esforços multisetoriais e colaboração entre atores
A participação de diversas partes interessadas na elaboração da visão é essencial para envolver e capacitar diferentes atores, orientar a estruturação do plano de ação e garantir o sucesso da implementação. Isso exige esforços multissetoriais e colaboração entre os diferentes setores e departamentos municipais, bem como com outros atores envolvidos.

3. Equidade, acessibilidade e diversidade sociocultural
As comunidades em áreas urbanas circulares devem se comprometer a promover a equidade e a acessibilidade para todos os seus habitantes. Além disso, a diversidade sociocultural presente nessas comunidades deve ser valorizada, buscando agregar valor financeiro e estimular a inovação como parte integrante de sua visão de desenvolvimento para enfrentar o status quo linear vigente.

4. A governança desempenha um papel fundamental na promoção desses princípios e na garantia de que as políticas, regulamentações e ações urbanas estejam alinhadas com a construção da economia circular em comunidades fortes, igualitárias e justas. Uma governança sólida pode ajudar a traduzir essas intenções em práticas eficazes, garantindo a participação democrática, a distribuição equitativa de recursos e o cumprimento dos princípios de igualdade e justiça em todas as áreas da vida urbana.



Fonte: Ideia Circular, 2022.

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Links descendentes: [16] Governança e participação pública. [17] Equidade e acessibilidade. [18] Saúde e bem-estar da população. [19] Valorização sociocultural. [20] Valor financeiro agregado. [21] Inovação.