Resource Efficiency and Resilience in Urban Settlements _

Two Complementary Approaches Toward Sustainability

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ABSTRACT **The built environment is a specific historical result of social and political processes, based on the transformation of natural resources. The demand for these resources has increased dramatically in the last decades, leading to unprecedented levels of pressure on the environment and ecosystem services. Most of the flows of resources are toward urban agglomerations, which thrive thanks to enormous inward streams of supplies and thanks to the hinterland where they dissipate or dispose of wastes. There is an urgent need to increase the efficiency with which urban areas use natural resources, while at the same time understanding the critical interconnections and interdependencies between energy and material flows, thus reducing cities' exposure to risks.**

The chapter provides a review of notions and strategies around the concepts of 'resource efficiency' and of 'resilience' and describes related case studies. Some common areas of action between the two concepts are shown, as well as potential contradictions and conflicts. Analysing and understanding the common ground between these two concepts can help to find a balance between the need to reduce the pressure on resources and the need to enable urban settlements to withstand and endure threats. The insights found at the interface of these concepts can help meet broader sustainability goals.

KEYWORDS natural resources, urban metabolism, resilience, resource efficiency, transdisciplinarity

1 Introduction

The survival and material wellbeing of human communities depend upon the use of natural resources that are "both the raw materials necessary for most human activities as well as the different environmental media, which sustain life on our planet" (EC, 2003, p. 6). Natural resources are used to create and operate the built environment in which people live. Their basic functions are to provide mineral ores, combustibles, and biomass for the production of goods and services, and to receive, dissipate, or clean the waste originating from man's activities - through air, water, and biologically active land - reintroducing it into the cycle (EC, 2002).

On a global scale, the consumption of resources is constantly on the rise. Estimates indicate that between 1970 and 2015 the amount of materials globally extracted and used has increased by three times (UN-Environment, 2016), water withdrawal has doubled (Wada, de Graaf, & van Beek, 2016) and the proportion of land used for human activities has increased by 10% in the same period (Turner, Lambin, & Reenberg, 2007). Between 2015 and 2050 the world population is estimated to grow by 33%. This increase, together with the constant economic growth, in a business-as-usual scenario, is likely to dramatically raise the already high pressure on the environment and on the demand for resources (Krausmann, Fischer-Kowalski, Schandl, & Eisenmenger, 2008; UN-Environment, 2012a): the material extraction will double, food and water demands will increase by more than 50%, and global energy consumption by 30% (UN-Environment, 2016; Alexandratos & Bruinsma, 2012; OECD, 2013; EIA, 2017).

The Earth's resources are being exploited with an intensity that increasingly exceeds the capacity of its systems to absorb the waste and to neutralise negative environmental impacts (UN-Environment, 2016), and the effects of this excessive exploitation are visible at a global level. While on a local scale, communities have long been aware that their actions can have an impact on the local environmental systems, it's only in the last few decades that there has been clear evidence that local activities can cumulatively have a global impact and affect the atmospheric, geological, hydrological, and biological processes of the planet. The most recognised changes are the rise in global temperatures, the acidification of the oceans, and the increase in the number of world's areas subjected to water stress (UN-Environment, 2012).

The scientific community is warning that an ever-increasing human pressure on natural resources will lead to an irreversible alteration of the state of relative stability in which the planet has been for the last 10,000 years, possibly causing extreme environmental changes and leading the planet to less favourable conditions for human development (Rockström et al. 2009). The latest global agreements on the control of the impact of human activities on the environment, such as the climate conference *COP 21* in Paris, have moved towards building a 'safe operating space for humanity' (Steffen et al., 2015) in accordance with the Earth's biophysical limits, within which man can continue to develop for generations to come (UN-Environment, 2016). There is no unanimous agreement on the thresholds that should define this space, and even less on what actions should be undertaken to remain safely within them, but there's a growing awareness among researchers, policy makers, and supra-national institutions of the fact that urban regions are, and will be in the future, the key point of this topic (UN-Environment, 2016).

Urban settlements occupy only about 2% of the world's land, but host most of its population and account for about 75% of the world's consumption of natural resources, having a significant impact on resource availability and ecosystems even in areas that are far beyond urban boundaries (Dodman, Diep, & Colenbrander, 2017). Global sustainability is therefore highly influenced by the way we manage the flows of resources through cities, and by their use, consumption, and disposal (Ferrão & Fernández, 2013).

Reducing cities' use of resources to address the threats of environmental changes and of resource scarcity is crucial for global sustainability. Reducing consumption, restoring the built environment, and decoupling urban development from the use of resources are among the main and most urgent challenges in urban development (Swilling, Robinson, Marvin, & Hodson, 2013). But that alone is not enough: due to the concentration of people, infrastructures, and economic activities in cities, they are also greatly susceptible to a range of hazards (Resilience Alliance, 2007) and therefore they should also seek ways of reducing their "vulnerability, build resilience and responsiveness to natural and human-made hazards and foster adaptation to climate change" (UN, 2017, p. 19).

The second section of this chapter analyses how the demand of resources in urban settlements can be assessed and managed, and it introduces the concepts of 'resource efficiency' and of 'resilience'. Although these concepts are often considered separately, this chapter underlines the connections between the two, as integrating the two agendas can lead to a more comprehensive approach to pushing for a broader sustainable development (Dodman et al., 2017).

According to Ferrão & Fernández (2013), the use of natural resources in cities is devoted to the following sets of urban activities: the provision of habitable space and the movement of goods and people (i.e. respectively the built environment and transportation); and the provision of goods and services - especially air, water, food, fuels, and waste removal. According to this scheme, the third section of this chapter deals with built environment and mobility. By analysing strategies that aim to provide a more efficient and resilient built environment and related case studies, it addresses the issues of a more sustainable urban form, introducing the concepts of 'green infrastructures' and of 'sustainable mobility' (Abdelaal, 2015). Although the general approach of the chapter is to consider natural resources as mutually dependent, and thus their analysis is not totally compartmentalised, the resources considered in this section are mainly soil, fuel, and environmental media. The fourth section more specifically addresses water, energy, food, and waste removal. It provides examples of resource efficient arrangements, showing how these activities can enhance the resilience of the urban environment.

2 Resources and Metabolism of Cities

2.1 Classification of Resources

The term 'natural resources' - which combines the concept of wealth with that of nature - is used to describe any physical component that constitutes the Earth and has a function to satisfy the material or cultural needs of a community, both in the present and in the future. The inventory of natural resources changes over time, and aspects of nature previously neglected or unknown may gain the attribute of 'resources' after technological improvements or changes in human needs (Mureddu, 1997).

In resource economics, a general distinction is usually made between renewable and non-renewable resources (WTO, 2010). Renewable resources - e.g. solar energy, wind energy, agricultural lands, forests, air, and water - are characterised by the fact that they can be replenished. In a sense, most natural resources are renewable, the only thing that differentiates them is the length of time it takes for them to be replenished. While some fish can reproduce by the millions each year, it takes millions of years for biomass to be transformed into oil by geological processes (EC, 2002). Therefore, non-renewable resources - e.g. fossil fuels and mineral ores - are those resources that do not renew themselves within the human timeframe and will, through extraction, be depleted in the long run (de Zeeuw, 2000).

A popular and widely shared definition of 'sustainable development' describes it as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 16). In this sense, the relationship between sustainable development and non-renewable resources seems to be a contradiction, since non-renewable resources exist in the earth in finite quantities and so every unit consumed today reduces their overall availability in the future. However, according to Le Blanc and Kjollerstrom (2008), this analysis is not accurate. For example, in the case of minerals, technological innovations may find "ways to renew the supply of minerals through advances in exploration techniques, extraction processes, recycling, and substitution" (Nooten, 2007, p. 37). In addition, non-renewable resources are necessary for the economic wellbeing of our societies; if revenues from non-renewable resources are reinvested in social, economic, and environmental activities, then non-renewable resources can contribute to guaranteeing the capacity of future generations to enjoy the same or a better standard of living (Green & Blatner, 2015).

2.2 Regeneration of Resources

The term exhaustible is sometimes used as a synonym for non-renewable, but it has to be said that some renewable resources may also run out if the consumption rate exceeds the natural system's capacity to regenerate them. The Ecological Footprint (EF) is a popular renewable resource accounting tool developed by Rees and Wackernagel (1996), that is used to measure the extent to which a population is exploiting natural resources faster than they can be regenerated. It indicates how much biologically productive area - whether it be land or water - "a population would require to produce on a sustainable basis the renewable resources it consumes, and to absorb the waste it generates" (Schaefer, Luksch, Steinbach, Cabeca & Hanauer, 2006, p. 5). EF is usually presented together with biocapacity (BC), which measures the quantity of a biologically productive surface available in the city or region the relative population lives in. Both are calculated on the basis of the same unit of measurement - global hectares - and the subtraction between the EF of a population and the BC of a city, or a region, tells us if the population's needs exceed that area's biological capacity to produce goods and to clean pollutants. In the world, there are ecological reserves whose biocapacity exceeds the EF of their populations, while there are also areas in which the deficit is enormous. The latter are characterised by high population density, huge demand for resources, and little intrinsic biocapacity.

Urban settlements fit well within this description. Almost the entire global consuming class - i.e. segments of the population with enough income to buy not only basic necessities but also discretionary goods and services - concentrates in urban areas (Dobbs & Remes, 2013). At the same time, as the capacity of a site to generate resources decreases with the increase in the density of the built surface, cities have usually little biocapacity (Ferrão & Fernández, 2013), as shown in Figure 2.1, which highlights the correlation between urban density and the productive capacity of the land. Wealthy cities prosper by largely relying on natural resources located in areas outside their boundaries, whose extension is much wider than the spaces that such cities physically occupy. For example, Greater London is reported to rely on a productive area 300 times larger than the actual urban area, which is approximately twice the size of the United Kingdom (Petrić, 2004).

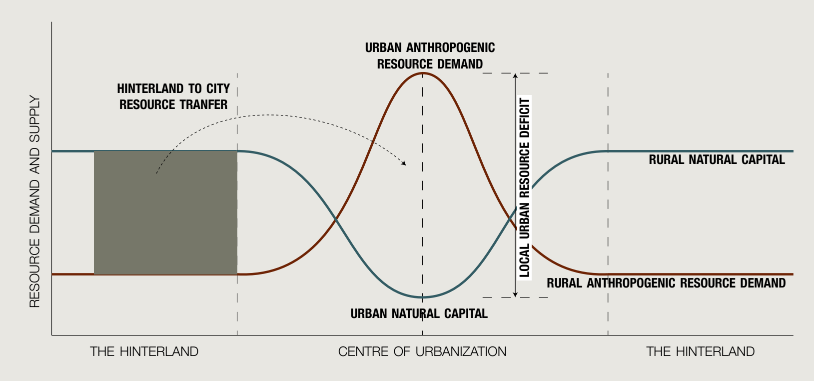

FIG. 2.1 Relationship between urban density and the productive capacity of land. Based on Ferrão and Fernández (2013). *(Image by author, 2017)*

As cities grow, they require ever greater quantities of food, material commodities, and energy from their surrounding areas (Rees, 1999). From a historical perspective, these areas were initially local, but they have become progressively regional, national and, ultimately, global (Lee, Quinn & Rogers, 2016). Lewis Mumford, in *The natural history of urbanization* (1956), argues that, from the Neolithic period up to the 19th century, the size of urban areas - in terms of both population and spatial area - "could not grow beyond the limit of their local water supply and their local food sources. (...) Cities like Rome, which drew mainly on the distant granaries of Africa and the Near East, (...) were exceptions down to the nineteenth century" (Mumford, 1956, p. 389). For a long time, urban areas were mostly powered by biomass, whose characteristic - low energy density - sets limits for the distance from which goods could be transported. In addition, the maximum amount of biomass that could be produced per unit of land was limited, as was the number of people who could be nourished and heated by it. The advent of energy sources that were characterised by a much higher energy density - fossil fuels - together with the technologies to use them efficiently, increased productivity in agriculture and manufacturing and allowed the energy cost of long-distance transport to decrease. Consequently, urban settlements experienced an unparalleled expansion, as well as an exponential increase in the inward flows of natural resources, which were used to build and operate infrastructures and buildings, to allow a high level of mobility of goods and of people, and to guarantee to the citizens a higher standard of living (Krausmann, et al., 2008).

2.3 Urban Metabolism

The way natural resources are used by urban societies is the subject of study of an emerging discipline called 'urban metabolism'. There is no commonly agreed definition of the term, but it generally refers to the exchange processes whereby cities transform streams of resources into useful energy, physical structures, and waste (Decker, 2000).

The concept of 'metabolism' draws from an analogy with the metabolic processes of organisms and it has been used since the 19th century to describe the interaction between society and environment (Fischer-Kowalski, 1997). Karl Marx theorised a rupture in this metabolic interaction originating from industrial production and the growing division between cities and countryside (Foster, 1999). The starting point of his idea of 'metabolic rift' was the recognition of the fact that "food and fiber, containing the elementary constituents of the soil, were being shipped long distances in a one-way movement from country to city", causing the loss of the nutrients in the soil, which had to be replaced by fertilisers (Foster, 2013, p. 17). "Whole industries for making artificial fertilizer would arise to address this rift - in turn causing further metabolic rifts elsewhere" (Wark, 2015, p. 12). This example can be easily applied to contemporary urban settlements, which depend on natural resources that come from all around the globe and which can't return waste products to the place where the resources were extracted, thus making it impossible for the cycle to renew itself.

In recent years, the idea that urban areas operate as metabolic systems, and that production and consumption patterns in cities can be modelled as flows of materials, energy, people, information, and power, resulted in the rethinking of how the relations between society and nature shape urban phenomena (Broto, Allen, & Rapoport, 2012). The disciplines committed to urban metabolism are inherently multidisciplinary, therefore there are significant overlaps in the interests of scholars coming from different areas, but it is still possible to identify different slants and specific approaches (Broto et al., 2012; Zhang, 2013; Musango, Currie, & Robinson, 2017). According to Ferrão & Fernández (2013), the current methods and tools of urban metabolism have been primarily originated and promoted within 'Industrial Ecology', the disciplinary field studying the interactions between industrial systems and the environment (Graedel, 1994). Here the metabolism of a city is understood as "the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy, Cuddihy, & Engel-Yan, 2008, p. 44). From this perspective, emphasis is given to the fact that urban systems are mainly linear reactors: their metabolism consists of taking energy and materials from elsewhere and transforming them into buildings, infrastructures, and waste, which are rapidly discarded (Girardet, 2000; Brunner, 2007). Instead, cities should shift from a linear to a circular model of metabolism, wherein waste can be reintroduced into the system to become inputs (Ferrão & Fernández, 2013). The Industrial Ecology approach to urban metabolism aims to assess and quantify the flows and stocks of resources, and thus identify alternative ways in which a more efficient use of resources can be achieved (Musango et al., 2017). Resource efficiency can be defined as "the ratio of services generated from resources to resource input" (Fertner & Große, 2016, p. 68); therefore, using resources more efficiently means "create more with less, delivering greater value with less input, using resources in a sustainable way and minimising their impacts on the environment" (EEA, 2015a, p. 20).

Another approach to urban metabolism originated from the field of 'Urban Ecology', which the journal 'Nature' defines as "the study of ecological processes in urban environments" (Nature, n.d.). This perspective understands the city as a dynamic, complex, and adaptive ecosystem "embedded in a larger system, and thus employs the concept of metabolism to describe the interactions between subsystems within an urban region" (Broto et al., 2012, p. 853). Rather than adjusting urban metabolic flows to idealised models, the main focus of this approach is to understand how to achieve resilience to changes and shocks that will impact such a dynamic system (Broto et al., 2012). According to Alberti, Marzluff, Shulenberger, and Bradley (2003, p. 1170), urban resilience can be defined as "the degree to which cities tolerate alteration before reorganizing around a new set of structures and processes" and that depends on how effectively a city can simultaneously maintain ecosystem and human functions (Resilience Alliance, 2007). In this case, the concept of resilience goes beyond the recovery from specific disasters and refers to the resilience of the urban settlement to all kinds of disturbances, including unpredictable ones (Newton & Doherty,

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2014). According to Tyler and Moench (2012), the characteristics of a resilient urban system are:

- Flexibility: i.e. the ability to perform essential tasks under many conditions through the interplay of evolution and adaptation;
- Diversity: i.e. the ability to meet a given need in multiple ways and to physically distribute key assets and functions so that they are not all simultaneously affected by a disturbance event;
- Redundancy: i.e. a characteristic that, according to da Silva & Morera (2014, p.5), "refers to spare capacity purposively created to accommodate disruption due to extreme pressures, surges in demand or an external event";
- Modularity: i.e. being composed of smaller functional units that are interconnected and can replace each other if one, or even many, fail;
- Safe failure: i.e. the ability to absorb sudden shocks with minimum damage and avoiding cascading impacts across systems.

2.4 Differences and Analogies Between the Concepts of Resource Efficiency and Urban Resilience

The concepts of 'resource efficiency' and of 'urban resilience' described earlier were both considered to be of key importance at the *Third United Nations Conference on Housing and Sustainable Urban Development - Habitat III* (UN, 2017). Indeed, without huge increases in resource efficiency in cities, the current consumption patterns cannot be sustained (Resilience Alliance, 2007). At the same time, due to rapid urbanisation and a greater global connectedness, cities are the places where the security and wellbeing of people are mostly at risk, therefore the efforts on building resilience should be focused on them (Coaffee & Lee, 2016). The two concepts have different strategies and tools and may come into conflict. For example, the above-mentioned may help cities to be more resilient to shocks and stresses, but it may also be regarded as an inefficient use of resources (Santos Cruz, Costa, Ávila de Sousa, & Pinho, 2012). At the same time, there are also overlapping methods: for example, improving resource efficiency by reducing, re-using, and recycling waste can help overcome resource constraints that may result from internal or external limiting factors (Dodman et al., 2017).

In the case studies presented below, a certain number of areas of action are shown where the concepts of resource efficiency and resilience converge, with the common goal of achieving a broader long-term sustainable city development and reducing pressure on natural resources.

3 Efficient and Resilient Built Environment and Transportation

3.1 Urban Form

The urban form and the arrangement of land use are strongly related to the consumption of resources: they are directly connected to how efficiently water, energy, and soil are used (Santos Cruz et al., 2012), and alternative urban patterns have different effects on resilience (Alberti & Marzluff, 2004). Urban development affects the local provision of food and environmental services, fragments and isolates the remaining areas (Fertner & Große, 2016), disrupts hydrological systems - e.g. through the increase of impervious surface coverage (Arnold & Gibbons, 1996) - and modifies energy consumption, especially in the transportation and space heating/cooling sectors (Doherty, Nakanishi, Bai, & Meyers, 2009).

In the last decades, there has been a lively debate on the definition of the most sustainable urban form (Frey, 1999; Jenks, Burton & Williams, 2005), which has been often associated with the compactness of urban fabric (Jabareen, 2006; Schwarz, 2010). In fact, proponents of higher urban density claim that compact and close developments reduce land consumption, preserve the open space, increase accessibility to local services and jobs - thus reducing the use of cars - and promote a more intense and efficient use of infrastructures (OECD, 2012). In addition, some specific system configurations, such as district heating/cooling systems or Combined Heat and Power (CHP), have been deemed convenient only in dense urban areas (OECD, 2012). An example of the use of an extensive district heating network is the one in the city of Copenhagen, which serves 98% of homes (Hjøllund, Boldt, & Hendriksen, 2014).

Since 1999, a more compact urban development model has been proposed by the European Commission as a guideline for urban renewal and expansion (EC, 1999; 2007; 2010) and, in recent years, the concept has been endorsed by the United Nations (UN-Habitat, 2016). This can be understood as a response to more dispersed models of urbanisation, which have been the global trend for the last two decades (UN-Habitat, 2016).

On the other hand, some researchers state that evidence from case studies suggests a weak relationship, if any, between urban compactness and sustainability (Daneshpour & Shakibamanesh, 2011). According to Alberti (2007), the relationship between compactness and decrease of pollution and energy usage is controversial due to the difficulties of generalising the results of the studies. Santos Cruz et al. (2012, p. 65) underline that compactness and density may lead to lack of redundancy, "which, combined with diversity and modularity, enhances the resilience of a system". Indeed, landscapes made up of a combination of built and natural environment can be more resilient than areas of either abundant and well-connected natural environment or of

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extensive sprawl, since neither of the two can simultaneously support human and natural functions (Alberti & Marzluff, 2004). Therefore, improving the ecological connections and melding them with urban form offer the chance to create a more sustainable and resilient space for both humans and natural ecosystems (Lafortezza, Davies, Sanesi, & Konijnendijk, 2013).

A conceptual framework within which this linkage is enhanced is the Green Infrastructure (GI), which emerged as a complement to conventional 'gray infrastructures'. The European Commission (2013a, p. 7) defines GI as planned "networks of natural and semi-natural areas designed and managed to deliver a wide range of services" such as: the improvement of air quality by reducing nitrogen dioxide and particulate matter; the absorption of storm water to reduce the likelihood of sewer system overflows; and the cooling of the surrounding built areas through evapotranspiration and the shading of buildings and other surfaces (Meerow & Newell, 2017).

According to Amati and Taylor (2010), GI can also be used to limit cities' spatial growth, complementing the 'green belt', an already widely adopted urban planning tool. This, first implemented in London in 1935, is a ring of countryside which prevents urban sprawl by surrounding the city with a 'belt' of undeveloped land. Merging green belts with a network of green infrastructures can provide a lot of benefits (Amati & Taylor, 2010), as in the case of the Toronto Greenbelt, which has been developed since 2005 to circumscribe the urbanised region around the city. The accompanying Places to Grow plan for the same region (placestogrow.ca), states that "conservation can only be allowed if growth is also supported" (Wekerle, Sandberg, Gilbert & Binstock, 2007, p. 28), and therefore multifunctional activities, such as water taking, water purification, forestry, and biomass and aggregate extraction, are allowed throughout the protected countryside. Basically, the Toronto Greenbelt acts both as a physical boundary preventing urban sprawl and as a green infrastructure providing a sustainable context for future growth in the region (Amati & Taylor, 2010).

The main principle of GIs is to protect and improve natural systems by integrating these infrastructures into urban planning and development, and therefore also into mobility strategies (Smaniotto Costa, 2014). In fact, GIs have often been linked to the concept of 'sustainable mobility' (Schäffler & Swilling, 2013). An example of this are the *Corridors of Freedom*, which are currently being developed in Johannesburg, South Africa. This project is included in the *Growth and Development Strategy 2040* masterplan, consisting of an integrated plan for infrastructure, housing, and transportation systems (City of Johannesburg, 2011). One of the key goals of the corridors is to connect - through public transport systems - the sprawled, low-density settlements at the fringe of the city to the central area, thus providing access to jobs and economic opportunities in the inner city to marginalised communities living in the peri-urban areas (Young, 2015). In the *Corridors of Freedom,* bus and passenger rails will be aligned with an urban green infrastructure network, including linear parks, urban forests, and wetlands, that

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will provide the space for both ecological and economic functions, such as storm water processing and production of bio-energy and food. This programme has been devised as a "new hybrid urbanism" that "recognizes the importance of the existing open space system as the basis of an emergent new public realm which must not be a passive or a benignly naturalistic place. It should be green and living" (Young, 2015, p. 409).

3.2 Sustainable Urban Mobility

Achieving sustainability in urban transport and reducing the use of cars for commuting are important goals for the European Union. Current mobility patterns in cities account for 23% of greenhouse emissions from transport at community level, and European cities are exposed to such high concentrations of pollutants and particulate matters that many of them struggle to meet the European standards for air quality (EC, 2013b). Nonetheless, "with their high population densities and high share of short-distance trips, there is a greater potential for cities to move towards low-carbon transport than for the transport system as a whole, through the development of walking, cycling, public transport" (EC, 2013b, p. 1). In 2014, the European Union published the guidelines to develop a *Sustainable Urban Mobility Plan* (SUMP), which is intended as a new planning concept to address urban mobility issues in a more comprehensive way (EC, 2014). This new concept calls for citizens and stakeholders' involvement, for coordination between different levels of authorities, and for a trans-sectoral approach to planning. The sectors that should be coordinated within the plan include: transport, land use, environment, economic development, social policy, health, and energy (EC, 2014). A more comprehensive approach to planning was also invoked by Lam & Head (2012), who stated that transport should not be implemented by itself but in conjunction with other strategies, in order to develop sustainable urban mobility schemes while pushing for a broader sustainable development goals.

In Europe, cycling is becoming more and more popular and, in some cases, an integral part of urban mobility and infrastructure design (EP, 2015). Many case studies about bike mobility plans have been published in the European urban mobility observatory (eltis.org). For example, the website assesses the continuous progresses made by the city of Copenhagen towards the goal of creating a more liveable city and reaching carbon neutrality by 2025, through cycling as a highly prioritised political tool. On average, from 2008 to 2010, 36% of the trips to work or to educational institutions in Copenhagen were made by bicycle, and the goal is to reach 50% by 2025 (City of Copenhagen, 2012).

In London, despite the presence of a well-established public transport system, cycling is a growing trend: between 2000 and 2015, the number of daily cycling journeys increased by 230% (Transport for London, 2015). This was the result of urban policies that aim to improve this means of transport through some innovations, including a new bike rental scheme and the construction of eight *Cycle Superhighways*

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to create continuous cycle routes from outer London and across central London (Dix & Seagriff, 2012). In 2013, in line with the efforts of the public administration to increase bike commuting, Exterior Architecture, Foster + Partners and Space Syntax proposed *SkyCycle* as a new approach to cycling in London. *SkyCycle* is a bikeway that uses the space above the existing suburban railway corridors, providing 220 km of car-free cycle routes accessible from over 200 entrance points (fosterandpartners.com/projects/skycycle). A similar project has been recently developed in Xiamen (China), where the design firm DISSING+WEITLING has built the world's longest suspended bike lane. The aerial cycle way is a 4.8 m wide four-lane carriageway, stretching for 7.6 km with 11 exits connecting it to six public transport hubs. As shown in Figure 3.1, much of the pathway is beneath the elevated road used by the city's rapid transit bus line, thus providing shelter on rainy days and easier accessibility for commuters (Piciocchi, 2017).

FIG. 3.1 Xiamen Bicycle Skyway designed by DISSING+WEITLING architecture *(Image by Ma Weiwei, 2016)*

The use of spaces previously developed for transport infrastructure - which may be either active or not in use - is in line with the aforementioned goal of limiting land taking. Several projects have been developed over former railroads. For example, the celebrated *High Line* is a linear park that recycles a portion of the former New York Central Railroad on the West Side of Manhattan. Designed by Diller and Scofidio in 2009, it led to the redevelopment of the neighbourhood of Chelsea (Cataldi, Kelley, Kuzmich, Maier-Rothe, & Tang, 2012). Another example is the *Promenade Plantée* in Paris, a 4.7 km parkway designed over the former tracks of the Vincennes railway line by Vergely and Mathieux in 1993 (Heathcott, 2013).

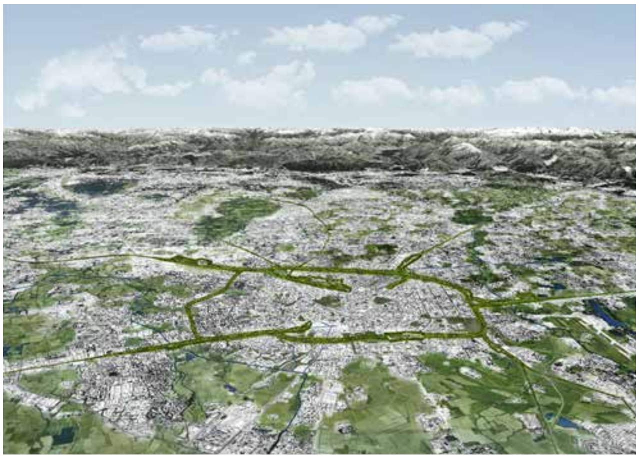

FIG. 3.2 Fiume Verde: aerial view *(Image by Stefano Boeri Architetti, 2017)*

FIG. 3.3 Fiume Verde: view of the park *(Image by Stefano Boeri Architetti, 2017)*

In Italy, the *Green River* project, recently proposed by Stefano Boeri, is based on the repurposing of the unused railway freight terminals in the city centre of Milan (https://www.stefanoboeriarchitetti.net/it/portfolios/un-fiume-verde-per-milano). The idea is to build a continuous system of pathways and parks along 37 km of former rails, now fallen into disuse (Figure 3.2). The project will include a public transport line connected to the Milan rail network as well as cycle lanes and footpaths. Along the *Green River* bends, high density urban edges are planned, hosting both private and social housing, residences for students, workspaces, and crafts and cultural services (Figure 3.3). The new buildings will be served by a district geothermal infrastructure consisting of a circular water network that carries groundwater extracted at the rail yards and then delivers it to each household. This technical solution will contribute to achieving the goal of reducing carbon emissions from heating, while, at the same time, limiting the trend of increasing groundwater levels, that has been observed in Milan since the '90s and that resulted in flooding in some areas of the city. The project also includes planting more than 200,000 trees, which will greatly benefit the urban environment through their annual absorption of 50,000 tons of CO_2 (Italia Nostra, 2017).

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4 Efficiency and Resilience in the Provision of Goods and Services

As seen before, resource efficiency and decoupling of the economic growth from the increasing resource use and from the environmental impact are two major European and global goals (UN- Environment, 2011; EC, 2011). However, some scholars argue that this is "good, but not good enough" (Haberl, Fischer-Kowalski, Krausmann, Martinez-Alier, & Winiwarter, 2009, p. 9), since decoupling does not necessarily imply a reduction in resource consumption in absolute terms as long as economic growth continues (Fertner & Große, 2016). Actually, global resource use during the entire 20th century rose "at a substantially lower pace than the world economy. Thus resource decoupling has already taken place 'spontaneously' rather than as a result of policy intention" (UN-Environment 2011, p. 11). Nonetheless, resource consumption in absolute terms has been steadily increasing (Krausmann, Gingrich, Eisenmenger, Erb, Haberl & Fischer-Kowalski, 2009). For example, the use of renewable energy - which is meant to be a way to lower the use of fossil fuels and to reduce CO_2 emissions - is rising and so is the proportion of renewables in the global energy mix, but the total amount of energy being produced from fossil fuels is rising too (EIA, 2017). Therefore, renewables are not replacing fossil fuels, they are just being used concomitantly, as noted by Rufo Quintavalle (2017).

Efforts to reach an absolute decoupling should be promoted, but to achieve this result "'end-of-pipe' solutions, generally used to solve environmental urban problems, are no longer sufficient. There is a need for an integrated approach and better coordination among sectoral policies, levels and scales" (EEA 2015a, p. 23). This approach has recently been applied to urban development projects, for example in the design of the Hammarby Sjostad, a district of Stockholm located in a former industrial waterfront area (Solly, 2016). The most interesting part of this project is the *Hammarby Model* (Bancheva, 2014), a systems integration scheme that aims at optimising existing systems of consumption and production by connecting them together to create synergies and reuse waste. Environmental and infrastructural core plans for this model have been jointly developed by three infrastructure companies of the city: Stockholm Energi, the city's energy company; Stockholm Vatten, the company that provides integrated water management all over Stockholm; and Skafab, the city's waste recycling company. The municipality asked these companies to co-operate, thus forcing them to find cross-sectoral solutions and to innovate not only in designing a new integrated solution for the district, but also in finding new working methods (Iveroth, Vernay, Mulder, & Brandt, 2013). In the *Hammarby Model*, as shown in Figure 4.1, organic waste is converted into biogas and fertiliser to produce biofuel, while combustible waste is used to provide the district with electricity and heating, and both are transported by an automated underground vacuum waste transportation system. The waste incineration plant provides part of the electricity that is consumed by the households and also powers the wastewater treatment plant, which treats the sewage. Digestion is used to extract biogas from the sewage sludge and the residue solids are then used to fertilise (Iveroth et al., 2013). This model of system integration shows how it is possible for different sectors to collaborate, aiming to achieve a better resource efficiency and to close the flow loop within a circular metabolism concept.

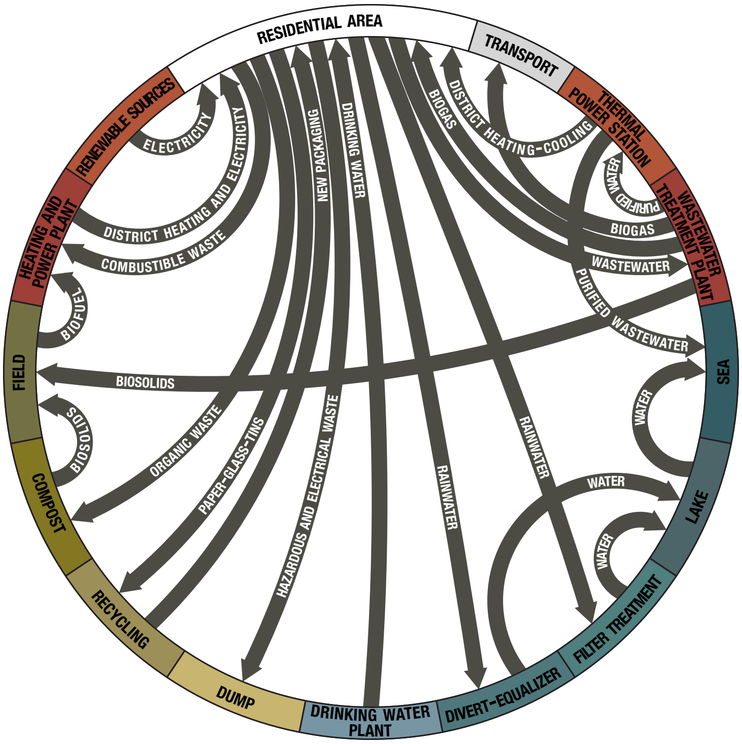

FIG. 4.1 The Hammarby Model. Based on Iveroth et al. (2013) *(Image by author)*

According to Coutard and Rutherford (2011), the *Hammarby Model* is an example of a new concept of infrastructure, namely the 'decentralized systems', that surpass the 'large technical systems' scheme, and are believed to be more sustainable and to reduce certain vulnerabilities and risks. An example is the programme under development in the New York metropolitan area for the design and construction of alternative power generation and distribution systems. The programme is part of a wider plan to build *A stronger, more resilient New York* (City of New York, 2013), which is an upgrade of the *plaNY* masterplan, sought by the administration after the catastrophic climatic events of recent years, and in particular after Hurricane Sandy, that struck the city in 2012, caused 43 deaths, flooded some areas of the city, and caused the interruption of the electric service for over 2 million people for almost two days (City of New York, 2013). The programme provides for the creation of several microgrid systems capable of providing electricity to hazardous areas and strategic city services. Microgrids are small-scale electricity production and distribution systems that can work either connected or disconnected from the main network, in what is known as 'island mode' (Prehoda, Schelly, & Pearce, 2017). They can be powered by a mix of energy sources, including photovoltaic panels, cogeneration systems, and more traditional power plants (Cohen, Eimicke, & Miller, 2015). During the Hurricane Sandy, some experimental installations proved to be effective, succeeding in providing electricity to some groups of buildings despite the widespread outages of central power plants (Van Nostrand, 2015). This helped to strengthen the idea of spreading similar systems in other areas of the city. Ten pilot projects have been recently financed and are currently under development. In the same metropolitan area - on the other side of the Hudson River - the *New Jersey TransitGrid* is under development. This is a project designed to power some strategic segments of the rail transport network. Here, the microgrids will allow transport to continue even during hurricanes or in case of network failure because the rail system will be powered by a number of decentralised production units that will use solar power, combined heat and power and fuel cells, and they will be located in transit stations, maintenance facilities, and bus garages (https://tinyurl.com/y76vmwx5).

Decentralised systems for other key resources have been proposed: for example, for the management of the urban water cycle. A leading example in integrated water cycle management through a mix of dispersed systems is the case of Singapore. Singapore, due to specific geographic conditions, does not have natural freshwater resources, and therefore efforts have been made to ensure its water security. The policies implemented to achieve this result include the minimisation of the householders' demand, the reuse of wastewater and the water supply through a mix of different sources (Irvine, Chua, & Eikass, 2014). This is in line with the 'urban harvest approach' proposed by Agudelo-Vera, Mels, Keesman and Rijnaarts (2012). According to the authors, cities should minimise their demands by stimulating changes in human behaviour and by technology implementation (demand minimisation); close the loop of urban cycles by reusing waste (output minimisation); and get the remaining resources from multiple sources in the adjacent areas (multi-sourcing). Singapore's water management approach provides for demand minimisation at multiple levels: at end user level - with awareness-raising campaigns and pricing policies; at product level - through the mandatory use of water saving devices; and at building level - through a water efficient building certification programme (Kiang, 2008). Water reclamation is achieved through *NEWater*, which is the largest wastewater reuse infrastructure in the world. It consists of five plants that depurate sewage providing water for non-potable uses. They are able to fulfil up to 40% of the city's current water needs and, by 2060, they are expected to meet up to 55% of Singapore's future water demand (The World Bank, 2006). Finally, the supply of water relies on several sources: the import by ship from the Johor river in Malaysia; the desalination of seawater in two reverse osmosis plants; and the collection of rain water. Rain water is collected on green and built areas of Singapore, accounting for 2/3 of its total land, and then channelled into 17 reservoirs. The recently-built biggest reservoir - the Marina Basin - is separated from the sea by a 350m wide dam, which also acts as a tidal barrier, preventing the sea from flooding the adjacent low-lying areas in the city centre. In addition to providing a way of harvesting rain and keeping seawater out, the Marina Basin is also an attraction for tourists and citizens (Khoo, 2009). Singapore's urban water system is a

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leading example of the so-called Total Water Management, an approach that "examines urban water systems in a more interconnected manner, focusing on reducing water demands, increasing water recycling and reuse, creating water supply assets from storm-water management, matching water quality to end-use needs, and achieving environmental goals through multi-purpose, multi-benefit infrastructure" (EPA, 2012, p. 3). Water security is achieved through an interplay of horizontal, cross-sectoral integration and vertical collaboration across different levels of governance.

In the presented case studies, the importance of an integrated approach to resource management based on greater efficiency has been underlined - i.e. the reuse of waste and the use of renewable energy - as well as an approach based on the reduction of urban systems' vulnerability - i.e. through decentralisation, modularity, and diversity. Another aspect to consider is the interdependence between resources in urban areas that can cause problems if their interactions are not understood and properly managed (Dodman et al., 2017). For example, in recent years, several studies have highlighted the cause-effect relationship between water and energy. In this context, it has been observed that energy is needed for the production of water and that water, in many cases, is required for energy production. If one sector fails, the other will suffer (Kenway, Lant, Priestley, & Daniels, 2011; Jägerskog, Clausen, Holmgren, & Lexén, 2014). This relationship can make cities more vulnerable since, for example, an interruption in the energy supply may consequently cause shortages in water delivery. Therefore, a comprehensive approach that considers broader influences and cross-sectoral impacts should be promoted (WWAP, 2014).

In 2011, the World Economic Forum introduced the concept of water-energy-food nexus to promote the inseparable links between these resources in order to provide basic and universal rights (Biggs et al., 2015). It has been noted that food production, transport, consumption, and disposal are responsible for over 70% of global freshwater use, about 24-50% of global CO_2 emissions (Schmidt & Merciai, 2014) and, in Europe, of 25% of total energy use (Monforti-Ferrario & Pascua, 2015). On an urban scale, Goldstein, Birkved, Fernández, and Hauschild (2016) analysed the metabolism of 100 cities and found that, in the reviewed sample, the urban food demand was typically the third largest source of mass flows - after water and fuels - and of carbon footprint, and generally the largest driver of urban ecological footprints. The authors also observed that food production - based on fossil fuels to increase productivity and to allow transport from long distances - had shifted well beyond municipal borders, making citizens unaware of the impact resulting from their 'foodprint'.

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FIG. 4.2 Jellyfish Barge: view of the greenhouse installed in Milan, developed by Pnat, 2015 *(Photo by Matteo de Mayda, 2015)*

In the past decade, developed nations have seen a renaissance of urban agriculture and local food systems, namely networks of food production and consumption that operate at close distance and involve fewer intermediate steps between the producer and the final consumer (Martinez, Hand & Da Pra, 2010). The practice of producing food in and around urban areas is considered as a way to reduce the environmental impact of food demand, especially regarding limiting CO_2 emissions due to food storage and transport (Goldstein, Hauschild, Fernández & Birkved, 2016) and, at the same time, to reduce cities' vulnerability, since producing food in small scattered units helps to diminish the risks associated with a national or a global supply chain - such as disruptions in the supply or rising prices (Ackerman et al. 2014). From a historical perspective, Maltz (2015) explains the role of local food systems to provide resilience to urban areas during the two World Wars, arguing that in the US and the UK the 'Victory Gardens' and the 'War Gardens' - the practice of producing food in small and dispersed spaces - "changed national food systems for the duration of the wars and created a lasting model of food resilience" (Maltz, 2015, p. 400).

However, to overcome the scarcity of large surfaces suitable for agriculture purposes in the city, many current solutions for urban agriculture improve crop productivity by using energy intensive technologies, such as artificial lights and air conditioning. An environmental life cycle assessment survey conducted among six different urban farms showed that the high-yield production of tomatoes and lettuce in heated greenhouses in the city of Boston had potentially higher environmental burdens than conventional methods in terms of CO_2 emissions and non-renewable resource depletion, due to the high energy inputs (Goldstein, Hauschild, Fernández, & Birkved, 2016). Louis Albright (2012) calculated that crops cultivated indoor with full artificial lights - i.e. in the so called 'plant factories' - can embed 2-8 tons of CO_2e per ton of produce, which is 3 to 10 times the carbon embedded in vegetables imported to New York from abroad.

A novel project to grow vegetables near the final consumer without impacting on water and energy resources is the Jellyfish Barge, a self-sufficient buoyant greenhouse that derives the fresh water, the electricity and the cooling it needs from the underlying body of water and from solar power (Studio TAMassociati, 2016) (Figure 4.2).

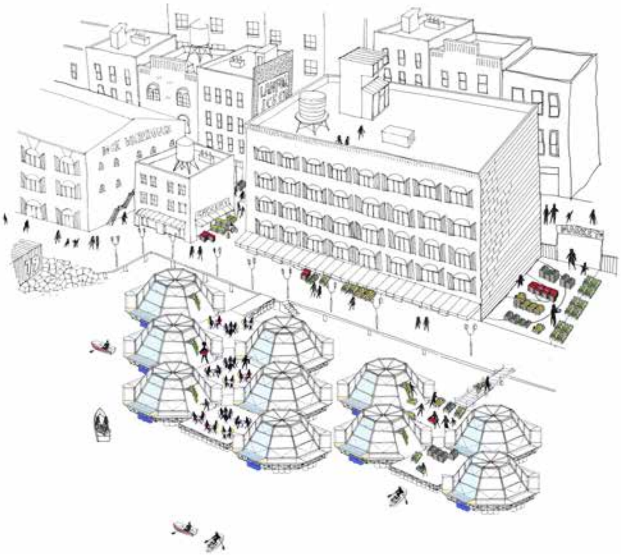

FIG. 4.3 Jellyfish Barge: view of an installation composed by multiple modules flanked together, developed by Pnat, 2015 *(Drawing by Cristiana Favretto, 2015)*

It is a cultivation facility that produces 8-10 tons of vegetables per year, which is enough to guarantee daily nutrition for about 75 people. The water needed is extracted from the body of water on which the greenhouse floats, whether it be salt, brackish, or polluted water, using a technology called 'solar distillation' (Papapetrou, Wieghaus, & Biercamp, 2010). The internal environment of the greenhouse is cooled/warmed by the same water. This radically cuts energy use, and therefore only a small photovoltaic system (800w) is needed to provide the little amount of electricity required. The project - developed by the

Pnat team at the University of Florence (www.pnat.net) - includes a platform for setting up a weekly farmers' market or organising didactic activities: a space open to the public that allows a direct relationship between farmers and citizens. Figure 4.3 shows that many modules can be flanked together to create rural archipelagos where it's possible to produce, sell, and consume fresh fruits and vegetables.

5 Conclusions

The ever-growing urban demand for natural resources produces significant environmental impacts that go well beyond the cities' boundaries, endangering the ability of the planet to replenish resources and to absorb waste, and, in general, to provide a safe space for human development (Rockström et al, 2009). To mitigate these adverse impacts, it is strategic to use resources more efficiently, not only disconnecting their use from economic growth and from social well-being, but also reducing resource consumption in absolute terms (Swilling, Robinson, Marvin, & Hodson, 2013). At the same time, cities are hotspots of vulnerability: population growth, rapid urbanisation, and climate change put urban settlements under unprecedented risks. Therefore, there is a pressing need to strengthen local capacities in order to better protect human, economic, and natural assets and to recover quickly from any plausible hazards (Resilience Alliance, 2007).

In the case studies presented, some common areas of action between the concepts of resource efficiency and resilience are shown. The two concepts may be conflicting, but there are also significant overlaps. For example, waste recycling can contribute to achieving greater resource efficiency and at the same time make urban areas more resilient, since it reduces cities' dependency on the systems that provide resources (Dodman et al., 2017). On the other hand, green infrastructures can be an efficient way to increase resilience to a wide range of threats, including flooding and seasonal heat waves (Meerow & Newell, 2017). Researchers agree on the fact that cities should be able to increase their resource efficiency and their resilience against threats, but there are few comparative studies analysing the two approaches simultaneously. The 'marriage' of these two concepts, has the potential to improve the understanding of how urban areas can simultaneously reduce their pressure on natural resource and make the urban environment less vulnerable to various types of risks, in order to meet broader sustainability targets. To achieve this goal, efforts to overcome the traditional differences in terms of "narratives, metaphors, and tools for understanding and shaping urban development" that distinguish the two concepts should be promoted (Dodman et al., 2017, p. 3).

Moreover, it clearly emerges from the above case studies that there is a need to establish inter-sectoral dialogue among disciplines that normally do not speak to one another. For example, the development of the *Hammarby Model* was made possible only through a new working method that brought experts in water, energy, and waste to work together.

On the contrary, the underestimation of the energy implications of food production can lead to the promotion of solutions that can create negative environmental impacts. Finally, trans-disciplinary approaches are essential to capture the complexity of Green Infrastructures, whose effectiveness lie in the composite interaction between built and natural environments.

But, who will take care of the design of these hybrid structures? Which professionals will coordinate the interweaving of such different sectors? Which scholars will translate the language of one discipline into that of another and build the platform where different knowledge streams can merge?

An intriguing metaphor for this problem has been elaborated by the duo of New York artists and designers Levin and Sims with a work called "The Free Universal Construction Kit" (Free Art and Technology [F.A.T.] Lab & Sy-Lab, 2012). It is a work composed of a series of 80 pieces that allow complete compatibility between ten popular construction games for children, such as Lego, Duplo, and Fischertechnik. By constructing an interface that allows each piece to engage with the others, the designers let elements belonging to different constructive, morphological, and functional logics to communicate. Similarly, disciplines around architecture and urban planning should work to enable interoperability between different fields and create a space where different kinds of knowledge and practice might meet. "The insights found at the interface of these disciplines will provide valuable material for alternative multi-scalar design strategies" (Mostafavi & Doherty, 2010, p. 22) and open up new avenues for design disciplines to drive urban renewal.

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