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Smart District and Circular Economy: The Role of ICT Solutions in Promoting Circular Cities

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Abstract: Cities will have a decisive role in reducing the consumption of resources and greenhouse gas emissions by 2050. Various experiences of urban regeneration have exploited Information and Communication Technology (ICT) potentialities to optimize the management of complex systems and to encourage sustainable development models. This paper investigates the role of ICT technologies in favouring emerging design for Circular Economy (CE) in the urban context. The paper starts by defining the theoretical background and subsequently presents the goal and methodology of investigation. Through a scoping review, the authors identify case studies and analyse them within the Ellen MacArthur Foundation classification framework that splits the urban context into three urban systems: buildings, mobility and products. The research focuses on nine case studies where the ICT solutions were able to promote the principles of CE. The results show, on the one hand, how data management appears to be a central issue in the optimization of urban processes and, on the other hand, how the district scale is the most appropriate to test innovative solutions. This paper identifies physical and virtual infrastructures, stakeholders and tools for user engagement as key elements for the pursuit of CE adoption in the urban context.

Keywords: smart district; circular economy; urban systems; ICT; systemic design; urban metabolism

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1. Introduction

Sixty years after Kenneth E. Boulding's work [1], the concept of a 'closed' system has returned strongly in the interpretation of anthropic processes through the principles of Circular Economy (CE). In the same years scholars belonging to different disciplines, economists, business people, activists and heads of state from all five continents collaborated in the Club of Rome [2]. In this approach input-output models compared industrial systems to natural ones. Such studies highlighted the scarcity of the planet's resources and the catastrophic effects of an uncontrolled production of waste. Today, we are aware that the Earth is a finite space characterized by limited resources [3]. The transition to new circular economic models could establish a new balance between the components of the anthropized ecosystem. Cities, particularly, constitute the main space in which the challenge of the paradigm shift will have to take place. The percentage of the population that will live in urban centres is growing, from the current 55% to 70% in 2030 [4]. Urban spaces are now responsible for the consumption of 75% of natural resources, more than 50% of global waste and between 60 and 80% of greenhouse gases emissions [5]. The need for a regenerative economy is evident. The use of products, components, materials and services must be managed better through the introduction of circular and biological processes, in other words establishing a CE [6].

Nevertheless, this mission has to overcome the barriers highlighted by the literature in the CE definition, involving a social dimension in its goals [7].

The dramatic increase of consumption of non-renewable resources and emissions underlines how business-as-usual anthropogenic linear processes and activities are unable to follow the natural principles of circularity and regeneration. For this reason, urban space and the activities related to dwelling need a profound transformation. In this regard, the Sustainable Development Goals by the UN Summit in 2015 promote a more inclusive, safe, resilient and sustainable city (see SDG 11) [8]. Furthermore, it is necessary to deal with a society where the relationship between man and the environment is increasingly mediated by the digital dimension [9]. The rapid spread of ICT technologies (big data, Internet of Things, AI, etc.) is drastically changing our way of life [10]. This spread has favoured the use of new tools for the management of urban processes [11]. In particular, it is advisable to understand how ICT contributes to the development of 'emerging design and managerial approaches' solutions for CE in the cities.

In this context, the urban space, defined by Castells as a 'space of flows' [12], becomes an interdisciplinary design space [13]. Urban design, therefore, promotes the idea of cities as 'autopoietic' systems. These should produce goods and services by reducing waste and reintroducing as much matter and energy as possible into production cycles [14]. This approach favours the application of new methodologies to analyse, manage and conceive the urban space, such as Systemic Design (SD) [15,16] or Urban Metabolism (UM) [17]. Both facilitate the understanding of complex processes through a holistic and systemic view of the problem. The Ellen MacArthur Foundation (EMF) has developed a classification of Urban Systems (USs) for designers and policymakers. It divides the types of flows that characterize the city into three USs: building, mobility and product [5]. This classification aims to constitute a source of reference for urban policies with a point of view based on sustainable and circular development. The article's goal is to analyse the contribution of ICT technologies to promoting sustainable urban and housing development based on the principles of CE. To do this, the article maps the application of these principles in the most recent neighbourhood design projects. Nine case studies, selected following the emphasis given to the ICT role in the referenced literature, were developed to identify an overview of significant experiences in the new smart neighbourhoods built or renovated in Europe in the last decade. The goal of the investigation was to clarify the emerging design solutions based on the use of ICT solutions for smart districts capable of encouraging CE dynamics.

The paper is structured as follows: the Theoretical Background section analyses the main topics covered in the article. The subsequent section highlights the methodology that led to the choice of the case studies and their re-elaboration and comparison. Finally, the results are presented, and the conclusions highlight future developments on the subject.

2. Theoretical Background

2.1. Sustainable Urban Development

Future visions about cities development envision an urban space where the physical dimension hybrids with the virtual one. It redefines interaction and management ways between users and the city. These experiences based on the use of digital technologies on an urban scale are categorizable in the Smart City (SC) field of study, as defined by the recent standard ISO 37122:2019 [18]. It invites the use of modern technologies to promote efficient services capable of ensuring the people's quality of life from environmental, social and economic points of view. The acceptance of these challenges starting from the local communities could demonstrate the benefits obtainable in the context of application [19]. The neighbourhood scale will be crucial to effectively plan cities to promote CE [20]. Moreover, the development of selective densification phenomena [21,22] favoured an increase of attention to districts. Today, these are designed as little cities inside a bigger one [23]. Nevertheless, there is a strong interdependence between urban districts and urban planning policies [24]. For these reasons, the neighbourhood scale is suitable for providing analysis about the sustainability of contemporary cities. Moreover, the significance of the

neighbourhood scale is boosted by theories and practices such as the Moreno's '15 min city' [25]. It supports the need to design urban spaces where citizens can reach public facilities in 15 min by bike or walking from their home. Neighbourhood redevelopment and new design projects based on proximity, mixed use and sustainable mobility boost the experimentation of scalable digital solutions for the whole city. The integration of digital solutions in urban environment and housing spaces can promote the development of districts and cities based on sustainable principles [5].

Other important aspects of this paradigm shift were the economic crisis in the real estate sector and the new needs of users, which favoured the creation of a new development model fostered by ICT. New stakeholders emerged in this new system; they focused on the design of new services related to the housing and after-sales assistance services [26]. New stakeholders emerged in the market, more focused on the design of new services related to housing and after-sales assistance services such as facility management and asset management firms.

2.2. Urban Data

In this context, nationals and EU directives aim at climate neutrality transition by 2050. These promote careful and sustainable use of resources using digital technological innovation as a facilitating tool. ICT technologies in the urban and industry 4.0 fields (big data, Internet of Things, AI, etc.) have potential for this goal. Nobre and Travares defined them as fundamental and necessary factors to manage complex processes [27].

Today the research about this field envisions a sustainable future thanks to these innovations. ICT technologies will ensure that each building and component works with its optimal efficiency, thus ensuring virtuous management of all the resources that characterize the urban environment [28]. The designer's community is focused on the immediate benefits that these technologies can guarantee to promote circular solutions in urban housing contexts. Nowadays, the scientific community does not have a shared vision of the role that ICT technologies have in the transition to the CE. Pagoropoulos et al. [29] recognized their potential and rapid growth but highlighted that the intersection between digital technologies and the CE represents an area which has not yet been completely investigated. Other sectors such as automotive, agrifood [30] and manufacturing [31] are most advanced in the research of the potential benefits of a circular approach.

There is a limited number of studies in this regard for design at the neighbourhood scale, most of which were conducted after 2014. This situation can be defined as a pre-paradigmatic phase; ICT technologies could provide some practical solutions for the challenges related to the values of the CE [32,33]. However, the literature highlights that urban data management is closely tied to the scale of investigation. The willingness to introduce circular processes into the urban context requires continuous switching between the different scales of analysis [34]. In this sense, the lack of literature on this topic at the district scale represents an interesting field for further investigation mainly due to the scarcity of reliable data.

It is possible to declare that the importance of ICT technologies in the management and evaluation of processes is evident at different scales [35,36]. Today the technological maturity, developed by large multinationals in the ICT sector such as Huawei, Cisco, Google, Ericsson, Microsoft, Siemens and Alibaba, allows us to foresee an increasingly widespread use in cities [37].

2.3. Systemic Design and Urban Metabolism

The complexity of the research field requires a clear overview of the tools and methods most suitable for its analysis. Today, policies and design theories encourage new forms of conscious consumption, capable of overcoming the linear concept of 'take-make-use-dispose' [38]. People often interpret the CE and sustainability as synonyms, but this apparent similarity is not so obvious. Different scientific research gave different definitions on CE, and social aspects are not always mentioned. For this reason, the similarity

between CE and sustainability is not so obvious [39]. A recent literature review about it conceptualizes the CE via an analysis of 114 different definitions [40]. The terminology used to describe this approach includes economic, environmental and social matters. It underlines that the importance of adopting a circular approach does not consist exclusively of the optimization of the input and output processes of the flows. Instead, this approach is related to the set of solutions capable of responding to the original definition of sustainability, which includes social aspects [41]. For this reason, many authors chose to adopt an inclusive definition of CE as shown in Murray et al. [7]. The challenges that characterize the field of investigation are identified as sustainable digital innovations for contemporary urban housing contexts [42].

This uncertainty favoured the development of new disciplines for the study, the analysis and the design of urban processes. Two emblematic examples in the field of design and urban analysis are Systemic Design (SD) and Urban Metabolism (UM). The first focuses on material, resources and information flow analysis. It is experimenting with the application of its principles in some crucial sectors to address the challenges defined by the 2030 Agenda [43,44]. The systemic methodology aims to make complex service systems capable of enhancing the outputs of each activity by transforming them into inputs for other activities inside the same system. Where it operates, it aims to valorise local resources by building relationships between all the stakeholders belonging to the system. In short, it aims at the construction of 'autopoietic' systems capable of self-feeding while maintaining the focus of the project on the users [45].

The second, the UM, derives from the concept of 'industrial ecology' applied to the urban studies. The metabolic approach implies a holistic vision of the urban context investigated, in particular, it measures flows and identifies activities, needs, and drivers that act as 'facilitators/constraints' [46,47]. In particular, it considers the city as a complex ecosystem. It aims at the reorganization of flows by identifying the different typologies that characterize the system. Energy, materials, products, water, people and information are the variables analysed using the UM methodology. The impacts generated by the different flows are analysed to limit both the single effects and their combination [48–50].

In this methodology, the analysis and design of the Urban System (US) require tools capable of managing complex and highly multidisciplinary problems. The introduction of these principles in a complex and heterogeneous context, such as the urban one, involves a series of combined actions aimed at modifying the urban infrastructure, the network and the rules governing the different processes.

3. Urban System (US)

The paper searched for a classification able to categorize the most important fields for city analysis. After this step, the chosen categorisation is developed by EMF in the recent report 'Circular Cities' [5]. This analyses the relationship between the city and the CE using three USs: buildings, mobility, products.

3.1. Building

In Europe, the whole construction sector is the largest consumer of energy and one of the main contributors to carbon dioxide emissions. Buildings are responsible for 40% of energy consumption and 36% of greenhouse gas emissions over their entire life cycle [51]. Dwellings consumed between 24% and 27% of the total energy consumed in Europe from 1970 until 2014 [52]. The International Energy Agency (IEA) reports that almost two-thirds of countries in the world did not have mandatory energy codes for buildings before 2019. All countries need to establish mandatory building energy codes and incentivize new high-performance construction and energy upgrading of existing buildings to align themself with the SDGs by 2030 [53].

Today, the concept of Nearly Zero Energy Building (nZEB) [54] is a consolidated field of research and design. The challenge is now focused on positive energy buildings and on the development of smart grids [55–57] capable of self-feeding through the accumulation

and exchange of energy by renewable sources. Another goal is focused on the reduction of waste due to building maintenance and refurbishment. In this case, flows are designed to minimize the waste of each activity. Designers study this output and try to transform it into input for other activities [58,59]. This approach is important for the redevelopment processes of existing infrastructures and buildings too. The impact of existing buildings must be limited and users must be aware of their impact. Users' behaviours and infrastructure have impacts on the consumption of natural resources that feed building processes and actions [60]. Some typologies of a user's consumption are analysed: energy for heating/air conditioning, lighting and miscellaneous equipment. The drinking water, rainwater and wastewater are flows analysed too [61]. These specify solutions belonging to a broader system; it requires careful design at all stages of a building's life cycle. In this regard, the European Commission has developed Levels, a framework of indicators that focuses on six specific points concerning the life cycle, the healthiness of spaces and items relating to cost, value and future risk [62].

3.2. Mobility

The mobility US includes the set of products and services developed for mobility. This US represents a central issue in European urban development policies from an environmental, social and economic point of view. Today, the transport sector produces about a quarter of the continent's total greenhouse gas emissions [63]. The mobility system contributed to the creation of evident problems within European and world cities: heavy traffic, poor air quality, noise pollution and a high level of CO2 [64]. Citizens' dependence on owned vehicles and their addiction to fossil fuels contribute to the problems described above and favour wasted time and productivity. The space dedicated to mobility takes up to 50% of the available land within European cities [65]; 92% of the time these cars are parked, while when users utilize them, the average filling rate is 1,1-2 people [66], and the overall price of the owned vehicles for European families on average is equal to 20% of their income [67].

The transport sector aims to decrease its emissions and become more sustainable for these and other reasons. In this regard, the European Commission recently set the goal of reducing them by 55% for 2030 and 90% for 2050 [68]. In recent years, the Mobility as a Service (MaaS) [69] concept is one of the most important concepts about alternative mobility. The EMF report highlights how the combination of different factors can favour a systemic development of the sector. For example, new solutions based on digital innovation, new business models and new citizens' habits such as the increase in remote working can incentivize this change. The design goal is to model a new urban mobility system that supports economic, environmental and social prosperity in European cities [70]. Firstly, it depends on reduction objectives. The European Commission developed recently the document 'Sustainable and Smart Mobility Strategy' [71]. It highlights three fields of action for solving the main problems that characterize the sector: sustainable mobility, smart mobility and resilient mobility. In particular, there are a series of objectives that can be reached by 2030. The most important of these are: the reduction of dependence on fossil fuels, the increase of the alternative forms of mobility demand, the environmental assessment of transport costs and the improvement of physical accessibility and digital to multi-transport services.

3.3. Products

The products US includes in this field only the materials flows related to industrial consumer goods (clothes, appliances, furnishings, etc.) with particular attention to the food flow. It represents another challenge for the future of cities, as evidenced by the importance reserved for the issue in SD and UM [72,73]. For this reason, it is possible to categorize in the products US all things consumed in cities and homes. The field of inves-

tigation definition helps to identify what are the main problems related to this US, in particular, the design of consumer goods, the food supply chain management and the cultivation strategies.

The products US includes processes relating to the production and management of waste. In municipal solid waste, three-quarters are waste of consumer goods, the largest part of which cannot be valorised due to the absence of specific collection services and to being design rather than end of life oriented [74]. In consumer goods, e-waste is the category that constitutes an emerging problem. Only 20% of the 49Mt of e-waste produced each year is correctly collected and recycled under appropriate conditions [75]. The use rates of some objects constitute another problem; 80% of household items are utilized once a month [76].

Regarding food chain issues, this is responsible for one-third of all greenhouse gas emissions as well as the degradation of territory. From a quantitative point of view, it exceeds the combination of transport, heating and lighting emissions [77]. At the urban level, the structuring of the supply chain has a heavy influence on the user's choices too. Globalization of the food system advanced environmental degradation and biodiversity loss; it contributed to lowering the prices of high-energy but poorly diversified diets low in fundamental nutrients [78]. Overweight and obesity are higher than before in low-, middle- and high-income countries [79]. Similarly, food-related non-communicable diseases are increasing in low- and middle-income countries [80].

Once again, the initiatives implemented at the governance level highlights a clear direction by the European Commission. In the waste field, a new action plan for the EC [81] aims to intervene in the design phase of consumer goods production. It is focused on the entire life cycle and the urban infrastructures necessary for this goal. Regarding food issues, the main initiatives are the new Common Agricultural Policy (DG AGRI), the FOOD2030 policy framework (DG RTD) and the Circular Economy Package with actions against food waste (DG SANTE). These aim to provide concrete steps to solve the structural problems that characterize urban nutrition.

4. Methodology

This paper maps the most innovative experiences regarding the use of data and ICT technologies in the urban environment. Case studies of regeneration design projects were selected, based on similar socio-economic contexts. As evidenced by the literature reviewed in the Theoretical Background (see Section 2.1), the district scale may be the ideal dimension for testing actions in the sphere of CE. In fact, districts and neighbourhoods constitute an area in which solutions can be experimented with that can potentially be applied to the entire urban sphere. In the absence of a clear definition of the physical and conceptual boundaries of a district, exploratory research was carried out to identify the most significant experiences. A first selection criteria was the year in which work began or design project began. In order to identify the most recent and emerging experiences, only projects started in the last 20 years were considered. The choice of limiting research to Europe is due to the morphological features of European cities and their similar socio-economic and cultural contexts.

A hybrid approach was used to identify case studies capable of combining the experiences discussed in the literature with the research experience of the authors of this paper. This approach was found necessary because the search using the different strings of keywords ("Circular Economy") AND ("District" OR "Neighborhood") on the main online databases (Scopus, Science Direct, Google Scholar) did not meet the aim of this review. For this reason, the identification of projects was carried out mainly as a scoping review considering the sitography and technical documentation of real estate companies, European research projects and reports and bulletins of public institutions. This phase led to the identification of 30 case studies (Figure 1 and Table 1), reduced to 9 cases (Table 2) where the most innovative experiences in implementing ICT-based solutions are found. Relevance to the topic and research questions were the main selection criteria. In this way,

those case studies that presented ICT solutions that were not innovative or that did not significantly impact on process circularity were not selected. After carrying out this first phase, a literature search was conducted using the specific names of the projects, so as to enrich and validate the available documentation.

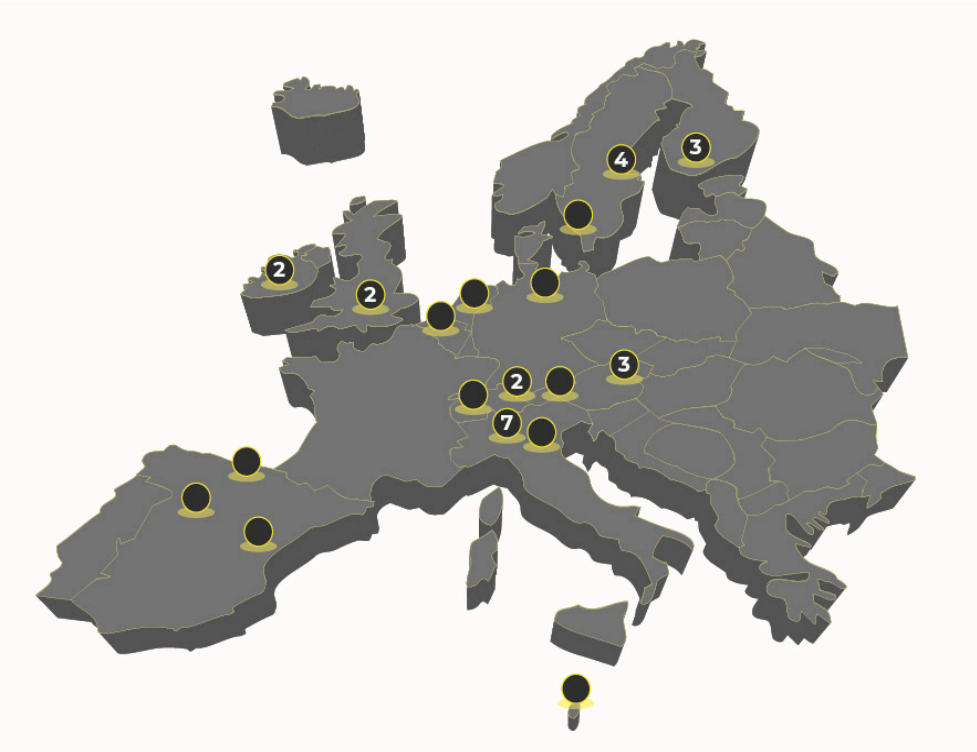

Figure 1. Geolocation of case studies identified.

Table 1. List of case studies identified with their and main characteristics.

N°	Nation	City	Case Study
1	Austria	Wien	Aspern Seestadt, Bike city/Time2Live, Penzing
		Insbruck	Centrum Odorf
2	England	London	Collective Old Oak, Greenwich Millenium Vintage
3	Finland	Helsinki	Jätkäsaari, Kalasatama Smart District
		Espoo	Kera Smart District
4	Germany	Hamburg	Hafen City
5	Ireland	Dublin	Mehr Als Wohnen, Smart Docklands
6	Italy	Milan	Cascina Merlata, City Life, Quartiere giardino, Santa Giulia, SeiMilano
7	Malta	Kalkara	Smart City Malta
8	Netherlands	Amsterdam	Circular Buiksloterham
		Brainport	Brainport Smart District
9	Spain	Barcelona	22@Barcellona
		Valladolid	Fasa Delicias District
10	Sweden	Malmo	Sustainable Rosengard, Hyllie Malmo,Western Harbour
		Stockholm	Hammarby Sjostad, Royal Seaport
11	Switzerland	Chêne-Bougeries	EMS Le Nouveau Prieuè
		Zurich	Kalkbraite, Mehr Als Wohnen

The most innovative experiences were then ranked using the classification identified by EFM (see Section 2.3) that includes three main USs: building, mobility and products.

From this classification, it was possible to identify the main areas of intervention, the potential benefits, the weaknesses and barriers and the stakeholders involved in the process. These considerations are then taken up in the conclusions in order to compare the state of technological maturity in the three different USs and to make considerations about replicability on an urban scale.

Table 2. List of case studies selected regarding the implementation of ICT-based solutions.

N°	Case Study Selected	Nation	References
1	Aspern Seestadt	Austria	[82,83]
2	Jätkäsaari	Finland	[84–88]
3	Kalasatama smart district	Finland	[89–93]
4	Cascina Merlata	Italy	[56,94–96]
5	Quartiere giardino	Italy	[97–99]
6	SeiMilano	Italy	[100]
7	Brainport Smart District	Netherlands	[101,102]
8	Royal Seaport	Sweden	[38,103–106]
9	Fasa Delicias District	Spain	[107,108]

5. Results

This section presents the results of the analysis. These are subdivided into three subsections following the three USs: buildings, mobility and products. The most significant experiences mapped in the case studies analysis are reported. Thanks to this classification, the results show the state of the art of ICT technologies for CE in district contexts, the main areas of application and the key elements to design this kind of solution. The policies and features of emerging districts (i.e., traffic calming, green lanes, energy conservation in building, design passive strategies, etc.) represent important aspects for circularity. Despite this, the paper reports only solutions closely related to the use of ICT technologies.

5.1. Building

Experiences related to the building domain are the most investigated and the most mature solutions in the market. They address a panorama of management applications focused mainly on the reduction of energy consumption as shown in Table 3.

Table 3. Challenges faced by the main ICT solutions in the building US.

Case Study	Solutions
Aspern Seestadt	Smart grid, BEMS, monitoring consumption (energy and water), smart maintenance
Jätkäsaari	Managing and monitoring consumption, feedback to users about daily choices
Kalasatama Smart District	Managing and monitoring consumption, smart grid, platform for maintenance information, System of System (SoS)
Cascina Merlata	Distributed Energy Optimization (DEOP), managing and monitoring consumption (ENEL e-goodlife), guidelines for users about consumption habits
Quartiere Giardino	Smart grid, intelligent lighting control, guidelines users behaviour
SeiMilano	Managing and monitoring consumption, gamification of consumption
Royal Seaport	Smart grid, monitoring consumption, material database (BASTA logbook)

Fasa Delicias District	Managing and monitoring consumption (REMOURBAN project)

The sustainability of an urban district is commonly estimated from the performances in terms of energy conservation. The concept of smart districts is changing and now tends to integrate the CE concepts, the quality of public spaces and the effectiveness of nature based solutions. This change has led to a focus on common and systemic strategies that can review the energy sustainability of an entire district rather than the energy performance of individual buildings. New projects tend to increase the possibility of automatic and manual control of domestic appliances and consequently of their consumption (Figure 2).

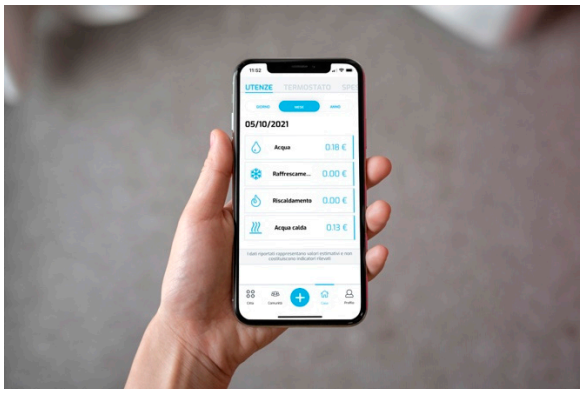

Figure 2. App for domestic consumption monitoring (source: Planet Smart City).

This is an important step in the design of a Smart Grid (SG). This should decentralize energy production and promote the production of local energy from renewable sources. This is the most important goal in the buildings US for the majority of the case studies, both for new and redevelopment projects. It highlights how digital technologies can represent a central economic and environmental advantage in urban development policies. The energy sustainability of the districts will depend on the ability to reduce overloads and variations in daily energy demand and redistribute energy according to the actual needs. For this purpose, ICT solutions are fundamental to undertake this challenge. In the Aspern project, the pathway to the smart grid system is one of the main subjects of research by Aspern Smart City Research (ASCR), starting from sensors installed to monitor consumption by the users, leading to the integration in the Wien electrical grid [82]. All the variables related to absorption and self-production methods are potentially manageable using in-situ storage. This example brings into question the role of multi-utilities as the principal supplier of services and the physical energy infrastructure. The districts seek to develop SG for companies and consumers based on scalable models and services [89]. The energy issue is reflected at the building scale through a series of experiences related to the smart home that allow the end-user to constantly and remotely monitor consumption and parts of their home (lighting, shielding, HVAC systems, etc.) [94,107]. In this context, the giants of the digital sector such as Huawei, Cisco, Google, Apple, Ericsson, Microsoft, Siemens, Nokia and Alibaba today invest in technologies and products for smart homes and smart monitoring designed ad hoc. For example, Gewiss, Microsoft and Siemens collaborated on the Aspern project. They created the Global System Model (GSM), which is a platform capable of connecting plant systems to the management infrastructure to guarantee complete digital integration [83,90]. Ericsson developed a technology that allows residents to monitor and control their energy consumption in Stockholm's Royal Seaport [103,106]. Sharokni et al. [104] highlight how the monitoring and transformation of these actions into forms of gamification can represent disruptive tools in encouraging sustainable behaviour in users. A dedicated app allows users to receive information on the activities taking place in Quartiere Giardino district [97].

Remote home, building and district control are present in all experiences analysed. A digital interface becomes a fundamental tool to facilitate management and user awareness. A digital twin at the district scale allows users to have a complete overview and stimulate complex intervention scenarios, especially for energy management. The Kalasatama district in Helsinki developed its own IGML model, which is able to contain a large amount of open data directly in the 3D image of the city.

This can be implemented by the user. They can upload information of different kinds and promote the development of different products, research and innovation on an urban scale. In this context, there are experiences based on CMMS tools for the management and maintenance of the building based on Building Information Modelling (BIM). These experiences can bring very high benefits in the procurement of activities and the final balance and traceability over time. The data model must always be kept updated with building interventions, as it is in the construction phase. Control operations and any restructuring activity could be simulated using this tool.

5.2. Mobility

Most services analysed in case studies aimed at optimizing mobility flows within the district boundaries (Table 4). These solutions try to face the mobility problems underlined in the backgrounds from the neighbourhood scale. In general, it is possible to highlight a typology of solutions to simplify the mobility choices of residents and visitors in almost all the districts. Nevertheless, only in Northern Europe cases is there a systematic approach to mobility problems and services.

Table 4. List of solutions and projects, related to the mobility urban system, developed in analysed contexts.

Case Study	Solutions
Jätkäsaari	UIA HOPE Project, mobility urban values, last mile delivery, AI for traffic optimization
Kalasatama Smart District	Sharing vehicle community, carpooling service, public transport real time monitoring
Cascina Merlata	Community carsharing
SeiMilano	Smart parking, smart platform roof
Brainport Smart District	System of System (SoS) mobility
Royal Seaport	Intelligent transport solutions, ICT to reduce/optimize travel
Fasa Delicias District	Carpooling platform

Regarding specific solutions, booking services for parking and transit areas are present in almost all the districts analysed. In this way, residents can easily return home while visitors can reserve a spot when they need it. This limits wasted time and emissions because the movement of the user is from point A to a predetermined point B. These solutions certainly make travel more efficient, limiting the repeated passage of cars [91].

Today, most ICT services aim at encouraging alternative mobility behaviours. These services' goals are to limit the use of owned cars as much as possible and make it more efficient where it is necessary. The strongest solutions to limit the use of cars are those based on the inclusion of external sharing services within the district. Alternative solutions are the community fleet with electric bicycles or minicars [96] (Figure 3).

Figure 3. UpTown community car sharing (source: Euromilano).

In Fasa Delicias district [108] they launched a service to facilitate connection with the rest of the city. It is a platform with a carpooling and sharing service where district citizens can both book a vehicle and share a journey with other users who are going in a similar direction [107]. These services take advantage of applications available to users' districts to organize their transfers. This often includes other features such as information mobility services about the district and the city or specific solutions developed within the application. Another field of intervention is about user's awareness. In Jätkäsaari [84], the UIA HOPE project [85] application collects data about the noise and the air quality of areas of the neighbourhood.

On this basis, it develops specific challenges for users to solve this problem with a gamification approach. This strategy aims to involve citizens in the development of alternative habits, providing quantitative feedback on the benefits generated by them depending on the chosen mode of transport (i.e., bicycle, walking, car, train, etc.). The Mobility Urban Values (MUV) project is another project which involves citizens. It collected data about users' mobility habits and air quality to raise awareness about the relationship between these two variables [86]. The main goal of these solutions is to decrease citizens' environmental impact by using alternative mobility solutions. The social aspect of these solutions is very interesting too. The services efficiency favours an increase in the sense of belonging of users to the district. It directs users' attention to the effects of their choices within the context, as amply demonstrated by environmental psychology [109].

In conclusion, the analysis underlined the third typology of services by ICT technology in mobility USs. The case studies present some experiences related to the development of a proactive district by the design of a complex system. These monitor different variables which characterize the field of mobility to create an intelligent management system. These solutions aim to make the mobility system more efficient with direct benefits on environmental sustainability and user safety. The most concrete experiences in this field are in the Finnish capital, where Jaaktasari's Mobility Urban Lab [87] constitutes an important place for experimentation in this field. There are solutions to monitor traffic and consequently facilitate it. For example, the Jätkäsaari Smart Junction [88] is a logistics service and traffic lights change their operation concerning mobility feedback in the district. Van Berkel's paper underlines the complexity behind these systems. His focus is on the relationship between architecture and the fourth industrial revolution [101]. These principles inspired the author's vision for the Brainport district [102]. The envisioned project in this district shows data potentialities. These allow the development of sustainable and efficient processes thanks to a system able to cross different primary and secondary data relating to mobility (real-time monitoring of public transport, energy demand from

refuelling columns, storage space available for logistics, vehicles available, lockers available, etc.). These systems are close to a shift point, where there is a step from monitoring systems to a complex feedback system.

5.3. Products

Contrary to the previous themes analysed, the field of collection and analysis of data to improve the sustainability of flows related to the consumption of goods (food, house appliances, furniture, garments, etc.) and production of waste is very wide (Table 5). The punctual analysis of the services present or planned within the different districts reflects the highly experimental state of the art of this type of initiative. Despite this, it is possible to identify macro-categories in which to include the different experiences analysed: the real-time quantification of household and condominium waste; the reduction of objects destined for end of life with the development of exchange and sharing services; user education and awareness; finally, there is a highly experimental research experience linked to the monitoring of user consumption flows aimed at safeguarding citizens their well-being.

Table 5. List of solutions, related to the product urban system, developed in analysed contexts.

Case Study	Solutions
Kalasatama Smart District	Smart bin for logistic, AI for food and health monitoring, System of System (SoS) solutions
Cascina Merlata	Guidelines for users, behaviour related to waste
Quartiere Giardino	Object library
SeiMilano	Object library, waste bin for logistics, guidelines for behavioural change
Brainport Smart District	System of System (SoS) food and health
Royal Seaport	Waste monitoring, Electrolux smart white goods

The services developed with respect to the theme of waste highlight a main focus on the quantification of flows, especially for the phase of condominium or street delivery. The monitoring of this step allows both the collection of data in an aggregate way about the habits of localized groups of users and the collection to be made more efficient on the part of the entity in charge. This has an immediate benefit on the logistics of collection of municipal waste, which is thus planned on the basis of the actual frequency of filling of the various containers [105]. These experiments are part of a long-term work with which the collection entities aim at a user-waste association. This approach would allow the development of point-in-time pricing strategies through which proper household waste sorting would be definitively encouraged.

The way in which things and objects are used and sent for disposal is an issue linked to the theme just discussed of waste. For this reason, digital services have been developed in various districts to encourage the sharing and exchange of objects. A virtuous experience concerns the library of things (Figure 4), that is, spaces in which developers make available a series of objects that users may need sporadically (drill, ladder, hammer, etc.) [98].

Figure 4. Library of Things (source: Planet Smart City).

This prevents the accumulation of the same objects in all homes despite very low usage rates. Through the neighbourhood referral application each resident easily reserves these items for the time they need them.

Another way of approaching the broad problem discussed in this section is through district user outreach. In several districts, applications or neighbourhood referral sites are used to provide informational materials. This is often focused on making users aware of the daily actions they take in the district and the environmental impacts of those actions. In the Cascina Merlata, Sei Milano and Quartiere Giardino districts community applications are used to provide guidelines about good practices related to consumption, waste management, choice of cleaning products and mobility choices (Figure 5) [60,99].

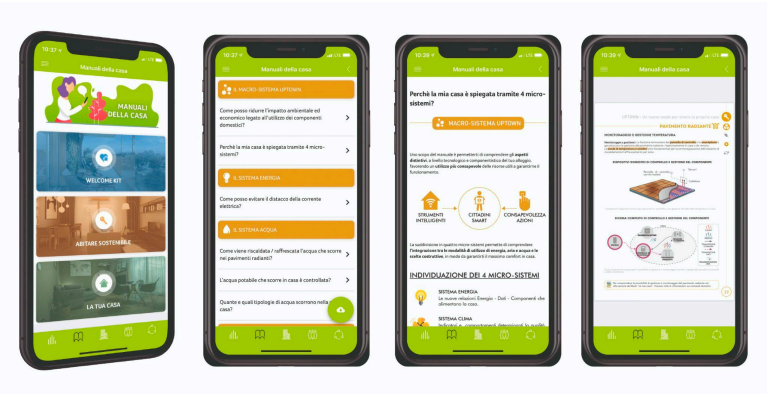

Figure 5. Cascina Merlata home handbook (source: Euromilano [60]).

In the Kalasatama district, information and awareness about lifestyles and best practices is done through the use of a web interface where smart services in the neighbourhood are explained in 10 points [92]. This set of initiatives serves to ensure that users understand the sustainable services developed by the neighbourhood and use them in the best way possible. Having services that are very efficient but with poor citizen adoption rates or incorrect use of them undermines their potential.

The most interesting field on consumption flow certainly concerns the views provided by van Berkel [101]. The paper identifies the need to work on the data that the user exchanges with any stakeholder connected to actions that affect nutrition and health. Such a connection would, for example, allow the nutritionist to easily observe the user's eating habits by viewing his or her online orders and the shopping done in neighbourhood stores. A further connection with the production site upstream would also allow the impact of the food that is consumed to be calculated, facilitating communication and awareness of issues related to the sustainability of the supply chain. Another significant experimentation concerns the use of AI to analyse the healthiness of a dish. In the specific case

of the experimentation underway in Kalasatama this report is structured for people suffering from type 2 diabetes. With this service, the user takes a picture, through a special application, of the dish he is about to eat, and the AI developed ad hoc provides feedback on the same [93]. These solutions well highlight the scenario towards which design tends, even in this area.

6. Discussion

The analysis of the emerging solutions with respect to the three USs identified by EMF (building, mobility, products) highlights some important differences in the development of the solutions for the different sectors (Table 6).

Table 6. USs of action for different case studies.

Case Study	Building	Mobility	Product
Aspern Seestadt	⊙		
Jätkäsaari	⊙	⊙	
Kalasatama smart district	⊙	⊙	⊙
Cascina Merlata	⊙	⊙	⊙
Quartiere Giardino	⊙		⊙
SeiMilano	⊙	⊙	⊙
Brainport Smart District	⊙	⊙	⊙
Royal Seaport	⊙	⊙	
Fasa Delicias District	⊙		⊙

The analysis of the results identifies a very wide field. The building US appears to be the most mature US in terms of technology and number of applications. Although still immature, the experiences in the field of mobility regarding autonomous driving are very interesting. These applications open future discussion on the redesign of urban space. Finally, the emerging applications in the field of products act on the entire production chain. Starting from all the experiences described, authors identify three key common factors in emerging design for CE: the need of physical and virtual infrastructure, the role of stakeholders, the importance of tools for communication and user engagement.

6.1. Physical and Virtual Infrastructure

By physical and virtual infrastructure, we mean the set of material and digital components necessary for the development of the proposed solutions. Most of case studies analysed are ex-novo projects originating in a conversion of land use from industrial to residential areas. Fasa Delicias District and Quartiere Giardino are the only two case studies of existing neighbourhoods renewal. The applicability of ICT technologies to existing housing contexts through the introduction of new services can change the habits of citizens without requiring a major redevelopment from the urban point of view. In particular, the development of virtuous solutions related to mobility and products is often linked to the provision of scalable services on the urban fabric without changing its structure (e.g., car sharing). On the other hand, interventions in the building sector require a series of structural deep and complex interventions on the constructions prior to their application, needing a considerable amount of money and involving many different stakeholders [110]. The existing contexts are therefore the main challenge of intervention because, as noted in the Theoretical Background, they are responsible for the main problems that characterize the contemporary urban fabric.

In the building US there are a great number of experiences and a uniformity of technologies and solutions implemented. ICT solutions in the building field allow an efficient management of a building over its entire useful life with solutions able to respond to the complexity of the different processes involved. The environmental and economic benefits generated by the use of ICT solutions in this sector have led to a greater degree of citizens' awareness compared to with mobility and products.

Although mobility and products USs constitute ideal fields for the application of ICT solutions, their degree of development is smaller. The experiences in the various districts are tied to specific solutions, often unable to supply an answer to the ecosystemic problems of these fields. This lack limits the inherent potentialities in the use of the data, which in turn determines a possible first future step for an optimal exploitation of their potentialities.

An emblematic case concerns the smart grid in the building US. The management of energy flow within these networks is a virtuous example. In fact, the ability to monitor the level of demand and supply of energy creates an optimization in the distribution of energy resources among all the different nodes that belong to the system. This guarantees the achievement of benefits from both an environmental and economic point of view. The great design challenge to be faced in the urban fabric will be the ability to investigate existing complexity by connecting the different processes belonging to different areas.

6.2. Stakeholders

The case studies analysis highlights the changes taking place in the real estate field. Real estate companies are transforming themselves into urban developers and providers of after-sales services linked to daily activities of dwellers and needs. In this changing context, data assumes an increasingly significant value in the relationship between stakeholders and new professional figures (e.g. data hosuing manager). Although these figures have not been clearly traced in the literature, there is a need to entrust the overall management of the information flow to specific figures. The need to develop systemic solutions involves the introduction of external stakeholders with whom investors and sometimes municipalities establish structural partnerships. This observation underscores what was described in the Theoretical Background regarding the new relationships that are being triggered between stakeholders that worked separately until a few years ago. A clear example is the central role that tech giants are assuming in urban housing design. The development of ICT solutions obliges designers to involve these companies in projects for their expertise in innovative technologies for the development of specific solutions. This analysis suggests the need for a coordinating role by these actors concerning the tenants' right of ownership over the data they generate at home. Real estate companies today are increasingly seeking the construction of partners with entities, companies and public administrations to bring useful services to citizens in contemporary residential contexts. The creation of these ecosystems would allow the collection of a variety of data which will broaden the vision of specific housing contexts. The concept of the house as a computer to inhabit could take over in this way. Real estate companies can thus become precursors in initiating this process.

6.3. Tools for User Engagement

Nevertheless, recent studies underline the need to adapt actions and ICT solutions to the specific social and cultural context to ensure the success of the policies. User behaviour represents the focal point of sustainability asking for an accurate design and tailored solutions. Most advanced experiences such as the Jätkäsaari district in Finland faced this issue using the contribution of UX firms in the design development and co-design actions with users and stakeholders. ICT solutions could stimulate the adoption of sustainable behaviours by inhabitants. This application is probably dictated by both the communicative effectiveness of specific processes (e.g., consumption) and the innovative interaction mode (e.g., smartphone, dashboard). By communicating and filtering the collected data,

these solutions raise awareness by adopting strategies typical of behavioural science [111,112], at times unconsciously. The increasing focus on user awareness highlights the need to form smart citizens in order to have smart cities [113]. For this purpose, the new interaction dynamics offered by digital tools constitute an innovative tool. These devices stimulate a behavioural change of the user through reinforcement techniques (gamification, coaching, timely feedback, etc.) that enhance the classic information strategies developed for the user. Thus, digital tools offer enormous potential for environmental awareness [114] that are not yet fully integrated into a systemic design of interventions within the districts.

7. Conclusions

This article offers an overview of the main experiences related to the development of ICT solutions in order to address the challenges of sustainable development within the urban fabric. Figures and information on the discussed case studies are mainly from grey literature and research reports while there are a few scientific papers focusing on CE at district level [37,104,107]. Nevertheless, the results evidence that ICT solutions could play a key role in fostering a switch in approaching complex problems the CE implies. The gap in the academic research in the metabolic and circular perspective at the district level is underlined by some scholars. The main reason lies in the data scarcity at this scale [46]. It could be observed that such a lack of data can be fulfilled by ICT technologies. In fact, the prevalence of aggregated data managed at the urban or regional scale does not allow a full awareness of what happens in specific contexts. For this reason, this research highlights the advantages of a renewed use of data at the neighbourhood scale.

Furthermore, the case studies analysed showed a focus on the control and optimisation of building environmental performances by ICT devices. The sustainable mobility and product lifecycle management are also features highlighted by the developers. The issues of the physical and virtual infrastructure, the stakeholders' relationship and the user engagement can be considered key elements for the pursuit of CE adoption in the urban context. ICT devices for energy and water consumption and indoor climate control are a focus point of such smart districts. A new and more complex relationship between stakeholders (developers, users, big-tech companies, facility companies, local authorities) is a further necessary point, above all for data sharing and data value matters. In fact, the adoption of a CE approach is inevitably linked to the evolution of the relationship between stakeholders. In this perspective, the collaboration between the public and private sectors could guarantee the creation of new services, responding to the interests of all the actors involved. These relationships imply a different management and collection of user data by introducing into the discussion the ethical issue that stakeholders have to consider. Risks related to an improper use of user data undermine trust in service providers. In fact, more transparency in data management can increase user involvement. Finally, the users' engagement is a crucial aspect in the districts analysed as well as in the CE perspective. The users' behaviour, although boosted by ICT devices, still represents a fundamental issue to be managed and a research topic for scholars [115]. In conclusion, urban districts constitute a strategic application area for testing innovative solutions that can be subsequently replicated at the urban scale. According to scholars [46], the field of study of the paper is promising. Further research is needed to verify the link between the urban district scale and the CE improvement as well as the investigation in a quantitative way of the effectiveness of the development of ICT and IoT infrastructures for this scope.

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