CLIC

Circular models Leveraging Investments in Cultural heritage adaptive reuse

D2.6

EU-policy oriented publication defining a European circular city / territory model of sustainable development through adaptive reuse of cultural heritage

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The circular city model: conceptualization and tools

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Abstract

The challenge today is to reduce poverty and inequalities, while preserving the vitality of natural ecosystems and ensuring inclusive economic growth and wellbeing, both now and in the future, thus including future generations. In this period of growing unsustainability (worsened by the COVID-19 pandemic) that we are living today, a new equilibrium [1] and a change of the way in which the human being lives, produces and consumes are required.

Cities can play a key role in facing this challenge but, to achieve this objective, we are called and "forced" to transform and plan cities in a different way than we have done so far. So, new urban development models are required.

In this framework, the circular city model is proposed in this contribution as urban development model able to produce multidimensional benefits, that is economic, environmental, social benefits. Today there are many cities that are defining themselves as "circular city" but, to date, a clear definition of this does not exist. Furthermore, in the transition towards the circular city, tools (such as evaluation, governance, financial, business tools) play a fundamental role.

This contribution aims to investigate the concept of the circular city and, starting from scientific literature and reports of concrete experiences, to analyze tools (in particular evaluation tools) for implementing this model and assessing (positive and/or negative) impacts that it is able to produce in the brief, medium and long term.

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1 Description of the Project

The overarching goal of CLIC trans-disciplinary research project is to identify evaluation tools to test, implement, validate and share innovative "circular" financing, business and governance models for systemic adaptive reuse of cultural heritage and landscape, demonstrating the economic, social, environmental convenience, in terms of long lasting economic, cultural and environmental wealth.

The characteristics of cultural heritage and landscape pose significant challenges for its governance. Cultural heritage is a “common good”, which enjoyment cannot be denied to citizens, although many buildings and landscape structures are privately owned. Furthermore, the large economic resources needed for recovery and maintenance of heritage goods are rarely available to the private owner, often charged of the additional cost of non-use due to limited degree of transformation allowed. The existing governance arrangements currently involve limited stakeholders concerning for the historic, aesthetic or religious sociocultural values, severely restricting the use of the heritage properties, and charge the central government of conservation costs. The approach of regulatory and planning tools throughout European countries has been to preserve cultural heritage by preventing transformation of buildings or areas having historic-cultural significance.

“The current monument-based, full protection, and government-financed approach that restricts the use of protected properties and relies almost entirely on public funds is incapable of tackling the vast urban heritage of most communities and of sustaining conservation efforts in the long term” (Rojas, 2016). To turn cultural heritage and landscape into a resource, instead of a cost for the community, the structures of authority, institutions and financial arrangements should be adjusted to ensure larger stakeholders’ involvement in decision-making, attract private investments and facilitate cooperation between community actors, public institutions, property owners, informal users and producers (Rojas, 2016). The risk is that without financing channels the decay of European heritage and landscape will increase, until its irreversible loss.

Flexible, transparent and inclusive tools to manage change are required to leverage the potential of cultural heritage for Europe, fostering adaptive reuse of cultural heritage / landscape. Tools for management of change should consider costs and benefits at the local level and for all stakeholders, including future generations, and should take into account the cultural, social, environmental and economic costs of disrepair through neglect, compared to the benefits obtained through diverse scenarios of transformation / integrated conservation.

Costs and values of cultural heritage adaptive reuse have to be compared in a multidimensional space: the relationship between costs and “complex values” influences the willingness to invest in the functional recovery of cultural heritage and landscape. Therefore, it is necessary to clarify what is intended for the value of cultural heritage. The higher the perceived value for potential actors, the higher the willingness to take the risk of investment. This “complex value” of cultural heritage depends on the intrinsic characteristics, but also from extrinsic (context) characters.

Investment costs are related to the materials, technologies and techniques to be used to preserve the cultural value of the heritage / landscape, and to maintenance / management / operating costs. The willingness to invest, the same value done, increases with the reduction of costs. Then, the social cost of abandonment – and eventual irreversible loss of heritage – must be included in the investment choice.

The investment gap in cultural heritage and landscape regeneration can be addressed through careful evaluation of costs, complex values and impacts of adaptive reuse, providing critical evidence of the wealth of jobs, social, cultural, environmental and economic returns on the investment in cultural heritage.

1.1 CLIC Specific objectives

The scopes of CLIC project will be achieved through a set of specific, measurable, achievable, realistic and time-constrained (SMART) specific objectives:

Objective 1 - To synthesize existing knowledge on best practices of cultural heritage adaptive reuse making it accessible to researchers, policy makers, entrepreneurs and civil society organizations, also with direct dialogue with their promoters;

Objective 2 - To provide a holistic ex-post evaluation of the economic, social, cultural and environmental impacts of cultural heritage adaptive reuse, stressing on the importance of appropriate conservation and maintenance approaches able to highlight the integrity and authenticity of heritage;

Objective 3 - To provide EU-wide participated policy guidelines to overcome existing cultural, social, economic, institutional, legal, regulatory and administrative barriers and bottlenecks for cultural heritage systemic adaptive reuse;

Objective 4 - To develop and test innovative governance models and a set of evidence-based, participative, usable, scalable and replicable decision support evaluation tools to improve policy and management options/choices on cultural heritage systemic adaptive reuse, in the perspective of the circular economy;

Objective 5 - To analyse hybrid financing and business models that promote circularity through shared value creation, and assess their feasibility, bankability and robustness for cultural heritage adaptive reuse;

Objective 6 - To validate the CLIC circular financing, business and governance practical tools in 4 European cities / territories representative of different geographic, historic, cultural and political contexts;

Objective 7 - To contribute to operationalise the management change of the cultural landscape also in implementing the UNESCO Recommendation on Historic Urban Landscape;

Objective 8 - To re-connect fragmented landscapes, through functions, infrastructures, visual relations at macro and micro scale;

Objective 9 - To design and implement a stakeholders-oriented Knowledge and Information Hub to make tools and information accessible, useful and usable and test them with policy-makers, entrepreneurs, investment funds and civil society organizations;

Objective 10 - To contribute to the creation of new jobs and skills in the circular economy through cultural heritage adaptive reuse, boosting startups and sustainable hybrid businesses and empowering local communities and stakeholders through public-private-social cooperation models.

Objective 11 - To contribute to the monitoring and implementation of SDGs (especially Target 11.4) and the New Urban Agenda, creating operational synergies with global initiatives of UN-Habitat, UNESCO/ICOMOS and the World Urban Campaign.

All partners have wide experience in developing and testing CLIC proposed tools, ensuring the effective and time-constrained achievement of all the above-mentioned specific goals. The integration of sectorial knowledge, tools and methods will be achieved through a trans-disciplinary approach promoting partners and stakeholders' cooperation, co-creation of knowledge and co-delivery of outcomes.

The expected impacts of the project are the following:

- Validation of integrated approaches and strategies for cultural heritage adaptive re-use, comprising innovative finance with high leverage capacity, business models and institutional and governance arrangements that foster multi-stakeholder involvement, citizens' and communities' engagement and empowerment;

- New investments and market opportunities in adaptive re-use of cultural heritage, also stimulating the creation of start-ups;

- An enabling context for the development and wide deployment of new technologies, techniques and expertise enhancing industrial competitiveness and contributing to economic growth, new skills and jobs;

- Innovative adaptive re-use models that are culturally, socially and economically inclusive;

- Contribution to implementing the Sustainable Development Goals (SDGs) (Goals 1, 15, 11 particularly) and the United Nations New Urban Agenda.

2 Introduction

Cities cover 3% of the earth's surface and are home to more than half of the world's population (www.metabolic.nl), consume 78% of the world's energy, produce more than 60% of greenhouse gas emissions and 50% of global waste (www.un.org). Considering these data, it is clear that cities play a key role in achieving (or not) sustainable development and in fighting the challenges of our time (climate change, social inequality, environmental crisis, economic crisis). Many researches and studies are demonstrating that human activities are producing polluting substances [2–4] that are contributing to climate changes with negative impacts on the air, land, sea, weakening also the immune system and making people prone to diseases (as that due to COVID-19 pandemic) [5].

The paradigm shift towards a more humanistic and ecological paradigm evoked by United Nations (§§ 15, 24, 25 of the New Urban Agenda) [6] and by the European Commission (EC) (in the European Green Deal) [7] is increasingly required in this period of growing unsustainability. Furthermore, the health emergency due to the COVID-19 confirmed (and is still confirming) the need to move towards this new paradigm, requiring a new balance between natural and man-made ecosystems. It has highlighted that “people and nature are interlinked” and thus the necessity to “resew” the “humanity's broken relationship with nature” [8].

The pandemic due to COVID-19 has produced negative impacts not only in terms of disease and illness but, as highlighted by the General Director of World Health Organization (WHO), it has revealed today's inequalities, injustices and contradictions, highlighting strengths and vulnerabilities of our society [9].The crisis due to the pandemic has also demonstrated that the ecological, economic and social dimensions are interconnected and dividing them has been a great mistake. This leads us to rethink the processes of the current economy, linking them more closely to those of ecology and society. People's health has to be also interrelated with the health of the ecosystem and the “health” of the economy (that is an economy characterized by a positive evolutionary dynamic able to generate and/or regenerate, and conserve value over time).

This necessary requires a new equilibrium [1] and a change of the way in which the human being lives, produces and consumes.

2.1 Document structure

The document is structured as follows: after the overview of the circular economy concept (sections 3; 3.1), the benefits from the implementation of this model are analyzing starting from empirical evidence (section 3.2). The circular city model is then investigated both in terms of conceptualization and tools (sections 3.3; 3.4), focusing the attention on the role that cultural heritage can play in triggering circular processes (section 4). The attention is focused on the implementation tools for this urban development model and, in particular, on impact indicators for evaluating the circular city (section 5).

3 From linear to circular economy

As a response to the challenges linked to climate changes, environmental degradation and socio-economic crisis, the European Union (EU) has approved a number of documents to promote measures to make our country more sustainable.

In particular, the EU recognizes the role that cities played in achieving a more sustainable future, as highlighted also by the United Nations in the 2030 Agenda and in the New Urban Agenda [6,10].

In 2016, the EU has adopted the principles, the commitments and the actions of the New Urban Agenda approving the Pact of Amsterdam [11]. This document identifies 12 challenges which our cities are called to face. These challenges are linked to the following themes: inclusion, air quality, urban poverty, housing, circular economy, employment, adaptation to climate change, energy transition, sustainable land use and nature-based solutions, urban mobility, digital transition, innovative and responsible public procurement. Therefore, the Pact of Amsterdam considers, among its priorities, the “circular economy” and the “sustainable use of land and nature-based solutions” as two important themes that will guide actions of the EU Urban Agenda for a smart, sustainable and inclusive growth.

In December 2019, the European Commission (EC) approved the European Green Deal [7]. It is a “new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU’s natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. At the same time, this transition must be just and inclusive. It must put people first, and pay attention to the regions, industries and workers who will face the greatest challenges” [7].

3.1 The circular economy model

The current economy can be largely considered as linear: virgin materials are taken from nature and used to produce goods, which are then consumed and eventually disposed of. In a world characterized by finite resources, this model cannot work in the long run, and there are evidences that it is reaching its limits.

We need to move towards a more virtuous economic model and, at the moment, we are only at the beginning of this way.

The circular economy model, based on the principle that nothing in nature is waste and everything can become a resource [12], aims to make the principles of sustainable development operational. The circular economy can be defined as “the restructuring the industrial systems to support ecosystems through the adoption of methods to maximize the efficient use of resources by recycling and minimizing emissions and waste" [13]. Reference is made to how resource flows can be closed [14]. Through circular economy processes, inputs are minimized and, at the same time, outputs are maximized, preserving as long as possible the value of the resources [13]. In this model the value of products, materials and resources is maintained in the economy for as long as possible and waste are minimized.

The circular economy concept originates in ecological and environmental economics and industrial ecology. The purpose of the closing the cycles (production of cycles), formulated for the first time in 1971 by Barry Commoner in The Closing Circle [15], is fundamental in the definition of the ecological paradigm, but has found only partial concretization today. One of the solutions to the challenges of our time is the implementation of models characterizing the natural systems that offer efficient management, production and consumption models [16].

The concept of the circular economy can be also brought back to Kenneth Boulding's work that deals with the limited natural resources available for human activities and Georgescu-Roegen's work on "thermodynamics in economic systems dictating matter and energy degradation from 1971" [17,18].

To date there are 114 definitions of circular economy existing in literature [19]. The United Nations have introduced in the Goal 12 of the 2030 Agenda [10] and in paragraphs 71-74 of the New Urban Agenda [6], the final document of the Habitat III conference (October 2016), the notion of circular economy as a general development model that produces impacts on natural and social systems, while generating economic wealth. This stimulates an indefinite extension of the life of the resources and their use values and promotes cooperation circuits between the different actors.

The European Commission has adopted a package for supporting the European Union's transition to the circular economy, including legislative proposals aimed at stimulating the European route towards the circular economy [20]. The objective of this package is to boost economic growth, making it more sustainable and competitive in the long term. It considers the circular economy as a means of contributing to innovation, growth and job creation [20].

According to the Ellen MacArthur Foundation's definition, the circular economy, that provides multiple value-creation mechanisms, is based on three principles: preservation and enhancement of natural capital; optimization of resources by circulating products, components, and materials; fostering system effectiveness by revealing and designing out negative externalities [12]. The Ellen MacArthur Foundation also identifies six business actions to support the aforementioned three principles: regenerate, share, optimize, loop, virtualize, exchange [12].

The circular economy model, not intended in a limited sense (that is strictly linked to waste management or the use of renewable energy sources) and therefore by expanding its field of action, can contribute to reduce the trade-off between environmental health, community health and economic "health". The circular economy model can be assumed as a way for re-integrating the economy into ecology [21].

In the general interpretation, a circular economy is mainly referred to the waste cycle management. However, this approach should be overcome and transferred from a sectorial approach (waste management) to the comprehensive city organization, its economy, its social system, its governance in order to improve urban productivity [22–25]. It can be recognized as a general development model, able to turn the linear urban metabolism into a new urban circular metabolism, in which input and output flows are "closed". The circular economy produces sustainable growth, good health and decent jobs and, at the same time, is able to save the environment and its natural resources.

The circular economy offers a great opportunity to increase urban productivity and to date there are some good practices of circularization of processes at different scales (industrial symbiosis, etc.) in which some benefits from the implementation of circular processes are achieved: reduction of materials and energy costs, reduction of carbon emissions, etc. [26].

The concept of circular economy can be implemented in the cities in order to achieve a sustainable development. Today there are many cities that are defining themselves as a "circular city". But what is a circular city? This concept is investigate in the following paragraphs.

3.2 Benefits from circular economy implementation: empirical evidence

Before analyzing the circular city concept and concrete experiences, it is important to underline that the circular economy has born in port areas, in particular through the implementation of the industrial symbiosis [14].

The symbiosis represents a means to create and multiply relationships and bonds at different levels. Thanks to the density of relationships that the symbiosis is able to generate, it makes the system more resilient, more efficient and less dissipative, improving its regenerative capacity [27].

The industrial symbiosis is a business model, based on sharing by-products improving resource efficiency and creating value from waste, for circular economy implementation [28–30]. Symbiotic processes play a crucial role in stimulating new circuits of value creation [27]. There are many good practices of industrial symbiosis in port cities that have demonstrated the economic, social, environmental and cultural benefits of these processes.

Three successful experiences of industrial symbiosis, showing empirically that connecting enterprises produces positive impacts in economic, social and environmental terms, are [28–30]:

- Kalundborg (Denmark);

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– Kawasaki (Japan);
– Dunkirk (France).

The aforementioned three experiences (summarized in the following paragraphs) demonstrate that symbioses/synergies/cooperation produce economic, social, and environmental benefits.

3.2.1 Empirical Evidence from Kalundborg, Denmark

Kalundborg is a Danish city with a population of 16,523, the main town of the municipality of the same name. It is situated on the northwestern coast of the Zealand island, on the opposite side from Copenhagen.

The Kalundborg industrial cluster in Denmark is one of the most famous examples of industrial symbiosis and it is often used as a reference case in literature [31–33]. Kalundborg Eco-Industrial Park is an industrial symbiosis network situated in Kalundborg (Denmark) in which companies collaborate to use each other's by-products and share resources (Table 1 and Table 2).

Symbiosis in Kalundborg is the strategy adopted by local companies to face the challenge of guaranteeing businesses survival and expansion despite a limited supply of groundwater. The creation of the pipeline bringing water from the lake to the local refinery involved several stakeholders in the area that have started of a long-term collaboration. The pipeline represents a key component of the network.

Table 1 - Kalundborg Eco-Industrial Park: an overview

Kalundborg, Denmark—Eco-Industrial Park
First output-input exchanges: 1961 **Geographical scale of cooperation:** Kalundborg **Nature of eco-industrial transactions:** Output-input exchanges: energy, water, and waste materials **Network members:** 8 partners **Denomination:** Kalundborg Symbiosis Centre **Creation:** 1996 **Founders:** Industrial partners and the Kalundborg municipality **Mission:** statement to educate and build new partnerships (encouraging, facilitating, and managing eco-industrial interactions)

Table 2 - Impacts of Kalundborg industrial symbiosis

Indicator	Data
Number of partners linked by commercial agreements exchanging output-input (2015)	8 (7 private industrial companies and the local government of Kalundborg)
Number of output–input exchanges (n. of symbioses) (2015)	30
Number of different resource streams exchanged	25
Amount of internal resources combined (number)	5000
Annual economies generated from transforming waste into valuable resources and reducing pollution and materials consumption	€80 million/year
Socio-economic benefits produced every year connecting enterprises	14 mill /year (Enough to buy 354 brand new electric powered cars)
Euros saved on the bottom line annually connecting the enterprises	24 mill/year (Equivalent to having 252 academics employed for a year)
Annual reduction in CO_2 equivalent emissions thanks to the partnerships	635,000 tons/year
Environmental impact saving—CO_2 after 30 years	175,000 tons/year
Environmental impact saving—SO_2 after 30 years	10,200 tons/year
Water saved thanks to recycling and reuse (2010)	3 mill m^3
Amount of gypsum produced from desulfurization of flue gas that replaced natural gypsum	150,000 tons/year
Amount of oil consumption yearly reduced thanks to 19 synergies	20,000 tons/year
Amount of gypsum consumption reduced thanks to 19 synergies	200,000 tons/year
Amount of the water consumption reduced thanks to 19 synergies	2.9 mill m^3/year
Resource saving—gas after 30 years	45,000 tons/year
Resource saving—coil after 30 years	15,000 tons/year
Resource saving—water after 30 years	600,000 m^3/year
Waste reuse—ash for cement industry after 30 years	130,000 tons/year
Waste reuse—gypsum for plasterboard products for the construction industry after 30 years	90,000 tons/year
Waste reuse—solid biomass used by 600 farms as fertilizer after 30 years	150,000 m^3/year
Employment (number of jobs)	Gyproc 165 Asnaes Powe Station 120 Statoil Refinery 350 RGS90 65 Novo Nordisk Kalundborg 3,500 employees
Number of employees in Kalundborg Symbiosis	Over 5000

Data source: [34]

3.2.2 Empirical Evidence from Dunkirk, France

Dunkirk is a town located in the north of France. It is the fifth most populated town in the "Hauts-de-France" region (88,000 inhabitants in 2016).

Dunkirk is located in an area where there are numerous heavy industries (from metalworking to energy production etc.) which for decades have produced negative impacts on the environment (so it is an area with high levels of pollution). In this context, Ecopal (association of Economy and Ecology Partners in Local Action), one of the first associations dedicated to industrial ecology in France, plays an essential role [35–38] (Table 3 and Table 4). The Ecopal was created in 2001 for promoting and encouraging, through pooling services assistance, industrial ecology and industrial symbiosis in Dunkirk [36].

Table 3 - Ecopal Dunkirk: an overview

Dunkirk, France—Ecopal
Network members: 101 members (mostly Small and Medium Enterprises) (in 2016) **Denomination:** Ecopal **Creation:** 2001 **Founders:** Local companies (bottom-up logic) and local public institutions **Mission:** To ensure local sustainable development by promoting the concept of industrial ecology through concrete and fruitful projects

Table 4 - Impacts of Ecopal

Indicator	Data
Amount of flows (raw materials, energy, waste, by-products, sludge and sewage, and unavoidable energy) inventoried from 147 companies (from 2007 to 2009)	5000
Amount of opportunities for cooperation affecting 55 companies (number of synergies)	30
Number of enterprises involved in synergies related to reuse of water	20
Number of firms that exchange by-products like scrap, steel slag, refractory bricks, steel mill dust, acid waste, tires, solvents, animal feed and used oil (2018)	14
Euros saved thanks to 60 shared collections every year	210,000 €/year
Percentage of saving on waste-management bills for each participant thanks to 60 shared collections every year	20%
Money saved from each enterprise annually	4800 €/year
CO_2 emission avoided thanks to 60 shared collections every year	45 tons/year
Amount of CO_2 emissions avoided in 10 years	230 tons
Amount of industrial residues managed from 60 shared collections every year	430 tons/year
Amount of drinking water yearly saved	130,000 m^3/year
Number of employees (2011)	57,000
Number of industries promoting industrial ecology	Over 200

Data source: [35–39]

3.2.3 Empirical Evidence from Kawasaki, Japan

Kawasaki is a city located in Tokyo metropolitan area (Japan). With a population of 1.42 million (2016), it is the ninth most-populous city in Japan. Kawasaki plays a central role in the Tokyo Bay area, where there are clustered heavy industries. Kawasaki was one of the first Japanese cities to initiate an Eco-Town Project [40,41]. Their project was approved in 1997 and the government has made an investment of 25 billion JPY. The government has funded six waste-recycling facilities to promote and encourage the exchange of by-products. The challenge at the basis of the implementation of Industrial Symbiosis in Kawasaki was the necessity of the municipality to find a solution to dispose of municipal solid waste in a sustainable way while enhancing the local economy [32] (Table 5 and Table 6).

Table 5 - Kawasaki Eco-Town: an overview

Kawasaki, Japan—Eco-Town
Geographical scale of cooperation: Kawasaki **Nature of ecoindustrial transactions:** Output-input exchanges in main industries of steel, electronics, communication, machinery, oils, chemistry, information, service **Denomination:** Kawasaki Eco-Towns **Creation:** 1997 **Founders:** municipality, supported by the Ministry of Environment and the Ministry of Economy, Trade and Industry **Mission:** to find a solution to dispose of municipal solid waste in a sustainable way enhancing at the same time local economy

Table 6 - Impacts of Kawasaki Eco-Town

Indicator	Data
Number of documented symbioses connect steel, cement, chemical, and paper firms and their spin-off recycling businesses	14
Economic advantage from industrial symbiosis activities involving the steel sector	6.74 mill €/a
Economic opportunity generating from waste diverted from incinerator and landfill thanks to 7 key material exchanges (565 kt)	130 million USD/year
Coal saved thanks to industrial symbiosis activities involving the waste-processing sector	9.1 kt/a
Limestone saved thanks to industrial symbiosis activities involving the waste-processing sector	55 kt/a limestone saved
Percentage of reduction in CO_2 emission due to the reduction of waste and by-products through industrial symbiosis (2017)	13.8%
Total carbon emissions reduction through industrial and urban symbioses	4.26 Mt CO_2e
Amount of waste deverted from incinerator and landfill thanks to 7 key material exchanges	565 kt
Reduction in the physical value of material use due to industrial and urban symbioses	6.4%
Emergy decresase due to industrial and urban symbioses compared to the case without industrial and urban symbioses	49%
N. of workers in Mizue-Town, Kawasaki Ward	About 400

Data source: [40,42,43]

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3.3 The circular city model

The urban organization and transformation model are recently increasingly investigated and questioned. The urban development strategies should place the human being at the centre of its processes, and thus his health and wellbeing, considering that the human right to the highest attainable standard of health is recognized by the Charter of the United Nations [44].

The challenge today is to reduce poverty and inequalities, while preserving the vitality of natural ecosystems and ensuring inclusive economic growth and wellbeing, both now and in the future, thus including future generations. Considering the changes and challenges cities are facing today, we are called and “forced” to transform and plan cities in a different way than we have done so far. So, new urban development models are required in order to implement the aforementioned paradigm shift and to move towards a more sustainable world.

In this perspective the circular city model is proposed. To date, a unique definition does not exist. There are many interpretations and definitions of the circular city, both in scientific literature and in reports by public and private bodies and cities that are implementing this model (Table 7).

Table 7 – Definitions of circular cities

Definitions of circular city	
Source	**Definition**
Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2015)	A circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative, accessible and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. A circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while aiming to decouple the creation of value from the consumption of finite resources. A circular city will likely include the following elements: – A built environment that is designed in a modular and flexible manner, sourcing healthy materials that improve the life quality of the residents, and minimise virgin material use. It will be built using efficient construction techniques, and will be highly utilised thanks to shared, flexible and modular office spaces and housing. Components of buildings will be maintained and renewed when needed, while buildings will be used where possible to generate, rather than consume, power and food by facilitating closed loops of water, nutrients, materials, and energy, to mimick natural cycles. – Energy systems that are resilient, renewable, localised, distributed and allow effective energy use, reducing costs and having a positive impact on the environment. – An urban mobility system that is accessible, affordable, and effective. A multi-modal mobility structure that will incorporate public transportation, with on-demand cars as a flexible last-mile solution. Transportation will be electric-powered, shared, and automated. Air pollution and congestion will belong in the past, and excessive road infrastructure will be converted to serve other needs of citizens. Central to vehicle design will be remanufacturing, durability, efficiency and easy maintenance. – An urban bioeconomy where nutrients will be returned to the soil in an appropriate manner, while generating value and minimising food waste. Nutrients could be captured within the

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	organic fraction of municipal solid waste and wastewater streams, and processed to be returned to the soil in forms such as organic fertiliser – used for both urban and rural agriculture. Through urban farming, the city will be able to supply some of its own food, reusing food waste and sewage in closed and local loops to produce vegetables, fruit, and fish. Such a system could also provide a more resilient, diversified and cost-effective energy system in the city through the generation of electricity from wastewater, biofuels and biorefineries. These will offer additional revenue streams to the city, capitalising on the utilisation of material and nutrients that are already in use. – Production systems that encourage the creation of 'local value loops'. This means more local production, and increased and more diverse exchanges of value in local economies. Maker-labs (to encourage local production, repair, and distributive manufacturing), collective resource banks (to even out the demand and supply of materials) and digital applications (to broker the exchange of goods, materials, and services) would feature in these local, circular production systems.
World Economic Forum (2018)	A circular city embeds the principles of a circular economy across all of its functions, establishing an urban system that is regenerative and restorative by design. In such a city, the idea of waste is eliminated, with assets kept at their highest levels of utility at all times and the use of digital technologies a vital process enabler. A circular city aims to generate prosperity and economic resilience for itself and its citizens, while decoupling value creation from the consumption of finite resources. Seven principles in the transition towards a circular economy can be identified starting from circular Amsterdam. These principles can be extended to define a vision and an action roadmap on circularity in cities: – Closed loop, all materials enter into an infinite cycle (technical or biological); – Reduced emissions, all energy comes from renewable sources; – Value generation, resources are used to generate (financial or other) value; – Modular design, modular and flexible design of products and production chains increases adaptability of systems; – Innovative business models, new business models for production, distribution and consumption enable the shift from possession of goods to (use of) services; – Region-oriented reverse logistics, logistics systems shift to a more region-oriented service with reverse-logistics capabilities; – Natural systems upgradation, human activities positively contribute to ecosystems, ecosystem services and the reconstruction of "natural capital". A circular city encourages the use of systems thinking to provide economic, social and environmental benefits for its citizens, while also looking to improve the quality of life.
www.argoit.com www.forumpa.it	Circular cities are sustainable and competitive cities that move from a linear economic model (in which life cycle of goods is "take-make-dispose") to an alternative model, whose key word is "reuse" (that is, a "circular economy"). In general, a circular city is a city that becomes rational in the use of energy, in the use of greenery and urban gardens. It is a city that valorizes all that can give quality to the environment, while promoting an increasingly qualified employment.
www.citiesintransition.eu	The Circular City is where we manage waste, commodities and energy in smarter and more efficient ways. What can we expect from a circular approach? Less pressure on our environment, new business models, innovative designs and new alliances and cooperation between different stakeholders.
www.ucl.ac.uk	Circularity in resource flows in cities can tackle the consumption of resources, such as energy, water, buildings and land.

www.circularcitieshub.com	Systems integration, flexibility, intelligence, cooperative behaviour, localisation, recycling and renewable resources are the key concepts under-pinning the Circular City. In a circular city: resources can be cycled between urban activities; resources can be cycled within city regions; cities can be designed so that land and infrastructure can be re-used/recycled over time.
Koenders and de Vries (2015)	The circular city is a metaphor for a new way of looking at the city and of organizing it. The idea is that linear processes in the circular city, from extraction to waste can be (partly) replaced by circular processes and that lasting connections can be made between flows. A circular society is less dependent on the import of scarce and precious resources and at the same time the negative effects of production and consumption will be limited.
Marin and De Meulder (2018)	It seems evident that a circular city should include more than the sum or multiplication of urban circular economies. They conceal transition drivers leading to varying circularity interpretations. However, even though circular city representations spatialize specific sustainability framings and the associated ideological positions, these framings generally remain unarticulated, creating confusion about the imaginaries' statuses. On one hand, certain images appear to be mere celebrations of technological progress, proposing generic solutions, such as green roofs and facades. On the other end of the spectrum, images not necessarily claiming to articulate circularity, integrate nature, culture, and society in place-specific circular configurations. Different ustainability framings exist for "circular cities" as well as potential drivers defining circularity.
Prendeville *et al.*, 2018	Cities are first-and-foremost places for people and their sustainable futures. In any conceptualization of a circular city these issues require consideration. According to EMF, the circular city is the city based on the following circular economy principles: Regenerate, Share, Optimize, Loop, Virtualize and Exchange. In addition, urban sustainability is about resilience and livability beyond the city's infrastructure and technology. In light of this, the concept a circular city can be seen as an element in the larger goal of developing a future-proof city. This means that a circular city is a city that practices CE principles to close resource loops, in partnership with the city's stakeholders (citizens, community, business and knowledge stakeholders), to realize its vision of a future-proof city.
Sukhdev *et al.*, 2018	A circular city embeds the principles of a circular economy across all its functions, establishing an urban system that is regenerative and restorative by design. These cities aim to eliminate the concept of waste, keep assets at their highest utility at all times, and are enabled by digital technology. A circular city aims to generate prosperity and economic resilience for the city and its citizens, while decoupling this value creation from the consumption of finite resources.
Williams, 2021	A circular city is a socio-ecological system, consisting of a bio-geo-physical unit and its associated social actors and institutions. It is a complex, regenerative and adaptive system, delimited by spatial and functional boundaries, surrounding an ecosystem. There are three actions fundamental to both a circular city and circular development: – Looping actions (reuse, recycling and energy recovery) – a circular city is an open system with many linear processes; however, where possible these processes will be closed. This reduces waste and promotes the most efficient use of resources. Examples include waste-heat recovery systems; food-reuse cafes; bio-refineries, grey-water recycling systems; adaptive reuse of buildings and land reclamation.

	– Ecologically regenerative actions – regenerate the urban ecosystem and ecosystem services. Ecologically regenerative actions are often operationalized through the inclusion of green and blue infrastructure (e.g. permeable surfaces, reed-beds, retention ponds, green roofs) into the urban fabric or the management of urban ecosystems (e.g. conservation, farming, forestry). – Adaptive actions – build capacity within the urban fabric and communities to adapt to change. Capacity is built through the use of flexible design, collaborative planning, co-provision and systems for learning.

Source: Author's elaboration starting from different sources

The circular city model can be able to reduce CO2 emissions by 55% by 2020, to make themselves natural gas-free by 2040, to use renewable energies, to recycle all waste, and to maintain existing built heritage by taking all materials from the demolition of old buildings [45].

There are many cities that are moving in this direction. Amsterdam, London and Paris have been the first cities to self-identify as circular cities and to express their willingness to adopt a circular approach to their urban development. They were then followed by other cities such as Rotterdam, Glasgow, Copenhagen, Brussels, Ljubljana, Maribor, Marseille, Oslo, etc. In addition, some cities, such as Stockholm, are adopting a circular behavior, despite not having an official circular strategy.

Many of these experiences confirm the benefits produced by adopting circular development strategies. There are referred to economic, environmental and social dimensions. For instance, reusing and recycling materials from construction sector contribute to the reduction of waste, material and energy consumption. Moreover, for example, it is estimated that this action would save 500,000 tonnes of materials per annum. The use of abandoned or under-used soil and properties also contributes to limit soil consumption (as in the experiences of Paris and Amsterdam). The circular city produces ecological benefits, as well as "healthier, more adaptive living environments, a more diverse economic base with a range of jobs, greater community engagement and social solidarity" [46]. However, these benefits are not equally distributed throughout the population, thus producing social inequalities [46].

The circular city model is conceptualized in different way across the different experiences. For example, while in London there is a more economic conceptualization of the circular city model, in Paris and Stockholm it is more holistic. Furthermore, in Paris and Amsterdam, the territorialization of this model emerges more clearly. Also in operational terms, concrete experiences highlight different pathways for implementing the circular city model: city-regional, eco-district and temporary-experimental pathways [46]. So, each city is implementing the circular strategy differently. Some of them are focused on strict implementation of circular economy principles, such as actions linked to the RESOLVE framework [12]. Other cities are focusing on circular business models (such as London) or industrial symbioses (such as Rotterdam). Still others, instead, are adopting more holistic approaches (such as Paris). However, there are also commonalities in the strategies of these cities, in particular around four resources flows: organic waste, construction waste, grey- and waste-water [46].

The circular city is a metaphor for a new way of looking at the city and of organizing it. The circular city model recognizes the importance of organizing the city's systems in analogy to the organization of natural systems (where “nothing is waste”). It incorporates the principles of the circular economy, establishing an urban system that is regenerative and accessible [12,47], but it is not a simple sum of urban circular economy projects [48,49]. The closure of loops is a fundamental concept at the basis of such city: linear processes are turned into circular ones. In fact, the idea is that in the circular city linear processes can be (partly) replaced by circular processes and that long-term connections can be established between flows [50]. These flows (i.e. people, food, waste) are at the basis of the city’s metabolism that represents the engine for the functioning of the city and its economy [50,51]. A circular approach makes cities independent, rich, and resilient [12,52–54].

According to Williams (2021), “creation of circular resources flows, support natural cycles, enable the city to renew (or recycle itself)” are three circular processes at the basis of the theoretical conceptualization of the circular cities.

The idea of eliminating (or at least minimizing) waste and the rational and efficient use of energy are highlighted in many definitions [50,52,55–62].

Sukhdev et al. (2018) [56] underline the role of digital technology to enable the circular city. It is also highlighted in some circular city reports, such as those of the cities of Glasgow, Rotterdam, Amsterdam [53,54,63–65]. The adjective “smart” recurs several times in circular city reports (in particular in those of Amsterdam and Rotterdam) in relation to the implementation of the circular city model. This adjective is intended exclusively with reference to the use of technologies (sensors, digital platforms, etc.) [53,54,64,66,67], and not to the wise use of resources.

It is also recognized that the successful transition towards the circular city model requires behavioral changes [54]. There is a need of a change in community lifestyle in order to successfully implement the circular city model. This aspect, although considered in many circular cities, is not highlighted much in their reports, while more and more space is left to the technical aspects of the circularization, to the tangible metabolism.

Flexibility (for example in the built-environment sector), cooperative behavior, integration, recycling are key concepts of the circular city. The greenery and the urban gardens are also recognized as elements for enhancing the environment of the circular city [49,59,68,69];. Furthermore, innovative business models are necessary to implement this new urban model [47,60,66,67].

As Williams highlights (2021), "circular cities are urban systems in which resources are looped, the ecosystem is regenerated and the socio-technical systems (infrastructure and communities) evolve with changing contexts. Thus, circular cities are resource efficient, resilient and operate within the global carrying capacity".

The Ellen MacArthur Foundation recognizes the circular city as a city in which, in particular, the built environment is designed in a modular and flexible manner; energy systems are resilient and renewable, consequently reducing costs and producing positive impacts on the environment; the urban mobility system is accessible, affordable and effective; and the production systems encourage the creation of "local value loops" [12].

The contribution of the circular city model implementation to the quality of citizens' lives [12,47] is little considered in literature, but is underlined several times in the official reports of circular cities, in particular in terms of production of new jobs and new businesses [52–54,64,66,67]. Employment is a key word related also to the wellbeing concept: it contributes to make people "feel good", not only because of economic aspects, but because it lets people be in a relationship with each other [70,71]. In addition, the social benefits are significant. This is demonstrated, for example, by the reuse networks that have arisen around food waste in the cities of London Paris and Amsterdam [46]. The emphasis on social solidarity as a motivation for implementing circular processes differentiates Paris from other circular cities.

The circular city model is also able to produce health benefits, just think for example of the improvement in air quality resulting from blue and green infrastructure.

Most of the definitions of the circular cities focuses their attention on material and energy flows, that is on tangible urban metabolism. The strategic actions are mainly related to the production of goods and services (product design, eco-design and use of eco-compatible materials, eco-compatible production processes, etc.), to the prolongation of the use value of resources (through reuse, repair, etc.) and waste management. They are referred to tangible resources, neglecting the intangible ones. In particular, they are referred to:

- a built environment designed in a modular and flexible way;
- renewable-energy systems and efficient use of energy;
- an accessible, economical, clean and effective urban mobility system;
- recycling and transformation of waste into a resource;
- production systems that encourage local loops closure and waste minimization.

However, as also Williams states (2019), looping actions in circular cities are referred to different themes (and related to different challenges), that are socio-cultural, economic and financial, information, regulatory, political, institutional, technical and design, and environmental. She recognizes that circular-city implementation is an issue related not only to technical questions, but it is related also to a systemic change in society and in restructuring our economy and governance systems.

As emerged from the circular city experiences (particularly in the case of Paris and Antwerp), urban planning plays a fundamental role. It contributes to stimulate circular/virtuous processes at different levels (neighborhood, urban and territorial, between the city and the rural territory) through a systemic approach and evoking the approaches and tools of industrial ecology [14] (strong attention is focused on the analysis of flows between city and territory, urban metabolism, synergistic exchanges between flows of resources possible thanks to spatial/geographical proximity) [72]. Urban planning can therefore significantly contribute to trigger flows of energy, materials, services, people to catalyze economic development (and not only) [54].

The engagement of citizens in urban planning is fundamental [54]. The necessity to engage citizens in urban planning is an element that emerges from the circular city experiences. It is evident, for example, in the city of Antwerp through the Circular South project (www.uia-initiative.eu).

The reuse of unused, abandoned and resulting spaces through urban planning can play a strategic role in the implementation of this new city development model. Their reuse is in line with the principles of circular economy (reducing waste and prolonging the use value of resources) and can also represent the physical space in which to activate new flows (i.e. Amsterdam and Glasgow that start from vacant land and empty building). Therefore, the places of abandonment and marginality play a strategic role, becoming key places for urban transformation/regeneration (in coherence with the "leave no one behind" principle of the Agenda 2030 - understood both in reference to man and to places – and with the New Urban Agenda). From this perspective, the reuse of abandoned real estate assets, unused public assets, and abandoned industrial areas can also be considered.

There are also some "elements" of the city that can play key role in the implementation of the circular city model, as trigger points of flows [22,73]. For example, in the city of Antwerp, the port (one of the largest ports in the European Union) is recognized as a key area for the implementation of this model. It is recognized as the perfect place to apply the principles of the circular economy (www.sustainableportofantwerp.com). The city of Antwerp is greatly investing in the circular economy starting from the port. Here, in fact, with so many companies (operating in different sectors) working in such proximity to each other, there are a lot of opportunities for jointly using sites or reusing a company's by-products and waste as raw materials in another company. Residual heat is transformed into heating, wood chips into biomass and so on. There are many other cities that are recognizing the key role of port in the circular processes implementation (Amsterdam, Rotterdam, Marseille, etc.)

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The municipal administration is a key player to promote the above considerations in urban planning. So, a circular city requires an integrated vision/management of the many existing planning tools at the municipal level.

In order to move towards the implementation of the circular city model, most of the circular cities have, as first step, deeply analyzed their status quo to understand what no circular is in the current economy and if it can be turn into circular organization. It needs to identify, first of all, which “areas/elements” (both in a physical sense and not) can be “used” to activate the circular processes. In the Glasgow experience, for example, the need to construct a flow map of existing flows is highlighted. This refers to the flow of energy, water, biomass, metals. The flows are exclusively material/tangible, excluding the intangible flows.

Each circular city is concentrating their strategies and actions mainly on the sectors in which the material/tangible flows are greater. For example, Amsterdam is focusing on construction chain and organic residual stream chains considering actions related to smart deign, material recycling and reuse. London is concentrating on built environment, food, plastics with attention on reuse, design, minimizing waste. Glasgow is focusing on healthcare, education and manufacturing sectors, implementing actions able, for example, to reduce waste, transforming waste of an activity/industry in nutrients for another one. In the city of Rotterdam the actions are mainly referred to the management of residual material flows of medical, food, clean tech/maritime, construction sectors.

Paris developed a White Paper with 65 circular initiatives in connection with metropolitan planning, identifying strategies and related actions referred to different field, as encourage product eco-design, create new business parks for circular economy, integrate a recoverable energy vision in land planning, create an on-line information platform for the circular economy, reduce the use of disposable packaging, renovate rather than demolish. Most of them are referred to material reuse, using of renewable energy and minimizing waste.

In all the circular city experiences, the relationship between the circular economy and the production of jobs is highlighted, specifying indicators relating to employment (contributions to the SDG no. 8). This highlights the contribution of this new model to the improvement of quality of life. Employment is a key word related also to wellbeing concept: it contributes to make people “feel good”, not only because of economic aspects, but because it let people be in relationship each other.

The adjective “smart” recurs several times in the circular city agendas (in particular in Amsterdam and Rotterdam) in relation to the implementation of this model. This adjective is intended exclusively with reference to the use of technologies (sensors, digital platforms, etc.). ICT and innovative technologies are certainly fundamental tools for the city to become a “circular city”, but they are a mean and not the aim. They are important for the circularization of processes, but they require a strong cultural base – culture –, “mirror” of how people live and work by organizing their behavior in a circular or linear way. The “technological aspect” of the circular city could exclude a part of community from its implementation (for example in relation to the use of technologies such as sensors, digital platforms, etc. not easily accessible and usable by everyone – seniors, children and the disabled, etc.). Instead, everyone should be able to take an active part in the creation of a circular city.

The adjective “smart”, in addition to referring to the use of technologies, should also refers to the wise (creative and efficient) use of resources in order to optimize the efficiency and effectiveness of processes and services of a city. Smartness is not synonymous with technology.

It is recognized that the successful transition towards the circular city model requires behavioral changes, for which society as a whole needs to be addressed. Those lifestyle changes, in turn, depend on citizen awareness of the issue. There is a need of a “cultural revolution”. This is the reason why, for example, the city of Antwerp is implementing innovative approach for engaging its citizens and raising their awareness about consumption and encourage circular lifestyles (using for example smart technologies and personal dashboard that displays real-time data-flows of water, waste bin and energy meters allowing citizens to comprehend their flows). This aspect, although considered in many circular cities, is not so highlighted in their official reports, while more and more space is left to the technical aspects of the circularization.

As emerged from different experiences of circular cities, the implementation of this model produces multidimensional benefits, thus representing a great opportunity to contribute to a significant number of the Sustainable Development Goals (SDGs), improving the lives of people and the planet.

The circular city contributes to the improvement of housing conditions in settlements through, for example, modular and flexible solutions, the increased greening of cities, and the promotion of clean and sustainable transport solutions. These are some of the aspects that contribute, for example, to the achievement of Goal no. 11.

Reduced air pollution resulting for example from circular mobility or reduced emissions from industrial activities through circular production models represents a significant contribution to improving people's health and well-being (contribution to SDG no.3). New circular business models and new systems for closing cycles are also key elements in promoting resilient infrastructures, promoting sustainable industrialization and fostering innovation (contribution to SDG no. 9). Many actions included in the implementation strategies of circular cities pay particular attention to the water cycle, contributing to the Goal 6 on "Ensure access to water and sanitation for all".

In brief, the circular city is a model that allows the two fundamental nodes of the cities to be tackled together in a systemic perspective: social inequalities and the ecological crisis.

The circular city is able to "hold together", at the same time, the objective of ecological/environmental sustainability with the goal of social justice, that is, the reduction of social inequalities. In other words, it aims at systemic/holistic management of the dichotomy between environmental issues and social issues, to guarantee the social wellbeing and quality of life of all its inhabitants. It means taking care of both natural ecosystems (i.e. the health of natural ecosystems) and the health and well-being of the inhabitants, in light of their multiple interdependencies. It means rejecting the trade-off between environmental health and people's well-being (and, therefore, the well-being of future generations).

3.4 Barriers and challenges in the circular city model implementation

As also underlined in the previous paragraph, to date, a clear definition of circular city doesn't exist and there are many discussions around it. Decoupling resource consumption from production and economic growth surely represents of the first objectives of a circular city. However, the circular city should be more than a sum of circular economy projects and more of a model for urban consumption and production. It should consider also other issues as community engagement and participation, social and environmental justice, intergenerational equity.

Thus, a clear definition of the circular city surely represents a first challenge in order to identify appropriate goals, strategies, policies and tools.

The key challenges to the implementation of the circular city model are cultural, economic, political, regulatory, institutional, physical and informational (Table 8) [63].

The inflexibility of institutions and their lack of engagement with civil society in local service delivery represent great challenges to the successful circular transformation.

The restructuring of the macro-economy and shift in cultural values required to implement the circular city model creates a great inertia to change. Inadequate political leadership, the erosion of municipal competencies and resources also represent a challenge (www.circularcitieshub.com).

Another important challenge is represented by the need to adjust the regulatory framework to the objectives of the actors to implement the circular city agenda. A lack of supportive regulatory framework is a real problem in aligning actor goals to implement the circular city agenda.

A lack of useful data for monitoring resource flows, the multidimensional impacts of this model on city productivity and for changing actor behavior also represent a problematic issue.

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Table 8 – The challenges to circular transformations

CHALLENGES	DESCRIPTION
Culture	Norms, ideas, customs and social behaviour of people
Economy	Production, distribution and consumption of goods and services
Physical environmental	Natural and built environment
Political and leadership	Policy preferences, issues of government and leadership
Smart	Data, information, monitoring, knowledge
Institutional	Organizational structures, cultures and practices
Regulatory	Regulations, regulatory instruments and policies

Source: Circular Cities Hub (www.circularcitieshub.com)

Another big challenge to implement the circular city model is related to financial aspects. How do we finance this transition and implementation? Considering the limited availability of public funds, new tools for financing circular cities should be identified (i.e. scope tax, crowdfunding, municipal bonds, etc.). It is necessary to guarantee a more effective financial base at city level, through new Public-Private-People-Partnerships), able to engage in a win-win strategy all stakeholders (also academic institutions, third sector associations, social entrepreneurs, etc.), innovative financial tools able to reduce the gap between the (many) needed resources and the ones concretely available (few), a strong/rigorous coordination between national tax return and local internal tax revenue, to avoid local insolvency/collapse. Furthermore, tax revenue systems based on land value should be transparent, open, agreed and participated, so that all local communities can check and assess in the public framework. All the stakeholders should be put in condition to participate to become aware of costs and financial returns. All financial tools and processes at local level should be put in strong relationships with planning processes.

The circular model goes beyond the singular actor (i.e. company). Its inclusive approach involves multiple and different actors to participate (citizens, associations, local authorities and companies). It needs to put in a synergic relationship all actors involved in this challenge and to create a network to accelerate the transition towards circularity.

Furthermore, the implementation of circular economy model necessarily requires investment in technology, innovation and knowledge that are linked to some identified functions (Circle Economy, 2016b). It needs to include “circular thinking” in political and socio-cultural level (Gemeente Rotterdam, 2016). It is necessary the aforementioned “cultural revolution”.

The resources necessary for the implementation of a circular city are both tangible (transport infrastructure, energy and natural resources) and intangible (human capital, social capital, education and knowledge, and intellectual capital of companies).

The circular city is not just an issue related to technological innovation, to material flows or to reuse and recycling of waste (it would be a key to reading that is too sterile and limiting). The technological innovation is only a part of it.

We must not forget to consider the human dimension according to the paradigm shift underlined in particular in the paragraph 26 of the New Urban Agenda that is characterizing the humanization of our cities. An ecological transition is characterized by a "renewable energy integrated system", by a strong effort of conservation and regeneration of natural resources, with a drastic reduction of waste, which are recycled/regenerated as much as possible, and transformed into resources (thus reducing the amount of extractions from the natural ecosystem) and making sure that the outputs can return to the natural ecosystem as much as possible [74]. But it is not enough. It is necessary to introduce also a cultural condition for the sustainable development implementation: the need to regenerate values on which the market economy itself is grounded, at least at the same speed of its consumption. This is an immaterial key energy as the blood for functioning our systemic organizations [74]. In addition, we need to be very careful during this ecological transition. Attention must be paid to the possible resulting human and social costs (i.e. this transition will result in the rise of many new businesses, but also in the closure of "old" businesses.). The circular economy needs to be more inclusive putting the human being at the core of its processes. If we think about how to design or how to trigger circular processes without considering human needs, "circular outcomes might not be the expected ones". Circular human flow has to be integrated into the "butterfly diagram" [12] in order to preserve and enhance human value [75]. There is a strong belief that a social dimension would be needed as an integral part of the powerful circular economic framework to preserve and enhance human value. It is necessary to consider human needs as the goal/core of the economic framework allow having a healthier economy.

So, the human dimension must be considered in the implementation of the circular city. The "heart" is represented by relationships and synergies. The "protagonist" of the circular city is not the single person or the single enterprise, but the community, a group of subjects that collaborate and cooperate, having a common goal. All the actors and stakeholders have the potential to influence the processes and decisions (and thus have responsibility).

4 Cultural heritage as entry point for circular city implementation

In the context of contemporary cities, that are characterized by high density and increasing unsustainability, we are also called to face many problems related to the redevelopment of the existing asset. In particular, in our cities, facing the challenges of our time (that is the ecological, social and economic crisis) is an issue more related to the sustainable use, management and transformation of the existing asset than to the planning of the new one. These are issues related to the energy efficiency, the efficient use of water and of construction materials. The redevelopment of the existing asset is also related to the use of biomass - natural capital, green roofs, urban greenery, etc.

In the European Green Deal there is an explicit reference to the built heritage. In fact, the need to start a "wave of renovations" of existing public and private buildings is highlighted to face the double challenge of energy efficiency and affordability of energy (currently the annual renovation rate in the Member States varies only from 0.4% to 1.2%). Indeed, the construction, use and renovation of buildings absorb significant amount of energy and mineral resources (such as sand, gravel, concrete). Buildings are also responsible for 40% of energy consumption. In March 2020, the European Commission adopted a new Circular Economy Action Plan [76] as one of the main building blocks of the European Green Deal. It provides "a future-oriented agenda for achieving a cleaner and more competitive Europe in co-creation with economic actors, consumers, citizens and civil society organisations".

The construction sector is among the key product value chains highlighting the necessity to promote circularity principles throughout the lifecycle of buildings in order to reduce climate impacts. To this end, the Commission is launching a new comprehensive "Strategy for a Sustainable Built Environment" [77].

Efficient building renovation would reduce the amount of energy bills, as well as boosting the building sector, thus providing an opportunity to support small and medium-sized enterprises and employment at local level. The EC with the Green Deal is committed to strictly enforce the legislation on energy performance in the building sector. In addition, it is committed to reviewing the Construction Products Regulation which should ensure that all phases of the design of new and renovated buildings are in line with the needs of the circular economy and lead to an increasingly climate resilient asset.

The EC also plans to set up a platform that brings together different "players" in the construction sector to collaborate and jointly tackle the obstacles to restructuring. In addition, forms of financing are envisaged for interventions aimed at energy improvement of buildings and specific actions for the removal of regulatory constraints in the matter.

Among the built asset, there is a specific asset characterized by particular values (historic, aesthetic, intrinsic, etc.), that is cultural heritage. This unique subset of the building sector is "expression of the ways of living, developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expressions and values" [78] (p. 21). It assumes a key role in sustainable development of the city, in achieving simultaneously economic, ecological and social goals, in the circular economy perspective [73,79,80]

Most urban areas today are saturated in terms of the built environment. Therefore, in the development of cities, greater attention is given to the recovery of the existing building stock (abandoned or underused) and disused areas, rather than to further urban expansion [81]. This also includes the reuse of cultural heritage buildings.

The adaptive reuse of cultural heritage can play a key role in the achievement of sustainable development of cities, contributing to its economic growth, social and ecological wellbeing [28,82]. Interpreted through the lens of ecology (re-integrating economy into ecology) [21], it is consistent with the principles of the European Green Deal [7] and the WHO approach [3,9,83].

4.1 Cultural heritage and circular economy model

As paragraph 3 highlights, the entry points for the implementation of the circular economy model in cities can be various. As emerges from the different experiences of circular cities, these are mainly linked to those production chains that include greater flows of resources in cities: food chain, construction sector, energy, etc. [53,54,64–67]. In fact, as already pointed out in this contribution starting from concrete experiences of circular cities, one of the first steps for the implementation of the circular city is the definition of its urban (tangible) metabolism and the identification of resource flows.

However, one entry point that is not considered in any circular city and that can play a key role in the implementation of this model is cultural heritage [73,79].

Today there are many abandoned and underused cultural heritage buildings because public administrations do not have enough resources to maintain them "alive", although cultural heritage is recognized as a driver of sustainable development [84]. Heritage buildings play a crucial role in transferring cultural identity to future generations: conserving cultural heritage can be helpful to future generations to understand where they are coming from [85,86].

City buildings can have a life span of up to hundreds of years. When a cultural building can no longer have its original function, it has to be adapted to new needs and identifying a new function is inevitable to preserve it. However, cultural heritage that no longer has its original use still has its historical, social and cultural values. Adaptive reuse is a strategy for preserving those values while adapting the function to the new community needs. According to the Leeuwarden Declaration, "new

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functions are thus brought together with heritage values in an active and meaningful dialogue" [87]. An appropriate new use for an abandoned or underutilized historic building needs to simultaneously both respect its intrinsic value and meet the needs of the local community, helping to improve its quality of life [88,89].

So, when heritage buildings are adopted to new functions, it is important preserve as much as possible the originality and architectural feature of the building [86], that is to identify the limit in the management of change [90]. This new use has to be appropriate in terms of preserving its cultural significance, its intrinsic value [91,92].

In the perspective of the circular economy, adaptive reuse is different from the one in the linear model, both in terms of design and in operational and management terms [21]. The organization/management of a reused cultural asset should be interpreted in a way similar to the organizational structure of the nature and requires a particular attention to all dimensions and values included in cultural heritage.

The adaptive reuse has to be interpreted in a systemic logic: each spatial and functional transformation produces multidimensional impacts in environmental (link with the European Green Deal), economic, social and cultural terms. In addition, there are different values to keep at stake when dealing with cultural heritage. Adaptive reuse allows to bring back to life a dead heritage. It represents a valid alternative to the demolition and replacement or to the new construction, reducing energy consumption and waste production and, at the same time, also provides social benefits thanks to the revitalization of traditional landmarks and giving them new life [86,93,94].

Cultural heritage conservation/valorization and circular economy are intertwined because they both prolong the use values in an indefinite time. The reuse, rehabilitation, restoration of cultural heritage/landscape are part of the circular-economy processes. In fact, there is a close relationship between conservation of cultural heritage (through its adaptive reuse) and circular economy. Both of them aim to extend the life cycle of the building as much as possible. The adaptive reuse allows to extend the use values of cultural heritage, preserving its integrity and authenticity, so that it can continue to be enjoyed by both present and future generations. So, it can represent an important contribution in "decoupling growth from resource consumption" and conserving resource values as long as possible; cultural capital is preserved, regenerating values for many stakeholders. The adaptive reuse produces impacts, and thus external effects, in a multidimensional perspective transforming this activity from a cost to an investment [23].

The reuse of cultural heritage takes place through circular economy processes and, vice versa, one of the sectors through which the circular economy can be implemented is represented by cultural heritage/landscape conservation.

Through the adaptive reuse of cultural heritage, a symbol of community is conserved “alive” (cultural benefits) and the construction of new assets – and the consequent use of other resources – is reduced (environmental benefits). Moreover, the adaptive reuse is able also to produce economic benefits (in terms of increase of productivity, touristic attractiveness, real estate values, etc.) and social benefits (in terms of employment, social relationships, etc.) [70,93,95,96]. The multiple benefits of re-using built heritage (economic, environmental, social and cultural benefits) are also highlighted in the Leeuwarden Declaration [87].

Adaptive reuse allows using cultural heritage in the present as in the future also saving its memory and, at the same time, adapting its functions to needs of the community, within a threshold that does not compromise its “complex value” [91]. It allows reducing the use of materials, of new land and building, to regenerate existing goods through new functions, to keep them “alive” [97].

The heritage reuse not only refers to fixed capital, but also to knowledge, in terms of values, language, significance, skills. Through functional re-use, we are able to regenerate values, keeping them in time. Heritage reuse can contribute to revitalizing the local economy with jobs, new businesses, tax revenues and local expenditure, to provide valuable wildlife habitat and recreational amenities, as well as to regenerate values [70].

There are many good practices related to the concept of circularization in cultural heritage/landscape field, as in Dublin, Liverpool, Hamburg, etc. The empirical evidence shows that circular economic processes are able to produce a reduction of costs (management and operating costs, environmental and socio-cultural costs) and the non-used cultural heritage represents a “cost”. Its creative functional re-use can reduce this “cost”, transforming it in an investment. Empirical evidence confirms that creative/productive activities prefer historic districts/assets for their localization [93,98–102].

The inputs of adaptive reuse are both tangible (water, waste, energy, materials, soil, goods) and intangible (values, creativity, technologies). The outputs of this activity are related to economic, social, environmental, and cultural dimensions.

Adaptive reuse is able to produce external effects that partially impact on the context and partially are able, in turn (in a circular perspective), to “come back” (from the context) to cultural heritage. It is able to produce economic impacts on the context that, in turn, become input again for cultural heritage. This economic value, in fact, can be “re-used” to support the activities included in the space/place.

Adaptive reuse is able to produce social values. They are referred, in particular, to the production of jobs. Producing jobs, adaptive reuse improves wellbeing and quality of life of the community that, in turn, become inputs for productivity. This is because if people are in a state of wellbeing, they are also more productive. This concept has been understood from some entrepreneurs, as Olivetti, Bata and Ferrero. They have understood the importance of the added social value produced by their own entrepreneurial activity and have provided evidence, pursuing “that great project of social commitment known as welfare capitalism” [103].

Cultural heritage adaptive reuse is able to produce also environmental values, in particular in terms of avoided costs (reduction of energy consumption, waste reduction, etc.). It produces benefits such as land-saving use due to building reuse (rather than demolished) and the reduction in CO_2 emissions thanks to restoration of a building rather than rebuilding it. Thereby, cultural heritage can help to face the climate change challenge, for example, “through the protection and revitalization of the huge embedded energy in the historic building stock” [104]. This environmental value comes back to cultural heritage also as economic value (circular perspective). The avoided costs linked to a more efficient building can be used, for example, to support the aforementioned creative hub.

Cultural values produced through adaptive reuse are linked to the capacity to generate and regenerate relationships. Part of these relationships impacts on the context and part of them become input for activities in cultural heritage (circular process). Cultural heritage has the potential to be a “connective infrastructure” [88], that is as an infrastructure “keeping society more cohesive” (now highly fragmented especially in big cities), creating and regenerating bonds and relationships. Regenerating cultural heritage contributes to regenerating the “connective infrastructure” [88], which in turn feeds the productivity of the activities within cultural heritage.

In brief, the circular city is the city that recognizes a key role of the cultural heritage to conserve/valorize (through circular processes) as a competitive resource. The construction of new buildings is reduced, using underused or abandoned cultural heritage (thus reducing the use of resources). So, cultural heritage is efficiently re-used producing economic, social, environmental and cultural benefits. The circular city invests in cultural heritage conservation/valorization, recognizing it as an investment for the community and not a cost.

5 Implementation tools

The implementation tools (financial, business, evaluation tools) play a fundamental role in making the circular economy/city model operational.

Evaluation tools to assess the efficiency of the circular economy/city model are necessary to support the transition towards the circular city model. Currently, there is not a recognized set of indicators for assessing how a city is effective in moving towards circularity, nor are there tools for supporting it. However, it is necessary to demonstrate the multidimensional benefits of the circular economy in order to convince policy-makers, community and companies that investing in a circular economy is convenient.

Although interest in the circular economy model is growing, the debate around it remains quite more on a theoretical level [73,105,106]. Knowledge about how to implement this new model is still confusing and lacking. There are some studies on circular economy indicators in literature, but they are rather sectoral and do not include simultaneously all the key principles of the model. However, evaluation tools are fundamental to assess and monitor the efficiency and effectiveness of the circular model, that is, to assess the impacts (positive and/or negative) of the projects and initiatives of the circular agenda.

This research has been based on a literature review, considering both scientific papers explicitly dealing with the topic of the circular city and the official documents and reports of cities that are concretely implementing this model. Starting from this analysis, indicators for circular cities are deduced. Today the cities that are implementing the circular city model are using different indicators for assessing and monitoring their transition to/implementation of this model. However, these indicators present some weaknesses and limitations.

The indicators have been divided in two sets of indicators. The first one has been deduced from theoretical papers; so, they are indicators that could be useful to assess the circular city, but it is not said that they are easily usable. Often, these indicators are not applicable due to the lack of data [107].

The second set is referred to the indicators deduced from case studies; so, these have already been (almost always) effectively used. The case study research is appropriate to investigate the circular city model because it is in its initial phase and rather complex [49].

The indicators deduced from cities include indicators related to cities that are defining themselves explicitly as "circular city" and that have produced systematized reports on their strategies and indicators related to cities that are moving towards this direction but that have not produced official documents related to a general local strategy/agenda—but that are implementing individual projects and initiatives related to the circularization of processes (and thus they are for the purpose of this study).

Both of the sets of indicators are, in turn, divided in three categories: indicators related to the environmental dimension, indicators related to economic and financial dimensions, and indicators related to the social and cultural dimensions.

Fourteen cities have been selected according to the following criteria. First of all, cities that are implementing a circular city programme/strategy/agenda have been chosen; so, not singular projects, but a circular global strategy at city level. Among them, first of all metropolitan cities and port cities (considering that the circular economy has born in the port areas) have been selected. Another selection criterion has been related to data availability: cities that provide data to assess the impacts of the circular model implementation in their reports have been chosen.

The cities are the following: London (United Kingdom), Glasgow (United Kingdom), Rotterdam (The Netherlands), Amsterdam (The Netherlands), Paris (France), Antwerp (Belgium), Brussels (Belgium), Maribor (Slovenia), Luibljana (Slovenia), Praga (Czech Republic), Kawasaki (Japan), Kalundborg (Denmark), Marseille (France), Göteborg (Sweden), Malmö (Sweden).

The greater complexity and difficulty in this work have been the gathering of data and indicators (able to capture the relevant aspects of the circular city) because many documents are lacking in transparency and clarity of data. Indicators are emerged many times, but only at theoretical level. Furthermore, although some of them are available, the data to feed them is not [107]. Data are not always systematized in reports of circular cities and they are often not explicitly written. Cities also use different indicators and unit of measure and, therefore, the impacts are difficult to compare. As emerged from the analysis of the documents, some experiences of circular cities are systematized and so their “reading” is more immediate and clearer, while others are not systematized, but the indicators are still reasonably deducible.

The indicators have been grouped into two tables (Table 9, 10) in which the unit of measure, the reference scale and the bibliographic reference have been indicated. The unit of measure or how to estimate the data are not clear for some indicators emerging from the case studies. These indicators are mentioned, but not assessed, in the reports. Where the unit of measure is not clear or does not emerge, the indicator is reported with a double asterisk. The three scales considered are those identified (and explained) later in this paragraph: micro, meso and macro scales.

Although it is a rich list of indicators, they present some weaknesses and limitations, analysed below.

Table 9 - Indicators of circular cities deduced from literature

Indicator	Unit of measure	Scale	Reference
Environmental Dimension			
Annual amount of greenhouse gas emissions; Annual amount of CO_2 emissions; Percentage of reduction of greenhouse gas emissions	%/year or tons/year	Mi–Me–Ma	[55,63,108,109]
Recycling rate of municipal waste	%/year	Me	[12,107,109]
Recycling rate of packaging waste	%/year	Me–Ma	[12,109]
Amount of landfilled waste Percentage of material solid waste landfilled Percentage of household waste ended in landfills	%/year or tons/year	Mi–Me–Ma	[12,63,107–109]
Percentage of material solid waste incinerated	%/year	Me–Ma	[63]
Percentage of material solid waste composted	%/year	Me–Ma	[63]
Using of recycled goods in municipal administration	%/year	Me	[108]
Using of recycled goods in industrial production	%/year	Me–Ma	[108]
Saving energy due to the use of recycled goods in industrial production	%/year or kWh/year	Mi–Me–Ma	[108]
Saving water due to the use of recycled goods in industrial production	%/year mc/year	Me–Ma	[108]
Amount of recycled goods sold	N./month (or year)	Me–Ma	[108]
Percentage of household waste reused or recycled	%/year	Me–Ma	[108]
Unsold products recovered every day for redistribution at the market itself or through nearby community facilities	Kg/day	Me–Ma	[108]
Input (energy, materials) in production processes from renewable sources	**	Mi–Me–Ma	[110]
Input in production processes from reused materials	**	Mi–Me–Ma	[110]
Input in production processes from recycled materials	**	Mi–Me–Ma	[110]
Output from production processes from renewable sources	**	Mi–Me–Ma	[110]
Output from production processes from reused materials	**	Mi–Me–Ma	[110]
Output from production processes from recycled materials	**	Mi–Me–Ma	[110]
Amount of resources saved	**	Mi–Me–Ma	[49]
Percentage of water consumption for habitat (reduction for example thanks to harvesting rainwater on the roofs)	%/year	Mi–Me–Ma	[49,63]
Volume (amount) of resource flow	**	Me–Ma	[111]
Amount of recycled resources	**	Mi–Me–Ma	[111]
Amount of reused resources	**	Mi–Me–Ma	[111]
Percentage of green roofs	%/ total city surface	Mi–Me–Ma	[107]
Amount of food waste treated Food waste treated in Small and Medium-size Enterprises (SMEs)	%/total food waste	Mi–Me–Ma	[107]
Percentage of retrofitting interventions on buildings	%/total building	Mi–Me–Ma	[107]
Percentage of degraded buildings	%/ total building	Me–Ma	[107]
Public transport usage	% of inhabitants using public transport	Me–Ma	[107]
Electrical energy consumed in the transport sector	%of transport sector using electrical energy	Me–Ma	[107]
Synergies among industries	N.	Me–Ma	[107]
Safe water accessibility (water issues regarding its treatment and distribution)	**	Me–Ma	[107]
Water efficiency (water issues regarding its treatment and distribution)	**	Me–Ma	[107]

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Indicator	Unit of measure	Scale	Reference
Separated waste (recovery and treatment of waste generated in city)	Kg/year	Me–Ma	[107]
Percentage of non-renewable energy use	%/year	Mi- Me–Ma	[63]
Percentage of renewable energy use	%	Mi–Me–Ma	[112]
Percentage of local nutrient recovery	%	Me–Ma	[112]
Buildings designed for complete disassembly	N.	Me–Ma	[112]
Reuse of building components at the end of life	%	Me–Ma	[112]
Design for flexibility by using modular systems	%	Me–Ma	[112]
Recycling rate of recyclable materials and constructions	%	Me–Ma	[112]
Low-impact and non-toxic materials used in production processes	%	Me–Ma	[112]
Sustainable materials sourced from certified or eco-verified sources	%	Me–Ma	[112]
Amount of waste heat from industry used for heating the city and horticulture	kWh/year	Mi–Ma–Ma	[50]
Amount of groundwater warmed in the earth and used to heat homes and offices	Mc/year	Mi–Ma–Ma	[50]
Number of homes getting their energy (heat and electricity) from biogas (i.e. fermenting the manure of cows)	N./total	Me–Ma	[50]
Amount of recovered phosphate from the sewage water	Kg/day	Mi–Me–Ma	[50]
Percentage of reuse or recycling of recyclable demolition materials	%	Mi–Me–Ma	[50]
Economic and Financial Dimensions			
Spending on waste management	€/year	Me–Ma	[109]
Disposable income of households (reduction through the reduced costs of products and services)	€/year	Me–Ma	[109]
Revenue from recycled goods sold	€/month €/year	Mi–Me–Ma	[108]
Potential value of the material after recovery/re-use	€	Mi	[111]
Circular economy innovation budget (in relation to the number platforms and businesses that lead to innovation in circular economy subjects)	%/year	Mi–Me–Ma	[107]
Annual cost saving from recover phosphate from the sewage water (precious and scarce fertilizer)	€/year	Mi–Me–Ma	[50]
Social and Cultural Dimensions			
Liveability (e.g. increase through reduction of time lost from congestion, reduction of air pollution, improved waste and wastewater treatment)	**	Me–Ma	[109]
Employment opportunities Job creation	N. of jobs	Me–Ma	[49,108,109]
Number of events and dissemination activities about circular economy	N. of events/year	Me–Ma	[108]
Participants in events about circular economy (including public bodies, companies, universities, research centres, professional associations, etc.)	N. of participants/year	Me–Ma	[108]
Active population in circular economy initiatives	%	Me–Ma	[107]
People involved in the informal waste recycling sector	%/tot. inhabitants	Me–Ma	[63]

Note: **The indicators whose unit of measure does not emerge or is not clear in the source are reported with a double asterisk.

Source: Author's elaboration starting from different sources [73]

Table 10 - Indicators of circular cities deduced from official documents and reports

Indicator	Unit of Misure	Scale	City Reference
Environmental Dimension			
Amount or percentage of recycled material	Tons/year or %/year	Mi–Me–Ma	Circular London Circular Rotterdam Maribor, Slovenia Luibljana, Slovenia
Amount or percentage of products reused	Tons/year or %/year	Mi–Me–Ma	Circular London Circular Rotterdam Maribor, Slovenia
Amount or percentage of products recovered	Tons/year or %/year	Mi–Me–Ma	Circular Prague Maribor, Slovenia Luibljana, Slovenia
Amount of raw materials used in the manufacturing processes	Tons/year	Mi–Me–Ma	Circular London
Average amount of materials retained in the cycle per citizen per year	Kg/year	Mi–Me–Ma	Antwerp Circular South
Percentage of incoming/outgoing flows	%/year	Me	Circular Paris
Amount of CO_2 emissions Amount of greenhouses gases emissions	Kg of CO_2/year	Mi–Me–Ma	Circular London Circular Amsterdam Circular Prague Malmö, Sweden
CO_2 (or CO_2 equivalent) emissions saved (also through industrial and urban symbiosis) GHG emissions saved (for example by an increase in circularity)	Tons/year or T Co2 equivalent /year or %/year	Mi–Me–Ma	Circular London Circular Glasgow Marseille Kalundborg Industrial Symbiosis Circular Prague Malmö, Sweden Gothenburg, Sweden Kawasaki, Japan
Amount of emissions of NOx	Tons/year	Me–Ma	Circular Prague

Indicator	Unit of Misure	Scale	City Reference
Amount of emissions of fine dust emissions Annual average air quality particulate matter	Tons/year or $PM_{2.5}$ µg/m3	Me–Ma	Circular Prague Circular Rotterdam
Reduction in embodied carbon (building environment chain)	kilograms of CO2e per kilogram of product	Mi–Me–Ma	Circular London
CO_2 intensity	tons / capita	Mi–Me–Ma	Circular Rotterdam
Embedded CO_2 emissions (“Further research is needed to calculate this indicator” [66])	tons / capita	Mi–Me–Ma	Circular Rotterdam
Percentage of reduction of emissions due to a smart and clean building logistics (construction sector)	%	Mi–Me–Ma	Circular Rotterdam
Air pollution and greenhouse gas emissions associated to transport	Tons/year	Me–Ma	Circular London
Average amount of products going to landfill or incineration	Tons/year	Me–Ma	Circular London Circular Prague
Waste reduction in production of goods–raw material efficiency	kilograms of waste per €1000 output	Me–Ma	Circular Amsterdam Circular Prague
Amount or percentage of waste separation	%/year or tons/year	Me–Ma	Circular Rotterdam Circular Prague
Increase in the clean plastics and drink packaging streams from residual waste	%/year	Me–Ma	Circular Rotterdam
Percentage of recycling of the solid waste generated in the city Percentage of recycle of packaging waste Percentage of recycle of municipal waste	%/year	Me–Ma	Circular Rotterdam Maribor, Slovenia Luibljana, Slovenia
Amount of construction waste by implementing of interventions related to circular economy	tons/year	Me–Ma	Circular Rotterdam
Difference between tonnes of waste and tonnes of products consumed	Tons of waste/tons of products consumed	Me–Ma	Circular Rotterdam
Tonnage of waste diverted via repair, reuse, recovery and upcycling activities (recycling centres, artisans, second-hand goods stores, fab labs, etc.)	tons/year	Me -Ma	Circular Paris
Traceability of hazardous waste	**	Me–Ma	Maribor, Slovenia
Amount of waste produced in the city Amount of waste generated per capita	Tons/year or tons/per capita/year	Me–Ma	Gothenburg, Sweden Circular London Circular Rotterdam

Indicator	Unit of Misure	Scale	City Reference
Amount of waste produced in the city and treated within the city itself	tons/year or %/year	Me	Circular Prague
Amount of solid waste reused	Tons/year or %/year	Me–Ma	Maribor, Slovenia Luibljana, Slovenia Circular Glasgow Circular Prague
Amount or percentage of waste avoided Amount of household waste reduced preventing waste and encouraging reuse	Tons/year or %/year	Mi–Me–Ma	Circular London Circular Glasgow Circular Prague Circular Rotterdam Antwerp Circular South Circular Paris Maribor, Slovenia Malmö, Sweden Gothenburg, Sweden
Amount of biowastes processed in biogas facilities	% or tons/year	Me–Ma	Circular Prague
Percentage of reduction of noise of waste collection fleet by a perceived percentage	%	Me–Ma	Circular Prague
Use of renewable resources	%/year	Mi–Me–Ma	Circular Amsterdam Antwerp Circular South Circular Rotterdam Malmö, Sweden
Energy savings per year	%/year	Mi–Me–Ma	Circular Glasgow Circular Paris
Tap water use	%/year	Me–Ma	Antwerp Circular South
Absolute (kWh) and relative (%) reduction of yearly electricity consumption	kWh/year or %/year	Mi–Me–Ma	Antwerp Circular South
Less use of peak power	%/year	Mi–Me–Ma	Antwerp Circular South
Primary resources used Virgin resources used Amount of primary resource use avoided	%/year or Tons/year	Mi–Me–Ma	Circular Rotterdam Malmö, Sweden Circular London

Indicator	Unit of Misure	Scale	City Reference
			Circular Prague Circular Glasgow
Primary raw material demand per capita	ton / capita	Me–Ma	Circular Rotterdam
Energy requirement per capita	GJ/person/year	Me–Ma	Circular Rotterdam
GDP per energy requirement	€ / GJ	Me–Ma	Circular Rotterdam
Supply of renewable energy	%	Mi–Me–Ma	Circular Rotterdam
Embedded energy use (“Further research is needed to calculate this indicator” [66])	ton / capita	Mi	Circular Rotterdam
Amount of material saving due to the implementation of circular strategies	tons	Mi–Me–Ma	Circular Amsterdam
More efficient resource use	**	Mi–Me–Ma	Circular London
Percentage of renewable or recycled energy use	%/year	Mi–Me–Ma	Malmö, Sweden
Renewable energy production on total energy production	MWh/year/total	Mi–Me–Ma	Malmö, Sweden
Fossil-fuel-free transport sector	%	Me–Ma	Malmö, Sweden
Percentage of renewable electricity supply for all municipal operations	%	Me	Malmö, Sweden
Number of families powered by energy produced by wind turbines	N./total	Me–Ma	Malmö, Sweden
Electricity consumption per capita	MWh per Capita/year	Me–Ma	Malmö, Sweden
Public transit ridership for work and school commutes	%	Me–Ma	Malmö, Sweden
Eco-car strategy–Municipal fleet powered by biogas, hydrogen or electricity (including plug-in hybrids)	%/ year	Me–Ma	Malmö, Sweden
Construction materials come from secondary sources	%	Mi–Me–Ma	Circular Prague
Tonnes of residual materials not utilised (construction sector)	Tons/total	Mi–Me–Ma	Circular Prague
Percentage of building heating mainly by natural gas	%	Me–Ma	Circular Prague
Percentage of building heating mainly by energy from incineration	%	Me–Ma	Circular Prague
Percentage of water heating by natural gas	%	Mi–Me–Ma	Circular Prague
Raw material consumption	%/year	Mi–Me–Ma	Circular Prague
Sq metres that includes facilities and services to develop their circular sustainable projects	Sqm/total surface	Me–Ma	Be circular Be.Brussels
Liters of households daily water-consumption	Liters/day	Me–Ma	Antwerp Circular South

Indicator	Unit of Misure	Scale	City Reference
Raw materials with high risk for impact on biodiversity ("Further research is needed to calculate this indicator" [66])	%	Me–Ma	Circular Rotterdam
Percentage of sustainable food	%	Me–Ma	Circular Paris
Maritime traffic (amount of maritime throughput)	Tons/year	Me–Ma	Marseille
Land covered by a circular platform in the industrial port area	Sqm	Me–Ma	Marseille
Percentage of the land area used for circular economy projects implementation	%	Me–Ma	Marseille
Number of plants involved in circular economy projects	N./year	Me–Ma	Marseille
Percentage of biodiversity	%	Me–Ma	Malmö, Sweden
Percentage of annual rainfall absorbed by green roofs	%/year	Me–Ma	Malmö, Sweden
Temperature of external facades (decrease for example thanks to green facades)	°C	Mi	Malmö, Sweden
Indoor temperatures (decrease for example thanks to green facades)	°C	Mi	Malmö, Sweden
Amounts of ground-level ozone recorded near the green facades	**	Mi	Malmö, Sweden
Creation of protected green areas	N./year	Me–Ma	Malmö, Sweden
Green areas used as stormwater storage	Sqm/total surface	Me–Ma	Malmö, Sweden
Energy consumption referred to transport sector	KWh/year	Me–Ma	Maribor, Slovenia
Proportion of green and recreational areas per capita	%	Me–Ma	Maribor, Slovenia
Percentage of improvement of fuel utilisation compared to a separate production of heat and power	%	Me–Ma	Kalundborg Industrial Symbiosis
Reduction of the total water consumption by recycling water and by letting it circulate between the individual symbiosis partners	%	Me–Ma	Kalundborg Industrial Symbiosis
Amount of ground water substituted by lake water that is processed up to drinking water quality by municipality. Amount of surface water saved	Cubic meters/year	Me–Ma	Kalundborg Industrial Symbiosis
Amount of reduced oil consumption through symbioses	Tons/year	Me–Ma	Kalundborg Industrial Symbiosis
Amount of newspaper/cardboard sold to cardboard and paper consuming industries producing new paper, egg boxes, etc.	Tons/year	Me–Ma	Kalundborg industrial symbiosis
Amount of rubble and concrete used for different surfaces after crushing and sorting	Tons/year	Me–Ma	Kalundborg
Amount of garden/park refuse delivered as soil amelioration in the area	Tons/year	Me–Ma	Kalundborg industrial symbiosis

Indicator	Unit of Misure	Scale	City Reference
Amount of bio waste from households and company canteens used in the compost and biogas production	Tons/year	Me–Ma	Kalundborg industrial symbiosis
Amount of iron and metal resold after cleaning for recycling	Tons/year	Me–Ma	Kalundborg industrial symbiosis
Amount of glass and bottles that are sold to producers of new glass	Tons/year	Me–Ma	Kalundborg industrial symbiosis
Amount of resources saved through the industrial symbiosis initiatives	Tons/year	Me–Ma	Kalundborg industrial symbiosis
Number of different resource streams exchanged	N. /year	Me–Ma	Kalundborg Industrial Symbiosis
Climate change adaptation	**	Me–Ma	Circular Prague
Number of symbioses/synergies connecting businesses (resources exchanged)	N./year	Me–Ma	Kawasaki, Japan Malmö, Sweden
Reduction in the physical value of material use due to industrial and urban symbiosis	%	Me–Ma	Kawasaki, Japan
Economic And Financial Dimensions			
Money saved (in a year) for average household due to reducing the amount of products thrown away	€/year	Me–Ma	Circular London
Financial savings to both consumers and businesses adopting more efficient circular business models	€/year	Mi–Me–Ma	Circular London
Financial savings to public sector bodies through improved procurement practices/waste management	€/year	Me–Ma	Circular London
Financial savings for consumers from decreased consumption of “new products”	€/year	Me–Ma	Circular London
Waste management costs	€/year	Me–Ma	Circular Glasgow Circular Prague
Budget allocated to stimulate pilot projects that employ circular economy at the local level	€/year	Me	Be circular Be.Brussels
Environmental costs (costs of exhaustion, water pollution, CO_2-emissions, toxicity and land use in € per kilogram)	€/kg	Me–Ma	Circular Amsterdam
Gross value added	€/year	Mi	Circular Prague
Return on investment	€	Mi	Circular Prague
Total revenue from sale/leasing of reused products	€/year	Mi	Circular Prague
Economic savings in purchasing reused products for citizens	€/year	Mi	Circular Prague

Indicator	Unit of Misure	Scale	City Reference
Resource usage: total raw material productivity	GDP / tons of primary material input	Mi–Me–Ma	Circular Rotterdam
Euros allocated from the municipality to various district heating and district energy projects	€/year	Me	Malmö, Sweden
Sustainability of investments from the municipality	**	Me	Malmö, Sweden
Average value of products	€	Mi	Circular London
Value of re-usable or recyclable used goods sent to landfill	€	Mi	Circular London
Money granted to businesses or research projects linked to the circular economy	€/year	Me–Ma	Be circular Be.Brussels
Increase in productivity for municipality by organizing the production chains in a circular way	%/year or €/year	Me	Circular Amsterdam
Net added value due to the implementation of circular strategies	€/year	Mi–Me–Ma	Circular Amsterdam
Value creation thanks to the growth of circular economy models	€/year	Mi–Me–Ma	Circular Paris
Volume of sales thanks to the growth of circular economy models	Amount/year or €/year	Mi–Me–Ma	Circular Glasgow
Sales of locally produced goods	Amount/year or €/year	Me–Ma	Circular Glasgow
Revenues through sales thanks to the growth of circular economy models	€/year	Mi–Me–Ma	Circular Glasgow
Change in GDP through circular activities	%	Ma	Circular Rotterdam
Turnover of organizations working in the circular economy (including all sectors and types)	€/year	Mi	Circular Paris
Global sales related to circular economy	%/year	Me–Ma	Marseille
Annual fees related to circular economy	%/year	Me–Ma	Marseille
Tenancy turnover	%/year	Me–Ma	Malmö, Sweden
Costs related to flood risk	€/year	Me–Ma	Malmö, Sweden
Resources productivity	**	Me–Ma	Maribor, Slovenia
Creating added value and economic growth	€/year	Me–Ma	Maribor, Slovenia Luibljana, Slovenia
Attractiveness in terms of tourist visits	N. of visitors/year	Me–Ma	Maribor, Slovenia Luibljana, Slovenia
Public funding in circular economy projects	€/year	Me–Ma	Gothenburg
Economic advantage from industrial symbiosis activities	€/year	Me–Ma	Kawasaki, Japan

Indicator	Unit of Misure	Scale	City Reference
Economic opportunity generating from waste deverted from incinerator and landfill thanks to material exchanges	€/year	Me–Ma	Kawasaki, Japan
Social and Cultural Dimensions			
Number of new jobs Share of circular jobs (full- or part-time jobs that are related to one of the seven basic principles of circular employment) Percentage of new jobs related to the circular economy Number of new jobs from recycling of packaging Number of new jobs from industrial ecology Number of new green jobs	N./year or %/year	Mi–Me–Ma	Circular London Marseille Circular Amsterdam Circular Rotterdam Circular Paris Circular Glasgow Kalundborg industrial symbiosis Maribor, Slovenia Circular Prague Luibljana, Slovenia Kawasaki, Japan
New business opportunities New businesses that have integrated circularity into their development process	N./year or %/year	Me–Ma	Circular London Marseille Circular Amsterdam Circular Rotterdam Circular Paris Circular Glasgow Kalundborg industrial symbiosis Maribor, Slovenia Circular Prague Luibljana, Slovenia Be circular Be.Brussels
Number of training opportunities related to circular economy	N./year	Me–Ma	Circular London Circular Prague
Unemployment rate	%/year	Me–Ma	Circular Rotterdam

Indicator	Unit of Misure	Scale	City Reference
			Maribor, Slovenia Luibljana, Slovenia Malmö, Sweden
Change in circular jobs	%	Me–Ma	Circular Rotterdam
Number of employees	N./year	Me–Ma	Kalundborg industrial symbiosis
Number of companies supported in the implementation of circular economy approaches	N./year	Me–Ma	Be circular Be.Brussels
Number of individuals trained through the education measures	N./year	Me–Ma	Be circular Be.Brussels
New collaborations between public agencies and enterprises	N./year	Me–Ma	Be circular Be.Brussels
Number of participants in circular economy processes	N./year	Me–Ma	Be circular Be.Brussels
Public tenders incorporating circular economy and resource efficiency criteria	%	Me–Ma	Be circular Be.Brussels
Number of people using a personal dashboard that display real-time data-flows from smart energy, water and waste bin meters, helping to increase awareness about consumption	N./year	Me–Ma	Antwerp Circular South
Training for employees to think in a circular way	N./year	Me–Ma	Be circular Be.Brussels
Percentage of population that shows an increase in circular behaviour	%	Me–Ma	Circular Rotterdam
Annual number of visitors (with active engagement) to the reuse hubs	N./year	Mi	Circular Prague
Social Cohesion (participate objectively)	**	Me–Ma	Circular Rotterdam
Percentage of population that describes their own health as good or very good	%/year	Me–Ma	Circular Rotterdam
Population with middle or high education	%/year	Me–Ma	Circular Rotterdam
Percentage of population dying from diseases of the respiratory system (diseases of the respiratory system can be an air quality indicator, but also of habits such as smoking)	%/year	Me–Ma	Circular Rotterdam
Average household income	€/year	Me–Ma	Circular Rotterdam
Population below poverty line	%/year	Me–Ma	Circular Rotterdam
Health benefits (how to evaluate this indicator is not specified in the report)	**	Me–Ma	Circular London
Alleviating food poverty (how to evaluate this indicator is not specified in the report)	**	Me–Ma	Circular London
Positive community activity (how to evaluate this indicator is not specified in the report)	**	Me–Ma	Circular London
Physical and mental health benefits (how to evaluate this indicator is not specified in the report)	**	Me–Ma	Circular London
Number of new circular initiatives	N./year	Me–Ma	Circular Rotterdam

Indicator	Unit of Misure	Scale	City Reference
Percentage of residents participated in dialogue and/or design related to circular economy	%/year	Me–Ma	Malmö, Sweden
Number of local "green" companies	N./year	Me–Ma	Malmö, Sweden
City attractiveness in terms of creation of recreational and cultural spaces	**	Me–Ma	Malmö, Sweden
Development of cooperative economy	**	Me–Ma	Maribor, Slovenia
Number of new forms of enterprises (SMEs, start-ups, incubators, etc.)	N./year	Me–Ma	Maribor, Slovenia Luibljana, Slovenia
Level of satisfaction of citizens with the administration services	qualitative	Me–Ma	Maribor, Slovenia
Transformation of neighborhoods and local community	**	Me–Ma	Maribor, Slovenia
Competitiveness of the economy	**	Me–Ma	Maribor, Slovenia
Competitiveness of the university	**	Me–Ma	Maribor, Slovenia
Professional and managerial transformation of the city administration	**	Me–Ma	Maribor, Slovenia
Interaction between residents	**	Me	Maribor, Slovenia
Number of private partners involved in industrial symbiosis	N. /year	Me–Ma	Kalundborg Indusrtial Symbiosis
Number of public partners involved in industrial symbiosis	N. /year	Me–Ma	Kalundborg Indusrtial Symbiosis

Note: **The indicators whose unit of measure does not emerge or is not clear in the source are reported with a double asterisk.

Source: Author's elaboration starting from different sources [74]

The deduced matrix of indicators is very rich, but some emerged indicators risk not being significant if they are not contextualized in the specific city and in relation to the circular city model. On the other hand, some indicators are instead very specific and should be generalized to be included in a general matrix of indicators reflecting the characteristics of the circular city. They should be contextualized, from time to time, according to the specificities of the context.

Indicators referred to recycling (one of the aspects of the circular city) are the most available, while indicators for measuring circularity strategies almost do not exist. To date the indicators identified to assess circular economy models are mainly focused on technical/tangible flows and materials cycles because “their circularity” and benefits for associated businesses are easier to understand. They are mainly specific for industries and production chain (as emerged from some experiences as London, Glasgow, Amsterdam, Marseille). The indicators used by each city are mainly related to the production chains triggering more flows in the city (food, construction, etc.).

Circular experiences highlight that there are two groups of indicators: indicators related to the intensity of the circular processes (representing the minority) and indicators related to the impacts of these processes on the city. They should be distinguished. So, first of all, it needs to be specified that the indicators should be referred both to the “circularity level” (i.e. ratio between the total of saved material and the total consumed material) and to the impacts that the “circularity” produces (environmental and socio-economic effects, i.e. cost reduction, employment, etc.).

In addition, another necessary classification should refer to the difference between indicators related to the transition process and those related to the achievement of circularity strategy, considering the (long) time that the transition process can take (as the European Network of the Heads of Environment Protection Agencies EPA Network - underlines) [113,114]. Therefore, the indicators related to the circular economy model can be classified distinguishing the transition process steps and the achievement of the circular model. Monitoring the “journey” towards this new model is important to understand if a city is going in the right direction or if additional measures are necessary.

Furthermore, three categories can be recognized on the basis of the reference level:

- Micro-level (Mi) - company level, building level, citizens level;
- Meso-level (Me) - companies’ network level, eco-industrial park, neighbourhood level, city level;
- Macro-level (Ma) - regional level, national level, international level.

In order to assess the circular city implementation, it is necessary to decide what is relevant and what can be measured in circular cities [107,115]. Then, it is necessary to identify a clear unite of measure and a unique way to estimate the data.

Moreover, all stakeholders need to be considered in the evaluation process. Stakeholders’ categories that can be considered in the circular economy model are, for example, individual company, private institutions, community, public institutions, etc. Each stakeholder plays a role and has responsibilities in the circular economy/city implementation. It needs to identify solutions at positive sum-game, able to produce multidimensional benefits for all stakeholders.

This consideration implies the necessity of indicators to be understandable to different stakeholders, which is fundamental for the implementation of the model. They allow raising awareness of performance and potentiality of circularity. Comparability is another key word for the indicators. Clear definitions and common understanding are fundamental for making data comparable among different cities, in order to have a common ground for comparing results and monitoring cities in the “journey” towards this new model.

Some important indicators (such as resource input and waste utilization), although significant, cannot be easily measurable because of the lack of urban statistical systems that should be improved.

Other important operational tools for implementing the circular city model are that related to the governance. The governance of the circular city has to be a collaborative, adaptive, experimental and reflexive governance [73].

A collaborative governance promotes culture from the bottom. In the circular city, public bodies collaborate with different actors and stakeholders (citizens, businesses, civil society, etc.) in order to join demands for action and ensure good governance practices based on transparency, legitimacy, and openness principles. This kind of governance is experimental and based on continuous feedback processes.

Furthermore, considering that we live in an ever-changing reality, in which conditions, needs and requirements continuously change, the governance of the circular city has not to be static and blocked in its inflexibility and technocratic character, but has to be based on dynamic changes, identifying from time to time the impediments to change and developing and, at the same time, solutions for these barriers.

In this perspective, an operational tool that can be useful to trigger the circular urban model is represented by the Local Action Plan (LAP). This operational document can guide the transition towards the circular city model implementation, identifying the concrete necessary actions, articulated in time and space. It is a co-created “action-oriented” plan, developed through a mixed bottom-up and top-down approach, assessing the feasibility conditions of the proposed actions. It is co-created with the community and all the stakeholders in order to create a vision that is as shared as possible, a necessary condition for its success.

This inclusive governance tool, starting from the analysis of critical issues and opportunities of the city, meets the identified needs and proposes feasible and sustainable solutions. It allows translating challenges and goals in actions in a specific city. The participatory process brings out critical issues and opportunities at different level, as political, cultural and regulatory.

A “matrix” that put in relationships the area of intervention, the actions, the human and financial resources needed to implement it, the involved stakeholders, the timeline and the impact indicators can support the transition to cities towards the circular city model and to guide them during its implementation. The actions referred to the brief term have to be accompanied by actions, researches, and recommendations that address the long term (where current conditions may change). The actions are related to different categories (from energy production, to water management, to local mobility, etc.) and can be divided in sub-actions.

6 Conclusions

As above highlighted, the circular city is to date still open concept for debate, that is identified by different perspectives in literature and in practice.

Tools play a fundamental role in the circular city model implementation. The evaluation framework in the circular city should be characterized by an iterative learning process through three stages: evaluation, monitoring and adaptation. In fact, considering that cities, and therefore its elements (as cultural assets), evolve and transform over time, a "dynamic" evaluation framework is necessary to be able to grasp the impacts in changing conditions in the short, medium and long term and to continuously monitor to understand if we are moving in the right direction. In this way, if the results are not as expected, interventions can be reviewed and adapted to better address the challenges. This could lead to several feedback loops over time (dynamic aspect of evaluation). The discipline of evaluations helps not only to compare the alternatives already given, but also to produce new solutions by aiming at a positive sum game in which all subjects obtain benefits [116].

The technology is a mean and not the aim of the circular city model. The "heart" of the circular city is represented by relationships and synergies. The human being has a central role. According to the paradigm shift (human scale of development), the human dimension (and thus the human social capitals) plays a key role in implementing the circular city model. The success of the implementation surely depends on human behaviour.

Cities are characterized by amount of waste related to industrial activities, to land use, to household, to building sector, etc., but also to "waste" of human and social capital. Circular economy related to cultural heritage contributes to minimize waste of different kinds of capital: natural capital, manmade capital but also human and social capital. The latter is referred to unemployed, marginal people, poor people, etc. Circular economy is focused not only on flows and recycling, but it is also linked to the relational capital, thus incorporating the avoiding "waste" of human capital, of skills, knowledge, creative, entrepreneur capacity of human beings [117]. This is coherent with the human-cantered approach.

Putting the human being at the core of the circular city model requires investments in research, but also investment in cultures for changing the mindset and the lifestyles by bottom-up. This challenge requires specific strategic development plans, financial tools, etc. but also a strategic plan for culture. This strategic plan for culture is grounded on enhancing competence and the capacity of critical thinking by each subject stimulating a circular way of thinking. This circular/relational rationality improves responsibility. Considering that responsibility is based on evaluation of impacts of each action and that critical thinking is the pre-condition for responsibility, the key characteristic of the strategic plan for culture is to be recognized in the evaluation capacity by each citizens.

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