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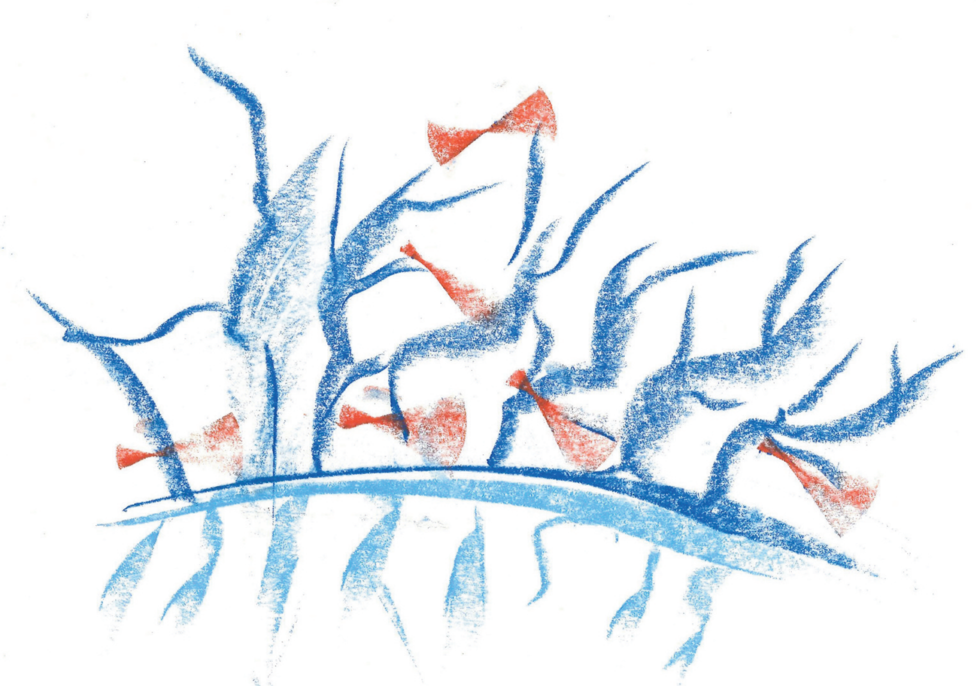
# Urban growth and greening goals for sustainable development

Presentation by
Mauro Francini and Simona Tondelli



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# Contents

# *Presentation*

by Mauro Francini and Simona Tondelli

The development of this volume arises from the need of the author, a young researcher in the urban planning research field, to disclose the results of her research on the theme "Urban growth and greening goals for sustainable development".

The topic is particularly original and escapes the urban plan logic and traditional planning. In this research, the residual hopes of urban planners emerge to operate to improve the quality of our cities using innovative methodologies and tools. It is a challenge for the practice of urban planning to be redefined both in the contours and in content.

The research deepened the topics of sustainable management of the urban growth and urban greening processes, well known to urban planning, through an unconventional lens: the use of innovative digital methods and tools, representing an area of exploration of considerable interest for urban and territorial planning.

The climate change determines negative impacts on the ongoing urbanization processes that have consequences on the health and well-being of people, on the increase in situations of urban and environmental degradation, on the loss of natural capital and related ecosystem services (ESs), and on increasing risks connected to natural catastrophes. The complexity of this context makes it necessary to evaluate and manage the relationships between urban growth and greening processes using innovative and flexible methods and tools capable of handling and assessing their relationships and mutual implications.

The volume is developed to give answers to some research applications on the question of the definition of methods to evaluate and manage the urban growth processes in parallel with urban greening processes: the first to satisfy the need for qualitative spaces quantitatively suitable for people, the latter to ensure urban sustainability and livability, as well as the ability to adapt to climate change. Specifically, the author guides readers through an innovative analysis and a research path on this issue, highlighting the opportunity offered using advanced technological and digital methods and tools. In an increasingly interconnected and technologically advanced world, these approaches represent a milestone for smart urban planning and the effective management of resources.

In the first part of the volume, the author took the concepts of urban growth, both compact and dispersed, and urban greening, analyzing their complex relationship, as well as the methods and tools developed to date to evaluate and manage relationships among these processes to pursue sustainability and urban livability goals. The author then dedicated herself to examining the main technological and digital methods and tools which, today, in the era of urban big data, are being affirmed in the field of urban planning as valuable support for decision-making processes, including intelligence artificial and geographical information systems that can be used via the web. These issues were integrated and deepened to define an innovative methodological approach for urban growth and greening processes planning and management. The experimentation of the methodology in the case studies presented in the last part of the volume has shown how this approach can be helpful for decision-makers and planners.

The volume is not limited to answering the initial research questions. It further proposes new questions and deepening issues that open the way to new perspectives of analysis, evaluation, and management of these processes. Therefore, it represents a new resource for all those involved in the analysis, management, and monitoring of urban and territorial planning and transformation processes, from the academic community to urban planners, from local administrators to professionals in the sector, offering a clear overview of the challenges and opportunities that the future of urban areas reserves for us.

In conclusion, this volume represents the outcome of a young researcher who has been enriched with countless collaborations and exchanges and has produced new valuable insights and experiments to promote a more sustainable and ecologically aware management of our cities.

# *Introduction*

Around 50% of the world's population resides in urban areas, serving as central hubs for economic activities, employment, and overall economic progress. Projections indicate that by 2050, urban areas will accommodate approximately 75% of the global population. Consequently, the future growth patterns of cities and territories can raise intricate socio-economic and environmental challenges that must be appropriately handled. Such challenges include unsustainable development trends which negatively affect carbon emissions, air and water quality, and waste control.

The unprecedented urbanization phenomena and the increasing environmental awareness have demonstrated that the intricate connection between urban growth and the pursuit of greening goals has become a crucial focus for urban planning research and practice. With cities persistently growing and transforming, it is imperative to comprehend the complex interdependencies between urban growth patterns and ecological sustainability. This understanding is essential for fostering harmonious, resilient, and enjoyable urban environments. In recent years, the need for urbanization and urban growth to deal with environmental challenges has reached significant consideration within the scientific community. The investigation and harmonization of these two objectives have inevitably become one of the most critical challenges of the 21st century.

Specifically, creating a balance between urban growth patterns, land take containment, climate adaptation, and availability of urban green areas (UGAs) and their related benefits is a challenge that impacts the urban dwellers' quality of life, economic performance, and the social cohesion of cities. Promoting social, economic, and land use growth while safeguarding the ongoing provision of resources and environmental benefits of natural systems in urban areas has become a great challenge for urban planners and decision-makers. This ambition aligns with the goals of the New Urban Agenda. It offers a pathway to realize the Sustainable Development Goals (SDGs), focusing on Goal 11, which seeks to raise inclusivity, safety, resilience, and sustainability in cities and human settlements. Moreover, the principles of green growth hold significant relevance in the context of the post-COVID-19 recovery efforts.

The interplay between urban growth and greening goals has been known since the end of the twentieth century. According to Naess (1997), for example, two sustainable urban development models contrast with each other: models that support the development processes of dense and compact cities to avoid negative impacts of dispersed urban growth and models focused on the development of green cities, a type of urban structure more open and permeable in which coexist the combination of buildings and green areas.

Even if the existence of such a complex relationship is known, observation and studies on the ongoing tensions between urban growth processes – both compact and dispersed – and the imperative to push the advantages afforded by green spaces within city limits are still limited. Moreover, as urban systems rapidly expand globally, comprehending their spatial evolution and implications for sustainable development remains complex and contentious. A robust conceptualization and empirical evidence are essential to understanding the spatial dynamics of urban systems and their effects and impacts. The physical growth of cities manifests in diverse spatial patterns, often resulting in urban sprawl driven by various factors and causing multidimensional adverse effects on the economy, society, and ecology. It is crucial to consider the impacts of urban growth processes on natural areas at larger scales and the neighborhood and household levels to pursue measured and well-qualified planning policies to guarantee urban sustainability.

This objective can be pursued only by implementing a well-calibrated set of planning policies and strategies to manage potential conflicts and generate positive interaction between urban growth and greening goals to pursue sustainability and liveability. At the same time, the definition of planning policies and strategies relies on the definition of effective and efficient decision support tools to monitor, assess, quantify, and update such processes.

Urban areas' growth patterns generally assume two forms: compact or dispersed. However, within the scientific literature, it has been demonstrated that both negatively impact the natural ecosystem of urban systems. While a compact city may lose UGAs due to densification interventions, urban sprawl determines a loss of UGAs in the urban area outskirts due to the suburbanization phenomenon.

Understanding the relationship between urban growth, both compact and dispersed, and greening to support sustainable urban planning is complex. This complex relationship between urban growth and greening has been investigated in many ways within the scientific literature. However, it emerged that understanding this complex relationship to support sustainable urban planning requires specific techniques and tools, which must be innovative and flexible. In this context, the use of innovative technologies and spatial analysis techniques has become imperative. Following these assumptions, the research addressed in this volume intends to answer the following research questions:

- How can innovative technologies, such as artificial intelligence (AI) techniques and geospatial analysis, contribute to a better understanding of urban growth patterns and implementing urban greening planning policies?
- How can these methods support urban planners and decision-makers in managing the complex relationship between these two policies and, therefore, define sustainable urban growth and greening policies?
- How can information about urban growth and greening policies be shared with different stakeholders and make them accessible and consultable?

The volume wants to answer these research questions and pursue the defined research objective through the following structure.

First, in Chapter 1, the analysis of the new and consolidated practices on urban growth and greening goals is performed. Indeed, despite the concepts of urban growth, the greening of the city, and the management of their complex relationship to achieve sustainable urban development are widely spreading within the scientific and public discourse, these concepts are not deeply and fully understood. Therefore, these concepts have been clarified in Chapter 1. The theoretical foundation on urban growth patterns of cities, both compact and dispersed, is analyzed, emphasizing concepts, definitions, and main characteristics of such kinds of city planning policies and development patterns. Then, the main concepts related to the policies of greening the city are defined. Indeed, in this case, while the idea of greening the city is currently spreading in the scientific and public discourse, it is unclear what introducing nature in the city means and which concepts are used in planning and designing UGAs within the context of sustainable urban planning. In Chapter 1, therefore, the most relevant concepts for urban greening planning policies, such as UGAs, ESs, and nature-based solutions (NBSs), are presented and analyzed. Finally, after introducing the complex relationship between urban growth and urban greening, the methods, tools, and decision support systems defined and employed to manage this relationship are presented and investigated.

Using innovative methods and tools based on Information and Communication Technology (ICT), especially with remote sensing technologies and innovative spatial analysis techniques, becomes imperative to support and manage the relationship between urban growth and greening. In this regard, valuable methods are represented by innovative AI techniques, geographic information systems (GIS) for spatial analysis, and web-based geographic information systems (WebGIS). AI techniques consent to analyze large volumes of data, including demographic information, traffic patterns, energy consumption, and more, through tools and techniques that can enhance city development's efficiency, sustainability, and overall effectiveness and make informed decisions. GIS consents to have a large amount of data and automatizing analysis computation. Both these technologies can be integrated into an innovative discipline, which is widely recognized as geospatial artificial intelligence (GeoAI), which can also be used via the web and integrated within WebGIS. In Chapter 2, these three technologies and their main characteristics are presented and analyzed, emphasizing GeoAI applications and WebGIS development for sustainable urban planning. Specifically, in the first part of Chapter 2, the advantages of the combined use of AI and GIS techniques are presented, while in the second part, a systematic literature review of the GeoAI applications for sustainable urban planning is performed. To date, a general recognition of the role of AI and its application combined with geospatial techniques in the urban planning scientific and technical sector is lacking and, therefore, a systematic literature review of the state of the art about AI and GIS applications in the urban planning context is performed. Following that review, a general analysis of the role of WebGIS within the urban planning field is also conducted. Moreover, focusing on Italian regional WebGIS platforms, an in-depth analysis of those WebGIS is also carried out.

Despite the common understanding that innovative methods and analysis could support policymakers in managing urban growth and greening goals sustainably, approaches and methods are not fully defined and not applied to make informed urban plans and strategies. The development and operationalization of such analysis are still far from being developed and used. Therefore, following these needs, Chapter 3 presents a comprehensive operational approach to manage urban growth and greening policies towards sustainable urban development. The proposed framework consists of three subsequent steps: (i) the identification of urban and greening changes over time to assess, evaluate, and monitor the changes in these two planning policies during an observation period and the analysis of their co-relation with population dynamics towards urban sustainability; (ii) the development of a multi-criteria decision support system to identify, assess and quantify the potential of urban areas to undergo for dense urban growth processes and greening interventions; (iii) the development of a WebGIS platform prototype to visualize, manage and update such information by stakeholders, who, for many reasons, could be interested in that analysis about urban and greening development.

Chapter 4 describes the results of applying the proposed approach to case studies. Specifically, the analysis of urban and greening changes and their co-relation with population dynamics towards urban sustainability over time is tested by selecting Matera (Basilicata, Italy) as a case study. The multi-criteria framework to assess the potential of urban areas for densification and/or greening interventions is tested in a union of municipalities located in the Emilia Romagna region (Italy), which is Terre d'Argine and encompasses four municipalities: Campogalliano, Carpi, Novi di Modena and Soliera. The WebGIS platform prototype and its functionalities are tested through the applications mentioned above, as the primary goal of the proposed WebGIS prototype is to support sustainable urban planning and, specifically, sustainable use of land.

Finally, in the last part of the volume, the author presents the conclusions, the recommendations, and the further developments of the research work presented in the volume.

# 1. *New and consolidated practices to assess the relationship between urban growth and greening goals*

## 1. Urban growth and greening goals: concepts and definitions

Urban areas are growing very fast worldwide due to the urbanization process. Population growth projections suggest that more than two-thirds of the world's population is expected to live in cities by 2050, with a marked increase from today's level of 55 percent (United Nations, 2019). This rapid urban development and the need for climate change adaptation represent a great challenge for urban planning. Therefore, spatial planning approaches and frameworks are needed to cope with urban growth's environmental, social, and economic effects.

Urban growth is a complex process. Its main drivers are population growth, increased motorization rates, and income capacity, such as Gross Domestic Product (GDP) (Haase et al., 2013). The urban growth process of cities depends on historical and contextual factors and can assume different spatial patterns, mainly identified as compact and dispersed development.

Dispersed development indicates the unplanned expansion of urban areas into surrounding rural or undeveloped land (Burchfield et al., 2006). It often leads to low-density development on vacant land and greenfield sites, causing adverse economic, social, and environmental effects (European Environment Agency, 2016). Scientists and policymakers recognize the need to manage dispersed urban growth processes and their adverse consequences by promoting compact urban development through urban densification interventions. This latter urban growth pattern generally involves increasing the population density within existing urban areas to promote more efficient land use.

In urban planning research and practice, it is widely recognized that both compact and dispersed urban growth processes (Jenks, 2000; Holden & Norland, 2005; Westerink et al., 2012) represent a threat to the provision of green and natural areas putting pressure on urban natural ecosystems (Nuissl et al., 2009; Gupta et al., 2012; Haaland and van den Bosch, 2015; Elmqvist et al., 2018; Wolff & Haase, 2019). Indeed, while urban sprawl produces scattered low-density development without UGAs, implementing densification and re-utilization interventions produces a loss of UGAs. In this context, spatial planning approaches to handle urban growth's effects on UGAs are needed to balance urban growth with preserving and enhancing green spaces.

UGAs are the natural areas in urban environments and include parks, open spaces, green squares, residential gardens, and urban forests. UGAs are essential services in cities as they provide a wide range of ESs that contribute to the well-being of people and the environment. ESs offered by UGAs include air quality improvement, temperature regulation, stormwater management, biodiversity support, physical and mental health benefits, noise reduction, socialization, educational and cultural value, and economic benefits. Therefore, the planning and management of UGAs to preserve and enhance these ESs are essential in creating sustainable, livable, and resilient urban areas.

Over the past decade, there has been a growing recognition in urban planning of the imperative to effectively manage the interplay between urban growth and the pursuit of greening goals. This acknowledgment has also been driven by the necessity to adopt planning strategies to realize the United Nations' vision of making

> cities and human settlements inclusive, safe, resilient, and sustainable (United Nations, 2015).

Consequently, the concept of sustainable urban development has gained significant prominence within the urban planning research and practice field (Hansen et al., 2019). Generally, the roots of sustainability in urban planning literature can be traced back to the 1970s when the concept began to emerge. Despite being somewhat radical initially, the 1987 World Commission on Environment and Development's Our Common Future (WCED, 1987), also known as the *Brundtland Report*, played a pivotal role in mainstreaming sustainability. Therefore, the concept of sustainability has been integrated into urban planning theory, advocating for promoting the urban growth process while guaranteeing urban livability.

The issue under extensive discussion, examination, and resolution pertains to the prevalent conflicts between the imperative of limiting soil consumption by limiting urban dispersion, advocating for compact cities, and ensuring high levels of the livability of the built environment through the preservation of existing green spaces, and the establishment of new ones.

This discourse has gained increased attention in recent years due to the challenges posed also by climate change. The imperative to address urban sprawl and its diverse negative consequences by advocating for compact urban development and urban reutilization has been widely recognized in urban science and policymaking. However, ensuring a high quality of life for urban residents requires comprehensive perspectives on the types of compact development to promote, particularly concerning UGAs within densification processes.

Although there is a general understanding of the need to balance urban growth with environmental protection to guarantee urban sustainability and livability, the concepts and definitions involved in managing the interplay between these two kinds of planning policies are not well understood. Furthermore, the scientific discourse and debate on methods, tools, and frameworks in managing such interplay has never been defined.

Therefore, within this Chapter, the author aims to illustrate the new and consolidated practices existing within the current urban planning research and practice to assess the relationship between urban growth and greening goals. Before exploring the tools and frameworks available within the scientific literature to analyze and manage the complex relationship between these two kinds of planning policies, the author defined the two main patterns of urban growth processes (compact and dispersed) and clarified what greening goals mean. First, the definitions, concepts, and characteristics of compact and dispersed urban development are defined. Then, the author introduced the main concepts and definitions of greening goals, such as green areas, ESs, and NBSs. Finally, the scientific literature on tools and frameworks to manage and assess the complex relationship between these two kinds of development within the urban planning field has been investigated.

## *1.1. Urban growth processes: compact versus dispersed*

Urban growth has become an unavoidable process driven by the social and economic development of urban areas. The urban growth process evolves and assumes different spatial patterns and forms depending on cities' historical and ecological background. Specifically, two main urban growth patterns can be identified: compact and dispersed.

Dispersed urban growth processes refer to a complex phenomenon usually associated with low-density suburban development and dispersed urban structure (Galster et al., 2001; Song & Knaap, 2004). The scattered pattern of urban growth and expansion determined by the sprawling of cities determined severe environmental and social impacts on urban areas and natural ecosystems. The sprawling of cities, notably, increased traffic congestion and transportation costs, promoted social segregation and determined the loss of biodiversity and natural ecosystems (Inostroza et al., 2013; Artmann et al., 2019).

Specifically, Burton (2000) pointed out that urban sprawl is connected to increased car dependency within the emerging urban peripheries. Furthermore, along with the forest cover alteration due to urban sprawl (Miller, 2012), this latter also determined substantial communal and social costs associated with low-density development (Deal and Schunk, 2004) as well as informal urban development (Inostroza, 2017).

Urban sprawl, as the dominant form of urban growth in the developing world era, has been criticized for its adverse impact on the environment, society, and economy (Newman & Kenworthy, 1989; Ewing, 1997; de Roo & Miller, 2000; Burton, 2000; Breheny, 1992; Elkin et al., 1991). This happened also because there was increasing attention to sustainability as a globally significant issue. This allowed for the development of a new planning paradigm, the compact and dense development of cities, considered a sustainable response to urban sprawl.

Before deepening the various definitions of compact cities within the urban planning research and practice field, it is crucial to understand and define the roots of this concept.

The compact city concept as the primary strategy to avoid urban sprawl's social, economic, and environmental problems and achieve sustainable urban development was born in the 1990s. Before this date, the term was not fully developed as a planning concept. Indeed, in the 1930s, it was just a response to urban expansion and the need to preserve the environment and agricultural land (O'Toole, 2009). This is demonstrated by the fact that the compact city term was coined in 1973 by two mathematical scientists, George Dantzig and Thomas L. Saaty, in their book *Compact City: A Plan for a Livable Urban Environment*.

Focusing on the compact city as a multidimensional strategy for achieving sustainable urban development gained support through various policy frameworks and urban agendas promoted from 1990 onwards. One notable example is Agenda 21, introduced by the United Nations Conference on Environment and Development in 1992. It underscored the importance of adopting a more efficient and compact urban form to diminish resource consumption, advocate environmental principles, and enhance resilience to the impacts of climate change. Additionally, the United Nations Framework Convention on Climate Change (UNFCCC) acknowledged the potential of compact cities to mitigate greenhouse gas emissions. This recognition stems from their capacity to reduce dependence on private vehicles, promote energy-efficient buildings, and facilitate the utilization of renewable energy sources in urban areas.

The growing interest in the compact city concept determined many definitions, making it impossible to have a standard definition for this urban form. For example, Dantzig and Saaty (1973) first defined that a compact city is characterized by a highly dense and low car-dependent urban form, clearly identified and distinguished by the surrounding areas, high diversity of land uses, and social equity and self-sufficiency. According to Newman and Kenworthy (1989), compact cities have intensive land use, centralized activities, and higher densities. Elkin and McLaren (1991) describe the compact city development process as intensifying the use of space in the city with higher residential densities. Breheny (1992) emphasized that:

> compact cities have high density and mixed-use, with growth encouraged within the existing urban boundaries.

According to Thomas and Cousins (1996), the main characteristics of a compact city are compactness, pedestrian, bicycle, public transport accessibility, and high respect for wildlife. For Churchman (1999), a compact city is characterized by high residential density, the principle of centrality, diversified land use, and a well-defined area that limits development outside of this area. Specifically, the characteristics that, according to the author, define it are the high density, declined in population density, built environment, and homes, the use of diversified soil, understood as the varied and copious offer of services and equipment distributed horizontally than vertically, and, finally, the intensity, understood as the increase in population, as well as the development of new density in correspondence with the nodes or sub-centers. Neuman (2005) pointed out that a compact city is characterized by 14 characteristics, including high residential and employment density, the diversified use of soil, the proximity of soil uses, the contiguous urban development, the high waterproofing of the soil and the high degree of accessibility and road connectivity, both internal and external. Daneshpour and Shakibamanesh (2011) described a compact city as:

> a city that mixes shared civic spaces with concentrated arrangements of structures.

The Organization for Economic Cooperation and Development (OECD, 2012) defines the main characteristics of compact cities, such as dense and compact development, the presence of systems of public transport, and accessibility to local services and jobs.

In general, a compact city is characterized by high density, a high functional mix, with high availability and good accessibility to services and equipment, as well as by the presence of an efficient public transport service and the possibility of moving by foot or bike. In addition to these characteristics, the growing attention to environmental and energy effects has enriched the definition of compact cities.

Along with the massive research in the scientific literature, many policies and strategies related to compact cities have developed since the 1990s onwards to reduce the use of private cars and minimize the loss of rural areas. In addition to these environmental benefits, compact cities are characterized by social benefits, such as easy accessibility to urban services by guaranteeing equity and distributional justice. According to Williams et al. (1996), thanks to these characteristics, the compact city can be considered a stimulating and lively environment capable of stimulating social and economic interactions. The compact city is more energy-efficient and less polluting than other urban development strategies and, therefore, is considered an efficient strategy for contrasting urban sprawl (Abdullahi et al., 2015; Chang & Chen, 2016; Dempsey, 2010).

The policies and strategies developed over the years are also accompanied by much research on compact cities' main characteristics. Specifically, many authors developed different frameworks and methods to measure the compactness of urban areas. From these frameworks, it is also possible to identify the main themes and characteristics of the compact city concept. They often include factors related to the urban form, accessibility, and transportation system. Tab. 1.1 summarizes the main indicators included in the most crucial framework developed worldwide.

*Tab. 1.1 - A summary of the leading compact city indicators developed in the scientific literature.*

| *Author/s* | *Aims of the study* | *Dimensions* | *Indicators* |
|---|---|---|---|
| Burton (2002) | Measure urban compactness by developing a large set of urban compactness indicators | Density | Density of population<br>Density of built form<br>Density of subcentres<br>Density of housing |
| | | Mix of use | Provision of facilities<br>Horizontal mix of uses<br>Vertical mix of uses |
| | | Intensification | Increase in population<br>Increase in development<br>Increase in density of new development<br>Increase in the density of sub-centers |

| | | | |
|---|---|---|---|
| Song and Knaap (2004) | Measure urban forms | Street Design and Circulation Systems | Int_Connectivity<br>Blocks_Peri<br>Blocks<br>Length_Cul-De-Sac<br>Ext_Connectivity |
| | | Density | Lot_Size<br>SFDU_Density<br>Floor_Space |
| | | Land Use Mix | Mix_Actual<br>Mix_Zoned |
| | | Accessibility | Com_Dis<br>Bus_Dis<br>Park_Dis |
| | | Pedestrian Access | Ped_Com<br>Ped_Transit |
| OECD (2012) | Compare policies of compact cities | Dense and proximate development patterns | Population and urban land growth<br>Population density on urban land<br>Retrofitting existing urban land<br>Intensive use of buildings<br>Housing form<br>Trip distance<br>Urban land cover |
| | | Urban areas linked by public transport systems | Trips using public transport<br>Proximity to public transport |
| | | Accessibility to local services and jobs | Matching jobs and homes<br>Matching local services and homes<br>Proximity to local services<br>Trips on foot and by bicycle |
| | | Environmental | Public spaces and green areas<br>Transport energy use<br>Residential energy use |
| | | Social<br>Economic | Affordability<br>Public service |
| Kotharkar et al. (2014) | Measuring compact urban form | Density | Gross population density & Average (built-up area) density<br>Land use split up<br>Average land consumption per person |
| | | Density distribution/dispersion | Density profile<br>Population by distance to the center of gravity or CBD<br>Density gradient |
| | | Transportation network | Mode share<br>Average trip length<br>Road network density<br>Congestion index<br>Walkability index |
| | | Accessibility | Public transport Accessibility |

| | | | |
|---|---|---|---|
| | | | Service Accessibility Index |
| | | Shape Performance | Dispersion Index |
| | | Mixed-use Use | Land use split up |
| | | Land Composition | Ratio of residential to non-residential use<br>Ratio of built to open area |
| Shi et al. (2016) | Analyze effects of a compact city on urban resources and environment | High density | Compactness index<br>Population density of built-up area<br>Proportion of built-up area in total urban area |
| | | Traffic Accessibility | Number of buses per 10000 people<br>Road area per capita |
| | | Mixed Land Use | Shannon's diversity index |
| Nadeem et al. (2021) | Scaling the potential of compact city development | Landscape Ecology | Land Use and Land Cover<br>Saturation level |
| | | Density | Gross population density<br>Built-up area density<br>Land use split up<br>Average land consumption per person |
| | | Density Distribution | Density profile<br>Population through distance to CBD |
| | | Transportation Network | Mode share<br>Average trip length<br>Road network density<br>Congestion index |
| | | Accessibility | Service accessibility<br>Public transport accessibility |
| | | Shape performance | Dispersion index |
| | | Mixed-Use | Ratio of residential to non-residential use |
| | | Land Consumption | The ratio of built-up to open area |

Compact city indicators encompass the physical and spatial attributes that define a compact city and are utilized for assessing the effectiveness of compact city policies (Burton, 2002; Lee et al., 2015; OECD, 2012). Various researchers have discussed multiple compact city indicators, with variations based on individual perspectives and the characteristics of cities designed around this concept. Dantzig and Saaty (1973) introduced composite indicators like urban forms, spatial features, and social functions. Similarly, Lee et al. (2015), and the OECD (2012) have formulated compact city indices incorporating factors ranging from density, land use, and urban form to trip distance, public transport usage, and proximity to services.

Compact development is, therefore, considered the opposite of dispersed development. Urban planners, administrators, and policymakers push to encourage and promote compact development patterns. However, both compact and dispersed development patterns are found to be responsible for UGA loss and the deterioration of their services and functions. In general, urban growth processes may lead to eliminating or weakening existing green spaces in ways that are challenging to reverse. The reduction and degradation of UGAs can contribute to health issues and produce negative impacts to the urban environment, such as air pollution, noise, chronic stress, and insufficient physical activity. Urban planners need to better plan and manage such complex interplay between these policies to mitigate health risks and promote the health benefits of urban living.

## *1.2. Greening goals: urban green areas, ecosystem services, and nature-based solutions*

The strategic introduction and maintenance of vegetation, green spaces, and natural elements within urban environments, defined in this study as urban greening, plays a crucial role in mitigating the adverse effects of urbanization, known as urban environmental challenges (Pan et al., 2021), and developing more sustainable and livable cities.

As highlighted by the new urban ecology research field, there is an urgent need to overcome the classical divide between natural and urban ecosystems through specific urban planning actions. In this context, as Niemelä (1999) stated, natural areas are an integral part of the urban environment and, therefore, must be protected and promoted.

UGAs are a range of forests, parks, trees, green allotments, and cemeteries (Breuste et al., 2013). The most common definition of UGAs used by European studies is the one proposed by the European Urban Atlas (European Commission, 2011). According to it, the UGAs are identified in the Urban Atlas code 14100. They include public green areas used predominantly for recreation, such as gardens, parks, and suburban natural areas and forests, or green areas bordered by urban areas managed or used for recreational purposes. In policy terms, it is crucial to focus on UGAs that are open to the public. Therefore, in a more general way, they can be defined as all parks and green areas that are publicly accessible and usable by citizens and provide multiple benefits.

The importance of UGAs planning and management for improving urban environment quality of life is widely supported both by the scientific literature (Artmann et al., 2019; Andersson et al., 2014; Niemelä, 2014) and by the policies that, at various levels, have been promoted over time. Specifically, Target 11.7 of the 11-th Sustainable Development Goals set by the United Nations (2015) defines that:

> by 2030, it is necessary to provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.

UGAs provide fundamental benefits to urban dwellers (Pauleit, 2003) and wildlife (Goddard et al., 2010). Specifically, UGAs provide different environmental benefits, which include air filtration (Jim & Chen, 2008), urban cooling (Aram et al., 2019), noise reduction (Tashakor et al., 2023; Dzhambov and Dimitrova, 2014), energy consumption reduction (Zhu et al., 2022; Simpson, 2002), carbon storage (Ariluoma et al., 2021; Sun et al., 2019) and rainwater infiltration (Técher & Berthier, 2023; Huang et al., 2023). UGAs contribute to mitigating climate change (Nero et al., 2017) and have essential ecological functions (Mell, 2009).

Besides these environmental benefits, UGAs improve urban residents' physical and mental health (Kabisch et al., 2016). UGAs contribute to improving mental health by reducing stress and promoting relaxation. These spaces promote physical health improvements through active and passive activities, such as experiencing nature, meeting other people, doing sports, and walking. These spaces stimulate physical activity by reducing obesity, improving the immune system, significantly reducing external noise and exposure to air pollution, and improving sleep (WHO, 2016).

In the scientific literature, the multiple direct and indirect benefits supplied by UGAs are conceptualized as ESs. This concept was introduced in 1997 by Costanza et al. to raise awareness for biodiversity, ecosystem preservation, and conservation (Birkhofer et al., 2015) and for the human benefits derived from their functions.

The ES concept received recognition among policymakers with the publication of the Millennium Ecosystem Assessment (MEA) (2005) by the United Nations. The MEA study defines ESs as:

> the ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems.

ESs considered in the MEA study are shown in Fig. 1.1.

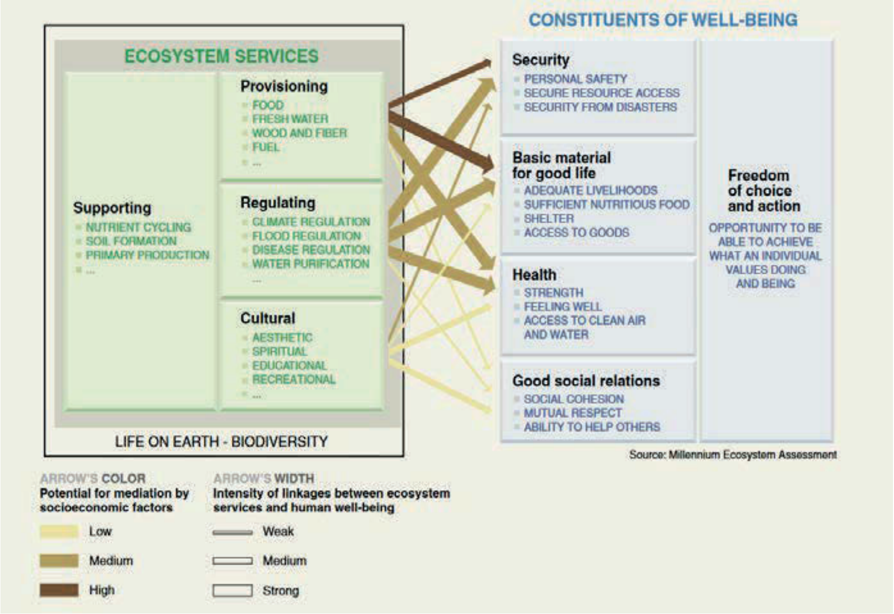


*Fig. 1.1 - ES framework developed by MEA (2005).*

They include supporting ESs (ecosystem functions underlying other ESs, such as primary production soil formation); provisioning services (products obtained from ecosystems, such as food, fiber, and water), regulating services (benefits obtained from the regulation of ecosystem processes, such as climate regulation, flood regulation) and cultural services (non-material benefits people obtain from ecosystems, such as recreational, aesthetic, and spiritual benefit). The MEA analyzed the influence of ES changes on human well-being, highlighting an "anthropogenic" approach to this concept, according to which people are an integral part of ecosystems. The critical result of this study is that, currently, 60% of the ESs evaluated are degraded or used in an unsustainable way due to human changes in ecosystems that happened rapidly and extensively.

Another global initiative is represented by the Economics of Ecosystems and Biodiversity (2010), which is focused on:

> making the values of nature visible.

Its main objective is to integrate the economic value of ESs in the decision-making process at all levels. The ESs recognized by the TEEB global initiative are shown in Fig. 1.2. They comprise provisioning, regulating, habitat, and cultural ESs.

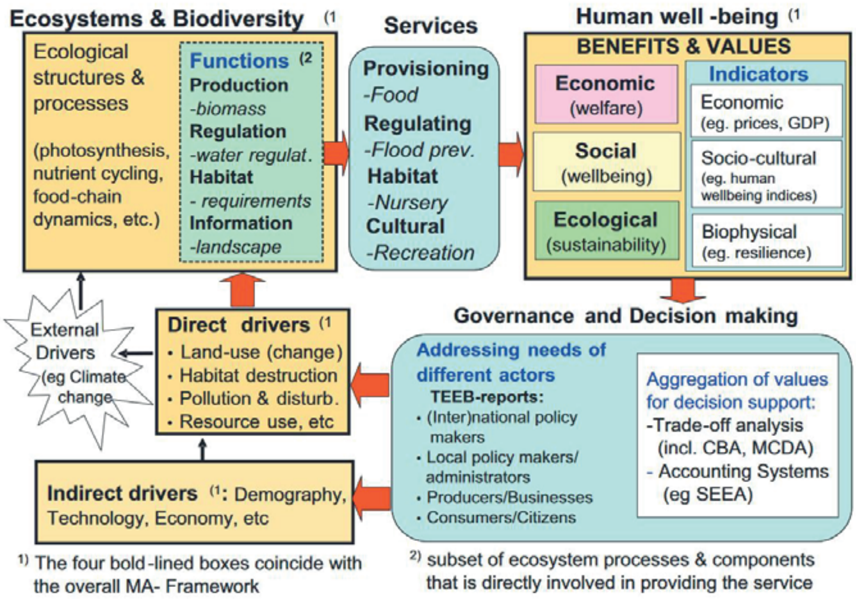


*Fig. 1.2 - ES framework developed by TEEB (2010).*

Another classification frame of reference for ESs delivered by UGAs is the Common International Classification of Ecosystem Services (CICES) for Integrated Environmental and Economic Accounting, which is proposed by the European Environment Agency (Fig. 1.3). This framework attempted to synthesize the different MEA and TEEB classification systems developed to date. For this reason, it has become an essential reference framework within the ES research area. Unlike the MEA and TEEB classifications, CICES merges supporting services with regulating services into a new category identified as regulating and maintenance services (Haines-Young & Potschin, 2018).

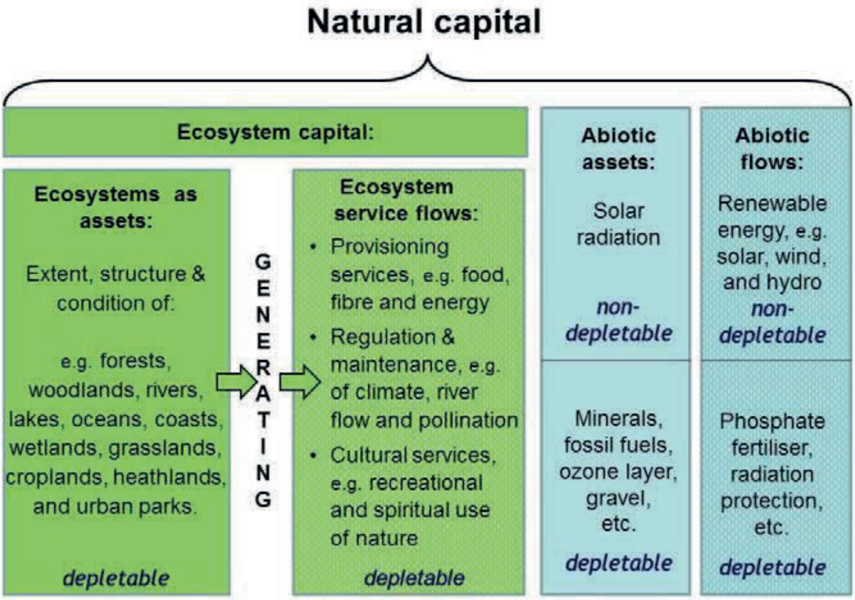


*Fig. 1.3 - ES framework developed by Haines-Young and Potschin (2018).*

Various global policy initiatives acknowledge the significance of ES, making their mapping and assessment a priority for all European Union (EU) Member States after adopting the EU 2020 Strategy on Biodiversity. The objective of the Strategy is to break biodiversity loss and ES degradation in the EU by 2020, with efforts to restore them as much as possible. To enhance understanding of ecosystems and their services in the EU, Member States were called to conduct mapping and assessment of ecosystems and their services within national territories by 2014, including their economic value. In the strategy context, "mapping" involves spatially defining ecosystems, quantifying their condition, and enumerating the services they provide. On the other hand, "evaluation" refers to translating this scientific evidence into understandable information for policymakers and the decision-making process (Maes et al., 2016; Maes et al., 2012).

From that moment, research on ESs about the definition and implementation of ESs methodological framework for spatial planning practices has been developed meaningfully (Gómez-Baggethun & Barton, 2013; Geneletti et al., 2020; Vignoli et al., 2021). They provided an overview of the most relevant urban ESs, identifying and measuring their value in urban planning and management decision-making processes with different methodologies and frameworks.

Although the importance of green areas in urban environments has been widely recognized, the research within the scientific literature has demonstrated how the urbanization process and, therefore, the conversion of natural areas into semi-natural, semi-artificial, and artificial areas represent a significant threat to the provision of ESs (Peng et al., 2017; Song & Deng, 2017; Cao et a., 2021). The lack of ES supply has been found in compact cities, as Larondelle and Lauf (2016) demonstrated. Within their study, the authors, through the supply and demand of urban ES assessment, detected that the most dense and compact structures are characterized by negative balance for almost every urban ES. These results align with what Jim (2013) discussed, who emphasized that compact cities are generally less green and, therefore, need for cities to be compact and green. Also, Larondelle et al. (2014), after mapping and regulating ES across European cities, noticed that the compact city concept should be redefined to promote enough green spaces.

In general, the regulation of urban growth processes and the solutions to the negative impacts of urban growth on natural areas related to the protection, enhancement, and promotion of green and natural spaces in the urban environment is of great importance. Nature-inspired solutions for addressing the multiple environmental, social, and economic challenges associated with the loss of ESs due to urban growth processes are represented by NBSs.

The NBS concept is the latest addition to the urban greening lexicon (Nesshöveret al., 2017), as it was first introduced in 2012 by the International Union for Conservation of Nature (IUCN). However, European countries adopted the NBS concept in 2015, when the European Commission established an expert group focused on Nature-Based Solutions and the Revitalization of Urban Environments (European Commission, 2015) to create a dedicated funding stream within the Horizon 2020 funding program. In that context, the European Commission (2016) stated that:

> NBSs are solutions inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient and systemic interventions.

Similarly, the IUCN defines NBS as:

> actions to protect, sustainably manage and restore (create) natural or modified ecosystems that address societal challenges (including urban ones) effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2016).

Building on this definition, therefore, NBSs are supposed to be the most suitable nature-inspired solution for addressing the challenges associated with rapid urbanization and urban growth processes, such as ESs degradation, including urban heat island (UHI) effects and flooding, as well as weakened human health and wellbeing (Tzoulas et al., 2007; Demuzere et al., 2014). For these reasons, they should be part of the planning processes, as Pan et al. (2021) revealed in their study.

To facilitate the implementation of the NBSs in the urban planning research and practice for addressing the challenges related to urban growth processes, Almenar et al. (2021), building on Eggermont et al. (2015) and (Cohen-Shacham et al., 2016), proposed three main types of NBSs, as shown in Fig. 1.4.

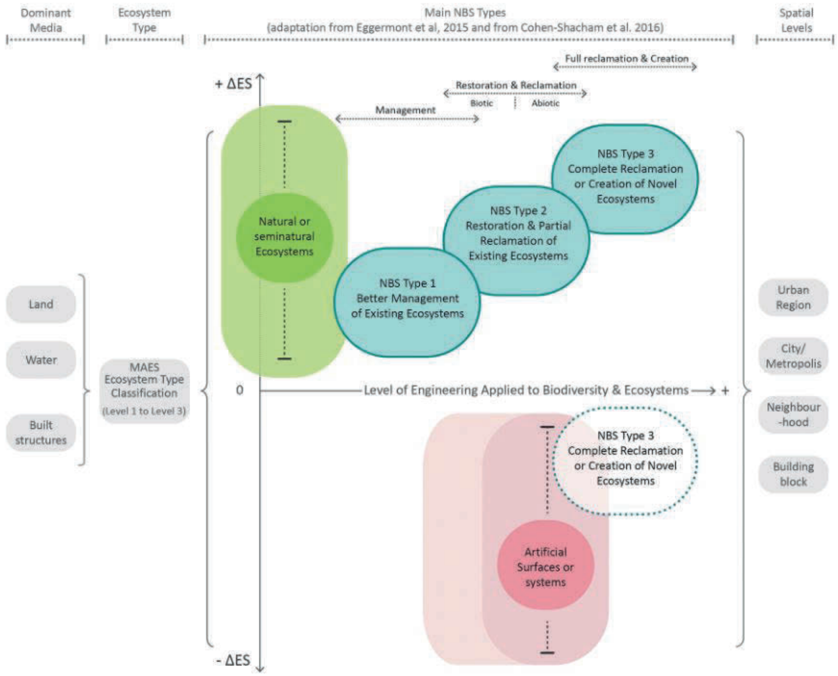


*Fig. 1.4 - Conceptualization of NBS types according to Almenar et al. (2021).*

The NBS Type 1 comprises solutions enabling improved utilization and management of current natural and naturalistic ecosystems, excluding physical alterations. NBS Type 2 encompasses solutions and processes designed for ecosystem restoration, further categorized into reclamation and restoration. NBS Type 3 involves the creation of new ecosystems, containing solutions that entail extensive (a large portion of the area) and intensive (high