

Le ICT a supporto della progettazione circolare in ambito urbano

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Francesca De Filippi<sup>1</sup>, Carmelo Carbone<sup>2</sup>,

<sup>1</sup> Dipartimento Architettura e Design, Politecnico di Torino, Italia

<sup>2</sup> Politecnico di Milano, Italia

francesca.defilippi@polito.it

carmelo.carbone@mail.polimi.it

**Abstract.** Le sfide connesse all'applicazione dei principi dell'Economia Circolare alla scala urbana sono state scarsamente studiate o interrogate criticamente. Il contributo intende definire possibili indicazioni per l'utilizzo delle ICT, allo scopo di stimolare e monitorare azioni circolari a scala urbana. Sono dunque individuati quattro sottosistemi urbani ai quali riferire i programmi urbani circolari e i principali benefici che possono derivare per specifiche categorie di stakeholders. Si indagano le principali possibilità offerte dall'uso delle ICT e le più ricorrenti funzionalità implementate negli strumenti digitali ad esse associate. Con riferimento agli indicatori presenti in letteratura, si individua infine una strategia per monitorare gli effetti delle azioni sull'ecosistema.

**Parole chiave:** Città circolari; *Digital Participatory Platforms*; ICT; *Circular planning*; Monitoraggio.

## Introduzione

L'Europa ha bisogno di risorse pari a due-tre pianeti per sostenere i propri attuali stili di vita (Gonçalves, 2008), con un trend in continuo aumento.

In questo quadro, l'emergere di modelli di sviluppo circolare spinge verso un sistema rigenerativo in cui sprechi, emissioni e perdite siano ridotti al minimo.

Se il concetto di sviluppo circolare pare molto approfondito per quanto riguarda il settore economico-produttivo, è di epoca più recente il dibattito intorno alle *Circular Cities*: le sfide connesse all'implementazione dell'Economia Circolare sono state infatti «scarsamente studiate o interrogate criticamente, specialmente a scala urbana» (Campbell-Johnston *et al.*, 2019), così come l'adozione di sistemi di monitoraggio è ancora scarsamente diffusa (European Commission, 2018). L'uso delle emergenti *Information and Communication Technologies* (ICT), per il potenziale nella raccolta, gestione, analisi e rappresentazione di dati, può essere di grande interesse nell'applicazione di modelli circolari alla scala urbana.

**Abstract.** The challenges related to the implementation of a circular economy at an urban scale have scarcely been studied or critically interrogated. This contribution aims to define the possible ways in which ICT can be used to stimulate and monitor circular actions on an urban scale. Four urban subsystems have been identified from which circular urban programmes can be linked, providing benefits for numerous categories of stakeholders. This work investigates the main possibilities offered by the use of ICT and the most recurrent functionalities associated with and implemented by digital tools. Finally, among indicators that already exist in the literature, this work identifies a strategy to monitor the effects of the actions on the ecosystem.

**Keywords:** Circular cities; Digital participatory platforms; ICT; Circular planning; Monitoring.

Con riferimento alla letteratura esistente, il presente contributo intende approfondire se e come le ICT possano essere utilizzate per stimolare e monitorare azioni circolari, per facilitare interazioni online e offline tra attori del territorio, comunità locali e competenze specifiche, evidenziando quali benefici possano derivare per specifiche tipologie di stakeholders.

## Economia circolare, città circolari e ICT

Le teorie riguardo a modelli circolari si diffondono nell'ambito dell'ecologia industriale a partire dagli anni '70 e teorizzano una rimodellazione dei sistemi industriali in ottica ecosistemica (Preston, 2012).

L'Economia Circolare è basata su cinque pilastri: *Make, Use, Reuse, Remake, Recycle* (Weetman, 2016), ovvero prevede un design e uso sostenibili, nonchè riflessioni sulle *End of Life strategies*, sintetizzate negli "R" *frameworks* (3R, 4R, 6R, o 9R) (Demestichas and Daskalakis, 2020).

Una città circolare estende la concezione del nuovo modello produttivo a quella di un nuovo modello di sviluppo urbano (Ellen MacArthur Foundation, 2017).

Non esiste un'unica definizione di Città Circolare (Fusco and Nocca, 2018) e sono molteplici i sottosistemi urbani all'interno dei quali vengono individuate azioni circolari, come evidenziano i report di città come Parigi, Londra o Amsterdam (Bastein *et al.*, 2016; LWARB, 2017; Mairie Paris, 2017), la letteratura scientifica (Petit-Boix, 2018) o, ancora, studi come quello dell'*Organisation for Economic Cooperation and Development* (OECD, 2020).

L'attuazione di programmi di Economia Circolare a scala urbana si misura con molteplici *key challenges*, riferibili a otto ambiti:

## Introduction

Europe needs resources equivalent to two to three planets to support its current lifestyle (Gonçalves, 2008), with a continuously increasing trend.

In this context, the rise of circular development models push towards a regenerative system in which waste, emissions and losses are minimised.

There is a thorough concept of circular development with regard to the economic-productive sector. However, the debate around Circular Cities is more recent. The challenges connected to the implementation of the circular economy have, in fact, "scarcely been studied or critically interrogated, especially at city level" (Campbell-Johnston *et al.*, 2019), just as the adoption of monitoring systems is still scarcely diffused (European Commission, 2018). The use of emerging Information and Communication Technologies (ICT)

for the potential collection, management, analysis and representation of data can be of great interest to the application of circular models at the urban scale.

With reference to the existing literature, this contribution intends to investigate if and how ICT can be used to stimulate and monitor circular actions, to facilitate online and offline interactions between local actors, communities and expertise, and to highlight the benefits that can be derived for various types of stakeholders.

## Circular economy, circular cities and ICT

The theories surrounding circular models spread in the field of industrial ecology starting in the 1970s, aiming to theorise and remodel the industrial systems from an ecosystemic perspective (Preston, 2012).

ICT as innovative tools for circular planning in urban areas

socio-culturale, economico e finanziario, informativo, normativo, politico, istituzionale, ambientale e tecnico (Williams, 2019). La digitalizzazione è considerata uno dei principali *enabler* dell'Economia Circolare (OECD, 2020) e si ritiene che le ICT svolgano un ruolo importante in tale processo di transizione (Pagoropoulos, 2017). Le possibilità offerte dalle ICT nel favorire la raccolta, l'analisi e la rappresentazione di dati consentono di apportare benefici in settori come l'economia, l'istruzione, l'energia, l'ambiente, i trasporti, generando opportunità per i cittadini e le imprese (Raghupathi *et al.*, 2014). Consentono inoltre di fornire servizi, pubblici e privati, e favorire azioni di monitoraggio e *decision making*. I principi dell'Economia Circolare (4R framework: *reduce, reuse, recycle, restore*) possono essere attuati facendo ricorso a diverse tipologie di ICT, tra cui: *Communications, Computing Technologies, CPS, Data Analysis and AI Algorithms, Data Collection and IoT, Data Management and Storage, Software and Simulation Technologies* (Demestichas and Daskalakis, 2020), grazie alle funzionalità di *Asset tagging, Geo-spatial information, Big data management, Connectivity* (Sukhdev *et al.*, 2018), che consentono molteplici opportunità, sia a scala del prodotto che urbana. Le piattaforme online rappresentano lo strumento forse più completo per gestire le dinamiche urbane, per fornire informazioni e servizi, per coinvolgere e coordinare la collaborazione tra i diversi stakeholders (De Filippi *et al.*, 2017).

### ICT come *enabler* di processi collaborativi

Le risorse necessarie alla realizzazione di una Città Circolare sono di tipo tangibile (infrastrutture di trasporto, energia e risorse naturali) e intangibile (capitale umano, istruzione e conoscenza e capitale intellettuale

Circular economy is based on five pillars: Make, Use, Reuse, Remake, Recycle (Weetman, 2016). It envisions sustainable design and use and reflects on the End-of-Life strategies, summarised in the "R" frameworks (3R, 4R, 6R, or 9R) (Demestichas and Daskalakis, 2020).

A circular city extends the concept of the new production model to that of a new model of urban development (Ellen MacArthur Foundation, 2017).

There is no single definition of a circular city (Fusco and Nocca, 2018) and there are many urban subsystems within which circular actions are identified. This can be seen in city reports such as those of Paris, London or Amsterdam (Bastein *et al.*, 2016; LWARB, 2017; Mairie Paris, 2017) in scientific literature (Petit-Boix, 2018) and in studies such as that of the Organisation for Economic Cooperation and

Development (OECD, 2020).

The implementation of circular economy programmes at an urban scale involves multiple key challenges relating to eight areas: socio-cultural, economic and financial, information, regulatory, political, institutional, environmental and technical (Williams, 2019).

Digitisation is considered one of the main enablers of circular economy (OECD, 2020) and ICT is believed to play an important role in this transition process (Pagoropoulos, 2017).

The possibilities offered by ICT in the collection, analysis and representation of data for benefits in sectors such as the economy, education, energy, environment and transport generates opportunities for citizens and companies alike (Raghupathi *et al.*, 2014). They also make it possible to provide public and private services and encourage

delle imprese); è ormai opinione condivisa che la dimensione sociale sia parte integrante del quadro economico circolare (Fusco and Nocca, 2018). Si assiste così a una nuova stagione di collaborazione e condivisione di conoscenze su temi e azioni di sostenibilità ambientale, che vede l'alternarsi di interventi di tipo *top down* e *bottom up* nelle politiche pubbliche, come dimostrano le reti globali di governi locali e regionali (ICLEI), le connessioni tra professionisti e sindaci (C40 cities) e le partnerships tra città (CIRCuiT).

Le piattaforme digitali rappresentano un luogo di incontro e valorizzazione delle competenze, un hub di innovazione e un mezzo per lo scambio di risorse (Metta and Bachus, 2020); consentono inoltre a persone e organizzazioni varie possibilità (Knonietzko *et al.*, 2019):

1. *market*, coordinare lo scambio tra attori;
2. *operate*, gestire i sistemi *Product-Service*;
3. *co-create*, co-creare prodotti e servizi.

I diversi attori (stakeholder) coinvolti, direttamente o indirettamente, nel processo di trasformazione sostenibile delle città (Fusco and Nocca, 2019; Williams, 2017; Azhar, 2011; Fraccascia and Yazan, 2018; European Commission, 2019) possono ottenere molteplici benefici dall'applicazione di tecnologie ICT e da strategie di sviluppo circolare (Tab. 1).

Un piano di utilizzo consapevole delle ICT per il supporto di programmi urbani circolari deve essere sviluppato seguendo una metodologia rigorosa, ma tenendo in considerazione lo spazio fluido in cui si muove l'innovazione sociale.

Un portale unico per tutti i dati consentirebbe di esplorare i dati catalogati (Lapi *et al.*, 2012), fornendo informazioni leggibili sulla base di criteri condivisi.

monitoring and decision-making actions.

The circular economy principles (4R framework: reduce, reuse, recycle, restore) can be implemented using different types of ICT, including: Communication, Computing Technologies, CPS, Data Analysis and AI Algorithms, Data Collection and IoT, Data Management and Storage, Software and Simulation Technologies (Demestichas and Daskalakis, 2020). This is thanks to the functionalities of Asset Tagging, Geo-Spatial Information, Big Data Management, and Connectivity (Sukhdev *et al.*, 2018), all of which facilitate multiple opportunities at both the product and urban scale.

Online platforms represent perhaps the most complete tool for managing urban dynamics, providing information and services, as well as engaging and coordinating collaboration be-

tween various stakeholders (De Filippi *et al.*, 2017).

### ICT as *enabler* of collaborative processes

The resources necessary for developing a circular city are both tangible (transport infrastructures, energy and natural resources) and intangible (human capital, education, knowledge and intellectual capital of companies), and it is now a shared opinion that the social dimension plays an integral part of the circular economic system (Fusco and Nocca, 2018). We are thus witnessing a new season of collaboration and the sharing of knowledge on environmental and sustainable issues and actions. As a result, we are seeing the alternation of top-down and bottom-up interventions in public policies. Some highlights include: global networks of local and regional governments (ICLEI),

Tab. 01 | Elenco degli stakeholder e rispettivi benefici. Elaborazione degli autori  
List of stakeholders and respective benefits. Elaboration by the authors

Stakeholder	Benefits
<b>Citizens</b>	ICT can promote citizen involvement in urban planning (Fusco, Nocca, 2019) and in the co-production of data (Williams, 2017), goods and services. The digitization of information allows you to stimulate sustainable actions and foster empowerment.
<b>Organizations and Associations</b>	The sharing of information about the actions carried out and the increase in communications can favor the activities of the organization.
<b>Designers</b>	The presence of updated databases allow the adoption of circular design choices. The use of ICT can facilitate the transformation and adaptability of the works as well as facilitate repair and maintenance operations. Further benefits can be identified in the use of BIM (Azhar, 2011).
<b>Enterprises, Producers, Supplier</b>	Companies can easily share information on their geographical location, the type and quantity of resources both produced and required, as well as their willingness to start new IS (industrial symbiosis) relationships (Fraccascia, 2018).
<b>Investors and Facility managers</b>	The availability of data allows for more prudent and effective actions. Fostering communication between the actors can result in an increase in profit and reliability.
<b>Public administration and Policy makers</b>	The use of ICT can allow the implementation of circular government policies ( <i>Regulate, Realise, Stimulate, Inspire</i> ) (European Commission, 2019)

Tab. 01

01 | Sottosistemi urbani per le Città Circolari. Elaborazione degli autori  
Urban subsystems for Circular Cities. Elaboration by the authors

## Le ICT a supporto di processi circolari in ambito urbano

Come anticipato, non esiste una metodologia condivisa per lo sviluppo di azioni circolari.

Per definire la strategia di intervento, gli strumenti e le funzionalità da implementare vengono pertanto qui analizzati diversi framework.

L'approccio metodologico di riferimento principale è il *Circular city implementation framework* (ITU, 2020), che stabilisce gli step per assistere gli stakeholders nell'attuazione di azioni circolari:

1. stabilire una *baseline* per la circolarità;
2. determinare il potenziale della circolarità in diversi asset e stabilire le priorità;
3. applicare gli *enabler* per catalizzare le azioni;
4. valutare gli impatti.

Ulteriori direttive sono fornite dalla European Investment Bank, sintetizzate in "*Plan, Act, Mobilise and Monitor*" e suddivise in 15 step (EIB, 2018), da Organismi o Enti quali Ellen MacArthur Foundation (*Regenerate, Share, Optimise, Loop, Virtualise, Exchange*) (Ellen MacArthur Foundation, 2015) e Circular Cities Hub (*looping, localisation, substitution, adaptation, sharing, optimising and regenerating natural capital*) (Williams, 2017).

La definizione di sviluppo circolare nasce da studi sui nostri impatti ambientali (Preston, 2012): un'azione si definisce "circolare" sulla base della misurazione dei suoi effetti sull'ambiente. In analogia, si propone qui una metodologia di sviluppo e monitoraggio di azioni urbane circolari basate su due assunti di partenza:

1. concentrarsi sugli "effetti" ambientali delle nostre azioni stimolando azioni sulle loro cause;

connections between professionals and mayors (C40 cities) and partnerships between cities (CIRCUIIT).

Digital platforms represent a place of connectivity and skill enhancement; an innovation hub and a means for the exchanging of resources (Metta and Bachus, 2020); they also provide people and organisations with possibilities (Knonietzko *et al.*, 2019):

1. market, to coordinate the exchange between actors;
2. operate, to manage Product-Service systems;
3. co-create, to co-create products and services.

The various stakeholders involved both directly and indirectly in the sustainable transformation process of cities (Fusco and Nocca, 2019; Williams, 2017; Azhar, 2011; Fraccascia and Yazan, 2018; European Commission, 2019) can obtain multiple benefits

from the application of ICT technologies and circular development strategies (Tab. 1).

A plan for the conscious use of ICT to support circular urban programmes must be developed following a rigorous methodology, but should also take into account the fluid space in which social innovation moves.

A single portal for all data would allow for the exploration of catalogued data (Lapi *et al.* 2012), providing readable information on the basis of shared criteria.

### ICT to support circular processes in the urban environment

As previously mentioned, there is no shared methodology for the development of circular actions.

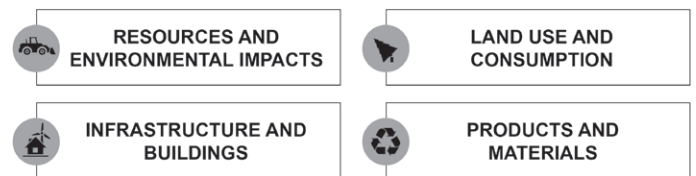
Various frameworks are therefore analysed to define the intervention strategy, the tools and functionalities to be

2. definire aspetti "quantitativi" e non qualitativi alla quale riferire le azioni (informazioni qualitative vengono ritenute non imparziali).

La piattaforma online è il luogo in cui convergono tali dati e che consente di fornire un quadro trasparente, di favorire lo scambio di risorse, e di gestire i processi. Si forniscono agli stakeholders gli strumenti per agire sulle cause dei nostri impatti (*bottom up*) e parallelamente si facilita il processo di *decision-making* (*top down*). Vengono di seguito individuati 4 ambiti (Fig. 1), a diverse scale, in cui declinare le azioni circolari e ai quali riferire il monitoraggio della circolarità di un territorio:

1. impatti e risorse ambientali;
2. uso e consumo di suolo;
3. infrastrutture e edifici;
4. prodotti e materiali.

I sottosistemi urbani individuati in letteratura convergono all'interno di tali ambiti.



01

implemented.

The methodological approach used as reference is the Circular City Implementation Framework (ITU, 2020), which establishes the steps to assist stakeholders in the implementation of circular actions. These are:

1. establish a baseline for circularity;
2. determine the potential for circularity in different assets and set priorities;
3. apply enablers to catalyse actions;
4. assess the impacts.

Further directives are provided by the European Investment Bank, summarised in "*Plan, Act, Mobilise and Monitor*" and are divided into 15 steps (EIB, 2018), by Organisations or Entities such as The Ellen MacArthur Foundation (*Regenerate, Share, Optimise, Loop, Virtualise, Exchange*) (Ellen MacArthur Foundation, 2015) and Circular Cities Hub (*looping, localisa-*

tion, substitution, adaptation, sharing, optimising and regenerating natural capital) (Williams, 2017).

The definition of circular development originates from studies on our environmental impact (Preston, 2012). An action is defined as "circular" on the basis of its effects on the environment. A methodology is proposed here for the development and monitoring of circular urban actions based on two assumptions:

1. focus on the environmental "effects" of our actions, stimulating actions on their causes;
2. define "quantitative" and not qualitative aspects to which to refer the actions (qualitative information is considered non-impartial).

The online platform is the place where such data converges, providing a transparent framework for the exchange of resources and the management of pro-



Tab. 02 | Funzionalità implementabili nelle piattaforme ICT per favorire azioni circolari.  
Elaborazione degli autori  
Functionalities that can be implemented in ICT platforms to encourage circular actions.  
Elaboration by the authors

LEVEL OF INVOLVEMENT	MAIN FUNCTIONALITIES
<b>Information</b>  <i>(one-way communication from the government to citizens)</i>	Updated "circular" regulatory references Education and updating (online-offline) Best practices (according to a framework - online and offline) Links to databases on product sustainability, etc. Monitoring of emissions and energy consumption (NRR) Resource use monitoring (biotic and abiotic) Monitoring of air, water and soil quality
<b>Interaction</b>  <i>(two-way communication with dialogue between citizens and government representatives)</i>	Soil mapping by type and monitoring of naturalized areas Monitoring of biodiversity (n° species and individuals) Mapped buildings (abandoned, underused and redeveloped) Database on materials and products in the end-use or waste phase Exchange of raw materials, secondary materials, products and services
<b>Collaboration</b>  <i>(two-way interactions go beyond the exchange of basic information to "materialize" into policy measures, provision of joint services or other interventions)</i>	Identification and mapping of synergies (e.g.: industrial) Stakeholder network (Circular economy office) Repair, recovery, reuse, recycling services Urban initiatives in progress (for participation)

Tab. 02

Alla macro-scala, per quanto riguarda gli impatti e le risorse ambientali, l'utilizzo delle ICT consente di migliorare il grado di informazione degli stakeholders, di promuovere azioni partecipative e l'uso di fonti e risorse rinnovabili o a basso impatto, oltre che stimolare la condivisione di beni, il riuso e il riciclo (Ellen MacArthur Foundation, 2019).

Inoltre, l'applicazione delle ICT può contribuire a raggiungere gli obiettivi sul consumo/degrado del suolo (bilancio non negativo entro il 2030 (UN, 2015), azzeramento del consumo di suolo netto entro il 2050), sulla tutela della biodiversità e sul contrasto al cambiamento climatico (ISPRA, 2018).

A scala intermedia, le infrastrutture e gli edifici sono interessati da numerose sfide che limitano l'adozione di un modello circolare (Lavagna *et al.*, 2019). Grazie alle tecnologie digitali è possibile eseguire la mappatura del tessuto urbano, incentivare l'uso e lo *sharing* di edifici abbandonati o sottoutilizzati mediante nuovi modelli collaborativi, sollecitare il riuso (Riusiamo l'Italia; Clicproject) e il recupero (Wijkman, 2018) attraverso approcci sostenibili, fornire nuovi spazi alla comunità tramite interventi a *positive handprint* o impatti contenuti.

A più piccola scala, le tecnologie digitali possono facilitare la quantificazione dei flussi materici, contribuendo, per esempio, a gestire e ridurre i rifiuti urbani (Iona and Gheorge, 2014).

Materiali e prodotti possono essere collegati a sistemi di *Automatic identification and data capture*, consentendo lo sviluppo di banche dati che tengano in considerazione LCA e LCC, oggi sottosfruttati. Attraverso l'attività di mappatura è possibile stimolare azioni basate sul riuso, riciclo, *remanufacturing* ecc. (Wijkman, 2018) e servizi circolari (*Product Service-Systems, pay per use, leasing, take-back, buy-back*, ecc.), oltre che consentire

cesses. Stakeholders are provided with the tools to act on the causes of our impacts (bottom up) and at the same time the decision-making process is facilitated (top down).

The circular actions can be broken down into four areas, as identified below (Fig. 1). The monitoring of the circularity of a territory at different scales must be viewed in accordance with these areas:

1. resources and environmental impacts;
2. land use and consumption;
3. infrastructure and buildings;
4. products and materials.

The urban subsystems identified in the literature converge within these areas. At the macro-scale, in regards to resources and environmental impacts, the use of ICT improves the level of stakeholder information to promote participatory actions and the use of

renewable or low-impact sources and resources, as well as stimulate goods sharing, reuse and recycling (Ellen MacArthur Foundation, 2019).

Furthermore, the application of ICT can contribute to achieving the objectives around land consumption / degradation non-negative balance by 2030 (UN, 2015), zeroing of net land consumption by 2050 the protection of biodiversity and climate change (ISPRA, 2018).

At an intermediate scale, infrastructure and buildings are affected by numerous challenges that limit the adoption of a circular model (Lavagna *et al.*, 2019). Thanks to digital technologies, it is possible to carry out the mapping of the urban fabric, to encourage the use and sharing of abandoned or underused buildings through new collaborative models, to encourage reuse (Riusiamo l'Italia; Clicproject) and

lo stabilimento di *industrial symbiosis/ synergies* (Fraccascia and Yazan, 2018; Wijkman, 2018).

Tali possibilità sono oggetto di crescenti sperimentazioni. È possibile associare ad esse una serie di funzionalità, a seconda del grado di coinvolgimento degli *stakeholder* (Tab. 2), come descritto anche in letteratura (Falco and Kleinhans, 2018), per favorire il superamento di alcune delle principali *key challenges* individuate.

### Monitoraggio di azioni circolari a scala urbana

Escluso il settore economico-produttivo, emerge come l'analisi di sistemi di monitoraggio della circolarità urbana sia ancora scarsamente diffusa e, nonostante la presenza di alcuni set di indicatori (European Commission, 2019; Commissione Europea, 2011), non esista ad oggi un metodo univoco per misurare la circolarità di un territorio.

Tra gli indicatori di monitoraggio proposti per la Circular Economy (es.: Circulytics; IDEAL&CO; European Commission, 2019), la sostenibilità urbana (ITU, 2017; OECD, 2020) e la circolarità urbana (Fusco and Nocca, 2019), si individua un set di indicatori su cui basare una possibile strategia di sviluppo circolare che utilizzi le ICT (Tab. 3).

recovery (Wijkman, 2018) through sustainable approaches and to provide new spaces to the community through interventions with positive handprints or limited impacts.

On a smaller scale, digital technologies can facilitate the quantification of material flows, contributing, for example, to manage and reduce urban waste (Iona and Gheorge, 2014).

Materials and products can be connected to automatic identification and data capture systems, allowing the development of databases that take into account LCA and LCC, which are currently underexploited. Through the mapping activity, it is possible to stimulate actions based on reuse, recycling, remanufacturing (Wijkman, 2018) and circular services (Product Service Systems, pay-per-use, leasing, take-back, buy-back, etc.), as well as allowing for the establishment of indus-

trial synergies (Fraccascia and Yazan, 2018; Wijkman, 2018).

These possibilities are the subject of increasing experimentation. It is possible to associate a series of functionalities to them, depending on the degree of stakeholder involvement (Tab. 2), as also described in the literature (Falco and Kleinhans, 2018), to facilitate the overcoming of some of the main key challenges identified.

Monitoring of circular actions at urban scale

Excluding the economic-productive sector, the analysis of urban circularity monitoring systems is still scarcely adopted and, despite the presence of some sets of indicators (European Commission, 2019; European Commission, 2011), there is currently not a unique method to measure the circularity of a territory.

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Tab. 03 | Sintesi degli aspetti e indicatori urbani monitorati. Gli aspetti monitorati devono essere scomposti in categorie omogenee o ponderati tramite coefficienti di equivalenza. Elaborazione degli autori  
*Summary of urban aspects and indicators monitored. The monitored aspects must be broken down into homogeneous categories or weighted by means of equivalence coefficients. Elaboration by the authors*

Sulla base degli assunti di partenza e delle categorie di sottosistemi urbani esposti, si propone una metodologia di monitoraggio focalizzata sugli aspetti della sostenibilità ambientale e la misurazione della circolarità.

### Circularità delle risorse / impatti ambientali

Il monitoraggio delle risorse e degli impatti ambientali analizza il territorio geografico di riferimento, indipendentemente dalle cause che li hanno determinati.

Tra i valori ritenuti prioritari figurano le emissioni di gas – e relativo GWP – e il consumo energetico proveniente da fonti non rinnovabili, aspetti al centro delle *European policies on climate and energy* (European Parliament, 2019). Inoltre, vengono tenute in considerazione alcune delle categorie di impatto più utilizzate nelle analisi LCA (Pellettier *et al.*, 2007) che, oltre ad analizzare l'uso di risorse ambientali, comportano l'esame degli agenti inquinanti.

### Uso e consumo di suolo

L'indicatore sulla circolarità del suolo monitora lo stato del "suolo" e della biodiversità in esso contenuto con l'obiettivo di stimolare l'incremento delle aree naturalizzate.

Analizzando il consumo di suolo netto, l'indicatore utilizza coefficienti di conversione riferiti alla tipologia di uso e copertura del suolo e il relativo impatto ambientale. Si veda, ad esempio, il *Land Use/Cover Area frame Survey* che classifica il suolo in classi di copertura e uso (Eurostat, 2013).

Un ulteriore valore considerato è la stima della variazione percentuale del numero di individui di flora e fauna delle specie monitorate. L'indicatore non tiene volutamente conto del grado di infrastrut-

Among the monitoring indicators proposed for the circular economy (e.g.: Circulytics; IDEAL&CO; European Commission, 2019), urban sustainability (ITU, 2017; OECD, 2020) and urban circularity (Fusco and Nocca, 2019), a set of indicators on which to base a possible circular development strategy that uses ICT is defined (Tab. 3).

On the basis of the previous assumptions and the categories of urban subsystems explored, this paper proposes a monitoring methodology focused on the aspects of environmental sustainability and the measurement of circularity.

### Circularity of resources / environmental impacts

The monitoring of resources and environmental impacts allows for the analysis of the geographical area of

reference, regardless of the causes that determined them.

The values considered to be priority include gas emissions – (and related GWP) – and energy consumption from non-renewable sources, aspects at the heart of European policies on climate and energy (European Parliament, 2019). In addition, some of the impact categories most used in LCA analysis are taken into account, (Pellettier *et al.*, 2007) which, in addition to analysing the use of environmental resources, involve the study of pollutants.

### Land use and consumption

The soil circularity indicator monitors the state of the "soil" and the biodiversity contained with the aim of stimulating the increase of naturalised areas. Analysing the net land consumption, the indicator uses conversion coefficients referring to the type of land use

	MONITORED ASPECT	INDICATOR	UNIT
1	Circularity of resources / environmental impacts	It measures the alteration of the ecosystem through percentage variations (of each value) compared to reference values	/
1.1	Use of biotic and abiotic resources * Respective resources restored	Balance between consumed and restored resources	Ton Y/pop (or) M <sup>3</sup> Y/ab
1.2	Emissions (GWP) *	Variation of CO2 equivalent emissions compared to reference values	(ΔCO <sub>2 eq</sub> Y) /pop
1.3	Energy consumption (from non-renewable resources)	Variation in energy consumption from non-renewable sources compared to reference values	(ΔKWh Y) /pop
1.4	Air quality *	Average of the pollutant content found on various air samples	μ pollutants/m <sup>3</sup> <sub>a</sub>
1.5	Water quality * (fresh and salty)	Average of the pollutant content found on various water samples	μ pollutants/m <sup>3</sup> <sub>w</sub>
1.6	Soil quality *	Average of the pollutant content found on various soil samples	μ pollutants/m <sup>2</sup>
2	Land use and consumption	It measures changes in natural areas through percentage variations (of each value) compared to reference values	/
2.1	Consumed virgin areas* Consumed areas converted*	Balance between consumed and reconverted areas (coefficients for coverage and use classes are used)	Km <sup>2</sup> /pop
2.2	Degradation of biodiversity*	Variation in the number of individuals (flora and fauna)	%
3	Circularity of Infrastructures and Buildings	It measures the transformations of the built heritage through percentage variations (of each value) compared to reference values	/
3.1	Structures built	Surface of constructed buildings	M <sup>2</sup> /pop
3.2	Structures demolished	Surface of demolished buildings	M <sup>2</sup> /pop
3.3	Abandoned structures redeveloped*	Variation between abandoned and redeveloped buildings compared to reference values	M <sup>2</sup> /pop
3.4	Redeveloped underused structures*	Variation between underused and redeveloped buildings compared to reference values	M <sup>2</sup> /pop
4	Circularity of Materials and Products	It measures the percentage variation in the mass / volume of waste in landfills compared to reference values	/
4.1	Non-recycled waste produced*	Quantity of waste produced that is not recycled or reused	Ton Y/pop (or) M <sup>3</sup> Y/pop
4.2	Recycled waste with downcycling	Quantity of waste recycled with excessive loss of value compared to the original product (eg: waste-to-energy, filling, etc.)	Ton Y/pop (or) M <sup>3</sup> Y/pop

Tab. 03

turazione già esistente, in quanto nei centri meno sviluppati dovrà seguire i requisiti fissati a livello nazionale e sovranazionale e prevedere adeguate compensazioni ambientali.

### Circularità di infrastrutture e edifici

Il monitoraggio della circolarità urbana a media scala si focalizza sugli edifici e le infrastrutture, responsabili per circa il 75% delle emissioni di GHG (UNEP, 2017) e di circa il 67-76% della domanda di energia globale (IRENA, 2020).

L'indicatore sulla circolarità di edifici e infrastrutture si foca-

and cover and the related environmental impact. See, for example, the Land Use / Cover Area frame Survey which classifies soil into classes of cover and use (Eurostat, 2013).

A further value considered is the estimate of the percentage change in the number of individual-flora and fauna of the monitored species.

The indicator deliberately does not take into account the level of existing infrastructure, as the new infrastructure of less-developed centres will have to follow the requirements set at national and supranational level, and provide for adequate environmental compensation.

### Circularity of infrastructure and buildings

The monitoring of medium-scale urban circularity focuses on buildings and infrastructure that are responsible for about 75% of GHG emissions

(UNEP, 2017) and about 67-76% of global energy demand (IRENA, 2020). The indicator on the circularity of buildings and infrastructure focuses on the redevelopment of abandoned or underused buildings. The monitoring considers those newly built and demolished. These activities, if not coordinated by circular processes, appropriately compensated or supported by analysis as LCA, can result in an increase in environmental impacts.

### Circularity of materials and products

With the aim of managing and reducing urban waste (Iona and Gheorghie, 2014), the small-scale circularity indicator focuses on monitoring the quantity of waste generated, i.e. biotic and abiotic resources that are not reused or recycled, in contrast to the definitions of circular models.

The indicator measures waste, divided into homogeneous categories, and the

lizza sulla riqualificazione delle costruzioni abbandonate o sottoutilizzate. Il monitoraggio considera le attività di nuovo costruito e demolito. Tali attività, se non coordinate da processi circolari, opportunamente compensate o supportate da analisi di tipo LCA, possono tradursi nell'incremento degli impatti ambientali.

### *Circolarità di materiali e prodotti*

Con lo scopo di gestire e ridurre i rifiuti urbani (Iona and Gheorghe, 2014), l'indicatore di circolarità a piccola scala si focalizza sul monitoraggio del quantitativo di rifiuti generati, ovvero le risorse biotiche e abiotiche non riutilizzate o riciclate, in contrasto con le definizioni di modelli circolari.

L'indicatore misura i rifiuti, suddivisi in categorie omogenee, e il quantitativo di risorse soggette a *downcycling*, ovvero a perdita di valore e risorse nei processi di riciclo. Per tale aspetto è necessario individuare definizioni specifiche di *downcycling* e adeguati modelli di analisi. Il monitoraggio può servirsi di strumenti e metodi per il *Nature-Based Solutions assessment* (Katsou *et al.*, 2020) e il *material passport*, per determinare la circolarità dei prodotti.

### **Conclusioni e direzioni di ricerca**

Con il modello della Città Circolare, la dimensione ambientale dello sviluppo urbano diventa

il driver delle trasformazioni economiche e sociali.

Sebbene le barriere per l'utilizzo di ICT e per la digitalizzazione dei principi dell'Economia Circolare siano molteplici (Ritzén and Sandström, 2017; Demestichas and Daskalakis, 2020; Raghupathi *et al.*, 2014), le tecnologie informatiche possono essere utilizzate per gestire i confini tra *knowledge* e *action*, aumentando

amount of resources subject to downcycling or loss of value and resources in recycling processes. For this aspect, it is necessary to identify specific definitions of downcycling and adequate analysis models. Monitoring can be done with tools and methods for Nature-Based Solutions assessment (Katsou *et al.*, 2020) and a material passport to determine the circularity of products.

### **Conclusions and research directions**

With the circular city model, the environmental dimension of urban development becomes the driver of economic and social transformations.

Although there are various barriers for the use of ICT and for the digitisation of circular economy principles (Ritzén and Sandström, 2017; Demestichas and Daskalakis, 2020; Raghupathi *et al.*, 2014), information technologies can be used to manage boundaries be-

tween knowledge and action, increasing the relevance, credibility and legitimacy of the information they produce (Cash *et al.*, 2003).

The representation of resources, competences, needs, goods and services allow stakeholders to build networks, collaborate and organise their actions in relation to community objectives, encouraging a circular development. ICT can be used to stimulate and monitor circular actions, but a shared strategy needs to be defined first.

The initial step is to establish the territorial priorities, define the limit (or reference) values and define the environmental and temporal objectives.

The second step concerns the identification and organisation of stakeholders and skills, as well as the development of the "fluid" infrastructure (technological and regulatory) that favours online and offline social innovation.

do la rilevanza, la credibilità e la legittimità delle informazioni che producono (Cash *et al.*, 2003).

La rappresentazione di risorse, competenze, bisogni, beni, servizi, ecc. consente agli stakeholders di costruire reti, collaborare, e organizzare le proprie azioni in relazione agli obiettivi comunitari per favorire uno sviluppo circolare.

Le ICT possono essere utilizzate per stimolare e monitorare azioni circolari, ma è necessario definire una strategia condivisa. Il primo step è stabilire le priorità territoriali e definire i valori limite (o di riferimento) e gli obiettivi ambientali e temporali.

Il secondo riguarda l'individuazione e l'organizzazione degli *stakeholder* e delle competenze, nonché lo sviluppo dell'infrastruttura "fluida" (tecnologica e normativa) che favorisca l'innovazione sociale online e offline.

Il terzo step prevede la definizione di luoghi e modalità per il monitoraggio del territorio e delle azioni. I dati prodotti, rappresentati in maniera trasparente, aperta, ed efficace (es.: banche dati, mappature, ecc.), sono alla base dello sviluppo delle azioni urbane.

Le potenzialità offerte dagli strumenti digitali racchiudono tuttavia molteplici aspetti critici e irrisolti, tra cui i concetti di *privacy*, identità, diritti di accesso, comunità, neutralità della rete, ecc. (Rodotà, 2013). L'uso delle ICT per interventi a scala urbana necessita quindi ancora di importanti interventi di tipo sociale, l'attuazione di misure volte a ridurre il *digital divide* (Van Dijk, 2006) e regolare il possesso e l'uso dei dati (Al-Khouri, 2012).

Le tecnologie, da sole, non sono sufficienti ad intraprendere uno sviluppo strategico e circolare. All'uso delle ICT è necessario associare azioni normative, incentivi, disincentivi e attività di informazione e promozione. La base per un utilizzo sostenibile

The third step involves the definition of places and methods for monitoring the territory and actions. The data produced, represented in a transparent, open and effective way (e.g. databases, mappings, etc.), is the basis for the development of urban actions.

However, the potential offered by digital tools contains many critical and unresolved aspects, including the concepts of privacy, identity, access rights, community, net neutrality, etc. (Rodotà, 2013). The use of ICT for urban-scale interventions still requires important social interventions, the implementation of measures aimed at reducing the digital divide (Van Dijk, 2006) and regulating the possession and use of data (Al-Khouri, 2012).

Technologies alone are not sufficient to undertake strategic and circular development. For the use of ICT, it is necessary to associate regulatory actions,

incentives, disincentives, information and promotional activities. The basis for a sustainable use of new technologies is the definition of a political vision for the medium and long term, and the provision of adequate tools for implementation and monitoring.

The sustainable transition of cities cannot transcend the adequate use of these tools.



delle nuove tecnologie è la definizione di una visione politica sul medio e lungo termine e la previsione di adeguati strumenti per l'implementazione e il monitoraggio. La transizione sostenibile delle città non può trascendere dall'adeguato utilizzo di questi strumenti.

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