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Study of the Role of Urban Infrastructure in Urban Green Network Formation*

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ABSTRACT

Expanding urban green space and creating a network of green spaces in the city, in addition to meeting citizens' needs for recreation and contact with nature by reducing air pollution, promoting biodiversity, enhancing diversity, and using existing agricultural and garden lands, lead to the formation of active urban ecosystems, and thereby expanded social relations, improved security and enhanced economic prosperity of gardens and agricultural lands. As a green infrastructure, it can influence the dynamism and sustainability of cities. In this research, the infrastructural components affecting the green network formation and ecosystem services provided by them were extracted from previous research by library study. Then, 25 urban green networks in the world, as case studies, were investigated to determine to what extent the abovementioned components were focused. The present study is descriptive-analytical correlational research. The samples were selected using a purposive sampling technique. The samples were evaluated and scored on a 5-point Likert scale. The results indicate that in the successful examples of expanding green infrastructure and forming urban green networks, there are basic components in the infrastructure and service sections that are necessary for the formation and expansion of the green network, as mentioned in the findings and conclusion sections. Moreover, considering the relationship between structure and service provision, the results show that the existence of infrastructure related to some ecosystem services does not necessarily lead to the provision of these services and influential lateral areas play an essential role in the efficient provision of ecosystem services.

Keywords: Urban Green Network, Ecosystem Services, Green Infrastructure, Urban Infrastructure.

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1. INTRODUCTION

Recently, the traditional meaning of urban green spaces in urban planning is changing. In the past, these spaces were thought of as sources with an originally recreational function, while, nowadays, they are considered natural spaces necessary to maintain urban balance (Fariña 2013). In this new concept, the term green infrastructure refers to green areas presenting various functions beyond recreational and landscape uses and providing ecosystem, social, economic, and environmental services. Therefore, using the concept of green infrastructure in the urban context prompts planners to re-examine the "urban green" value and the use of multiple benefits (environmental, social, and economic) provided by urban green areas (Vitoria- Gasteiz City Council 2014). Recent research has focused on the use of regulatory, cultural, provisioning, and ecosystem services, green infrastructure, and nature-based solutions to improve environmental, social, and economic conditions in cities (Haase et al. 2014). This literature has rarely emphasized the integration of systems for growing food and the benefits of ecosystem service provision in urban areas (Cameron et al. 2012). Ecosystem services bring significant benefits to the concept of a sustainable city (Ahern, Cilliers, and Niemelä 2014).

2. PROBLEM STATEMENT

Green infrastructures influence socioeconomic conditions and service provision for citizens, in addition to local and regional climate and air quality. However, existing green infrastructures in cities, which are considered national and regional capitals, are greatly prone to degradation by the ever-increasing expansion of urbanization and the development of construction. Despite the efforts made to maintain these infrastructures in Iran, the development of construction in cities is still considered a threat to them. The maintenance, improvement, and development of these infrastructures require developed plans, one of which is the formation of urban green networks. Reviewing global experiences and the plans developed on the city scale in the world to know how to deal with the challenges and what solutions are considered to maintain these infrastructures and take advantage of their services, especially the networks formed by connecting them, can result in a special approach to how to address these natural potentials.

In the present study, 25 case studies were reviewed in terms of their challenges, solutions, and goals, to extract their experiences and developed plans for green infrastructure management and urban green network formation. Then, it seeks to answer the research question by the approach of investigating the effectiveness of infrastructure in providing ecosystem services.

2.1. Research Questions

1. How does the formation of a green network help the sustainability of green infrastructure?
2. To what extent do the improvement and expansion of urban infrastructure influence the ecosystem services provided by green infrastructure?
3. Does the establishment of the infrastructures needed to provide ecosystem services necessarily lead to the provision of these services?
4. What is the relationship between the performance of urban infrastructure and ecosystem services?

2.2. Research Hypotheses

1. Connecting urban green patches through green corridors to form a green network makes these infrastructures known in the network and used by a wider range of citizens. In addition to forming a network and creating a multi-functional landscape, this approach can strengthen each patch and prevent the abandonment of green patches due to the weakening of some functions. The green network formation not only enhances the environmental sustainability of these infrastructures. Moreover, manipulating green networks is far more difficult than encroaching on the limits of green patches, making their management easier and people are more assiduous in maintaining them.
2. Considering the extent of infrastructure fields in cities and their various direct and indirect influences on green infrastructures and ecosystem services provided by them, one can conclude that the maintenance, improvement, and development of urban infrastructures can differently influence the ecosystem services provided in cities and help to provide them as best as possible.
3. Since the infrastructure needed to provide ecosystem services is considered one of the prerequisites for providing these services, its existence can lead to the provision of services dependent on that infrastructure, and promoting and improving the existing infrastructure are directly effective in improving the quality of services.
4. Promoting and improving the performance of urban infrastructure directly affect the services provided by that infrastructure. However, their effectiveness is different and depends on the lateral factors affecting the provision of services.

3. THEORETICAL FOUNDATIONS

To explain the research topic, in addition to the definition and history of urban green infrastructure, its position and the services provided by it are discussed:

3.1. Urban Green Infrastructure

In urban areas, "green infrastructure" refers to those elements of the natural environment that provide

ecosystem services. Urban green infrastructure includes not only open spaces such as parks, playgrounds, cemeteries, and private gardens but also green roofs and walls, street trees, sustainable urban drainage systems, ponds, rivers, and canals (Wentworth 2017).

According to the European Union's Green Infrastructure Strategy, green infrastructure is defined as follows: "Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation, and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions, and therefore, citizens' health and quality of life. It also supports a green economy, creates job opportunities, and enhances biodiversity." (European Commission 2019).

In cities, there are various interventions made according to the concept of green infrastructure and they can influence several different urban management areas. Measures taken to enhance the verdure of built spaces, create urban community gardens for local food production, or use new environmental criteria in the urban area design and management under the title of green design and management are examples of a wide range of significant approaches (Fig.s 1 and 2). Urban green infrastructures effective in forming green networks in cities can be divided into two categories: potential green infrastructure and actual green infrastructure.

1. Potential green infrastructure: potential urban infrastructures include lands that have previously been used as green space and their use has been changed or turned into brownfield land due to changes in economic interests, placement in the urban development plan, and so on. This issue has been discussed in developed countries since the formation of industrial cities, but in Iran, its history goes back to the 1960s and 1970s (Pourmohammadi and Ghorbani 2004).

In the structure of cities, these spaces, including brownfield lands with the possibility of greening, such as abandoned agricultural and undeveloped lands, as well as lands called backup for urban renovation or urban services in the literature of urban planning, such as the lands of abandoned airports, barracks, and so on can be identified to develop urban green spaces. These potential points can be used to expand patches where it is possible or used as green corridors to connect green patches in places with high building density (Parivar, Yavari, and Sotoudeh 2008).

Fig. 1. Development of Green Infrastructure by Reusing Lands with Agricultural Potential

2. Actual green infrastructure: These infrastructures include all types of green lands in cities. Green infrastructures in cities are considered an inseparable part of the structural elements of cities. Nowadays, these spaces play a more basic functional role in cities and can influence the performance of cities in economic, social, and environmental fields. These lands are divided into three categories in terms of ownership: public, private, and semi-private.

Figure 3 shows various types of potential and actual urban green infrastructures.

Fig. 2. Designing Green Lands in Cities, as a Place to Provide Services to Citizens

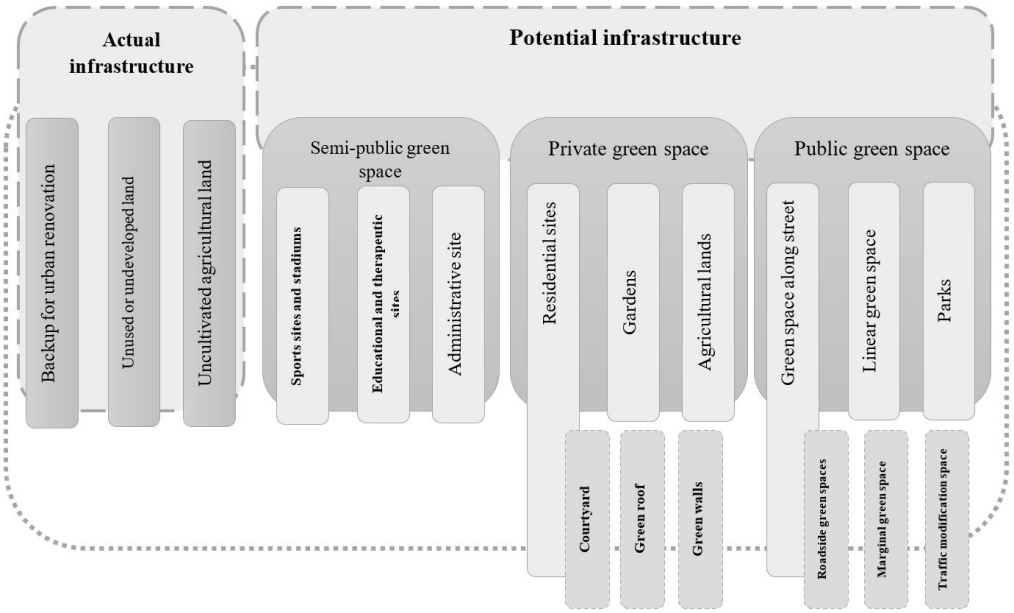

Fig. 3. Types of Urban Green Infrastructure

3.2. The History and Structure of the Green Network

Merriam (1984) first introduced the concept of landscape connectivity to emphasize the effect of landscape structure and interactions between species on the movement of organisms among habitat patches. The movement of species is important since it greatly affects species survival, gene flow, and other important environmental processes.

Initially, these concepts were defined to reach specific objectives and did not include multiple objectives, for example, protecting the environment (green corridor) (Groome 1990), controlling urban sprawl (green belt) (Kühn 2003), or providing visual connections (greenway) (Ahern 1995; Fabos 1995; Taylor et al. 1995). Spatial concepts, from greenways to green networks, are concepts that have been proposed from an ecological perspective to create open spaces (Forman 1995).

The more the connections are, the shorter the distances and the fewer the obstacles are to the movement of species among patches. Connecting habitats well provides ecological networks with better performance (Lechner et al. 2015; Baguette et al. 2013; Taylor et al. 1993). Greater connections have more practical effects. For example, enhancing the level of connectivity can lead to the reduced risk of local extinction and increased probability of species reproduction. Therefore, small ecological networks with good performance can act as a large habitat, and as a result, population growth for stronger species can be guaranteed (Rudnick et al. 2012; Bunn et al. 2000). Green infrastructure projects in different places and stages face numerous complex problems considering ecological aspects and landscape attributes, and there are interactions between landscape elements (patch, corridor, matrix) at different levels (Fig. 4). The type, number, location and limit, size, form, hard or soft edges of ecological patches, and how they interact with the surrounding environment are very important in assessing and valuing infrastructure programs.

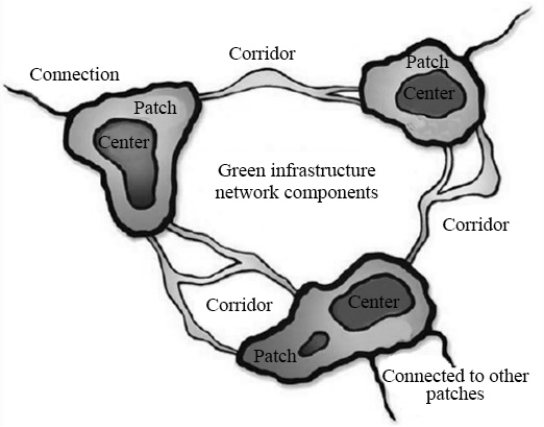

Fig. 4. How the Urban Green Network Elements are Connected

Humans' access to natural factors such as contact with green spaces and parks, natural corridors, wildlife crossings, linear built landscape elements, the existence of shared paths, connection with streets, and urban fabric, the creation of overpasses and underpasses, bridges and the availability of public transportation are considered the keys to the success of any infrastructure project. Continuity of parks and green spaces, streams and watercourses, highways and streets, railways, alleys, and side roads, the multi-functionality of the project plan to preserve

wildlife habitat, create built ecology, establish a balance between vehicle, bicycle, and pedestrian transportation, and meet the needs of recreation and leisure, as well as engineering functions, are basic fields that must be considered by planners, designers and managers (Khan Sefid 2016).

All urban green lands can form a green network if they are connected, due to their similar functions and uses. In the urban green network, green infrastructure is considered an interconnected network complementary to urban green spaces. It includes all important environmental, scenic, and cultural elements, as well as related environmental processes and flows. These elements are integrated into a single system and assume the function of territorial integration and improvement of urban environmental quality. The existence of a coherent network with formal, functional, and semantic unity guarantees the quality of city spaces and a better understanding and perception of them. Continuity is one of the important principles in the green network structure because it is structurally and functionally effective in the sustainability of green spaces and, subsequently, the sustainability and spatial coherence of cities, improving bioclimatic conditions, enhancing the quality of urban life, creating active natural ecosystems in urban environments, and increasing the livability of cities (Khan Sefid 2008).

Generally, to form a green network, different urban infrastructure networks in three areas are examined, and then an integrated urban green network is formed through their overlapping:

1. River network: river system, urban water, and runoff network.
2. Green space network: protected man-made areas, such as parks, gardens, agricultural lands, forests, green belts, and protected natural areas.
3. Transport greening network: sidewalks, bicycle lanes, tree corridor network along the streets, and trees around the transportation network within and around the cities.

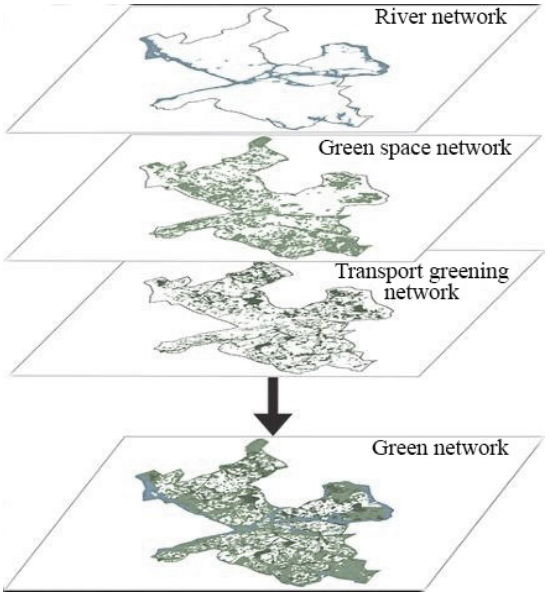

Fig. 5. Constituent Layers of the Urban Green Network
(Xiu et al. 2016)

The "integrated green networks" is a concept that integrates the abovementioned concepts and analyzes the green and blue structure of the entire city (Fig. 5). Green networks use network connectivity as a tool for integrating the abovementioned concepts with ecological and social functions jointly (Xiu et al. 2016).

Urban green patches are greatly prone to deterioration and destruction if they lack specific definitions and are not functionally justified in the urban space. Assigning a role to each of the patches within the cities makes each patch have its own value and operate in the network, resulting in the shrinkage of the strengths and weaknesses of patches in the network and their reinforced sustainability.

The development of cities due to population growth leads to an increase in the land price and the development of housing in the city and its suburbs, causing the development of construction to become a speculative activity in the city and its suburbs, and the value of undeveloped lands to increase. These lands include brownfield lands, agricultural lands, and gardens (Suzanchi 2004). In the urban space, one of the problems inducing the unsustainability of green patches is the specific use of each patch, and the decrease in the quality and prosperity of that specific use causes green spaces in the city to become abandoned spaces. Therefore, connecting urban green

spaces can form a network that brings the distribution of different activities and uses, and the introduction of unknown activities in other patches to the city and citizens, resulting in the reduced vulnerability caused by being single-use.

To form a green network and improve its capabilities in the social, economic, environmental, transportation, and land-use infrastructure, the components affecting urban infrastructure are presented in Table 1 by reviewing references.

Table 1. Components Affecting the Primary Infrastructure Required for the Formation of the Urban Green Network

Urban Infrastructure																			
Land-Use	Access and Transportation Infrastructure					Environmental Infrastructure						Economic Infrastructure				Social Infrastructure			
Using vacant lots as part of the green network	Connected bike network in the city	Restricting vehicle network	Facilitating walking access to different places	Improving the visual quality of urban corridors	Surface water management	Improving the quality of existing green spaces	Expanding green spaces and improving the connectivity of urban green patches	Expansion of green roofs and green walls	Strengthening and expansion of urban gardens	Protection and strengthening of urban rivers	Waste management	Establishing local retail	Developing focal points to attract tourists	strengthening specific destinations with economic goals	Expanding urban leisure space	Creating interaction nodes for citizens	Creating urban parks of different sizes	Improving access to sports facilities	

3.3. Green Network Services

The benefits of green spaces can be enhanced when they connect important natural, ecological, scenic, cultural, and social areas (Ahern 1995). Well-planned and designed green networks can provide an attractive environment for everyday life, create a distinctive identity for those places, and also be a guide for growth and development in the future.

Gardens and crofts can also be defined as a sustainable planned network of edible components and structures within an urban ecosystem, that as ecosystem services, serve the city primarily for providing food and then for reaching urban cultural goals (e.g. recreation, enhancing public benefits, and aesthetics) and regulatory services (such as removal of air and water pollution, temperature regulation, and flood control). These lands can include community gardens, green roofs, landscaping with edible cover, and urban forests (McLain et al. 2014). The effects of these ecosystem services on cities include reduced greenhouse gases (Grewal and Grewal 2012), improved access of low-income urban residents to healthy and affordable food (Zezza and Tasciotti 2010), saving money and energy in the food movement (Deelstra and Girardet 2000). In addition, urban green networks facilitate the connection between urban green areas and rural and natural areas around cities. Economically, investing in green infrastructure can also be used to promote regional and urban development in creating green employment. Connecting natural, semi-natural, and man-made open spaces to create an interconnected network, in addition to enabling physical activities for citizens, increases accessibility within towns and suburbs, brings a wide range of other benefits such as improvement of health and well-being, provision of job and educational opportunities, strengthening of biodiversity, helping to reduce climate change, enhancement of tourism, and promotion of the sustainable use of scarce natural resources (Scottish Natural Heritage 2012; Yuhong et al. 2011). These green networks, as urban ecosystems, can provide citizens with a set of benefits called ecosystem services, which refer to our fundamental dependence on nature for basic needs, well-being, and comfort. Ecosystem services are the benefits provided by nature to people. These services can be provisioning (providing food, clean air, water, and materials), regulating (regulating climate, nutrient cycling, pollination, or formation of fertile soils), cultural (recreational, or inspiring opportunities) services. Natural ecosystems are multifunctional and can provide a wide range of services simultaneously. The scope and flow of these benefits largely depend on biodiversity and ecosystem conditions (European Commission 2019).

The main services provided by the green network in cities include ecosystem services of green spaces, which are briefly listed in Table 2. This table presents those ecosystem services investigated in the case studies.

Table 2. Examined Ecosystem Services

Ecosystem Services																				
Habitat-related Services		Regulatory Services			Provisioning Services			Social Services												
Biodiversity	Creating active ecosystems in cities	Regulating local and global weather conditions	Reducing noise and air pollution	Resistance to climate change	Energy saving	Providing fresh and low-cost food	Protection and expansion of urban agricultural plots	Recreation and ecotourism	Improving social cohesion	Providing educational opportunities	Increasing access to nature	Providing job opportunities	The possibility of creating social relations	Improving the sense of belonging and of place identity	Human-nature contact	Improvement of health	Enhancement of security	Social participation	Promotion of aesthetic values

(derived from Masnavi and Dabiri 2017)

Achieving a green space network in the urban landscape aims to provide a quality and attractive environment for people who live there, work in the surroundings of that place or visit there. On the other hand, the formation of a green space network provides sustainable habitats for other living organisms, i.e. plants and animals. (Xiu et al. 2016). Connecting urban green spaces reduces construction and maintenance costs, and integrated landscape management is easier than the management of scattered small green spaces. Figure 6 displays the relationship between the green network formation and the services provided by it.

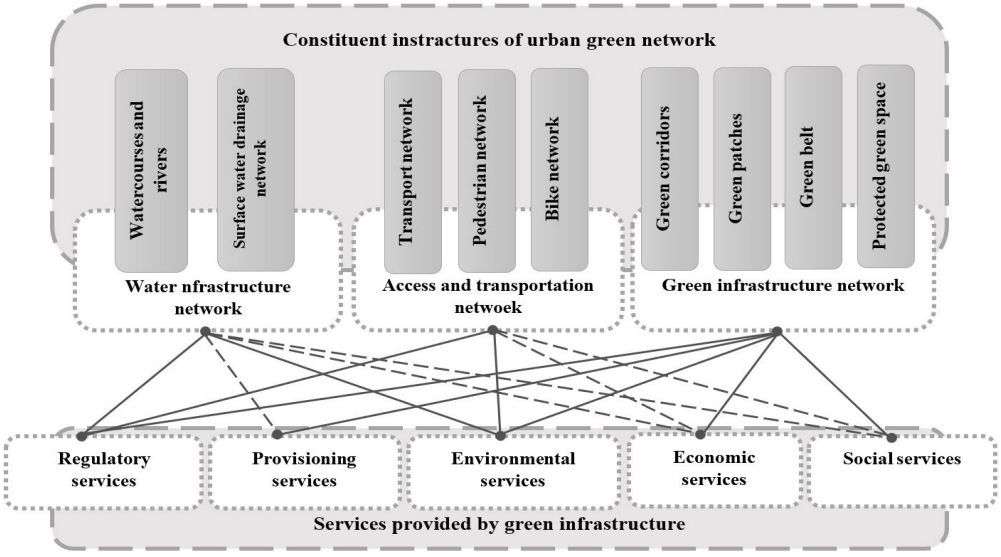

Fig. 6. The Relationship between the Constituent Infrastructures and Green Network Services

4. METHOD

The present study is a descriptive-analytical correlational research. The required data were collected using library studies. The samples were selected using a purposive sampling technique. The case studies included 25 urban green infrastructure networks in different countries of the world. The samples were evaluated and scored on a 5-point Likert scale. Data analysis was conducted using statistical data extracted from the abovementioned Likert scale-based assessment and logical reasoning. The research variables included urban infrastructure (an independent variable) and ecosystem services (a dependent variable). The relationships between independent and dependent variables were investigated using simple linear regression. Figure 7 shows the research process.

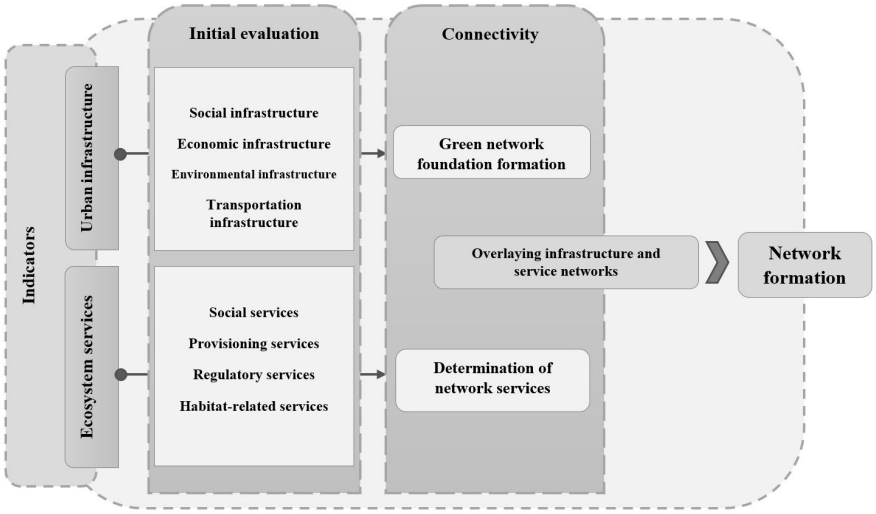

Fig. 7. Research Process

The formation of green networks in cities helps to enhance the multifunctional performance of landscapes and can serve as a framework for making changes and transformations in the social and environmental dimensions of the system in ways that benefit humans - including disadvantaged social groups- and the environment. The multifunctional performance of ecosystems has long been recognized as a condition for sustainability in uncontrolled systems (De Groot 2006), and recently, interest in multifunctional landscapes with extensive ecosystems has expanded (Brandt and Vejre 2004; Zander et al. 2007).

The concept of multifunctionality is characterized by four main features: 1. The functions have interactions beyond the colocation, 2. The landscapes have positive and synergistic interaction, 3. The landscape can provide products and services beyond the cultural functions, and 4. Rural and urban areas together are considered a connected matrix (Selman 2009).

5. FINDINGS

In the present study, 25 urban green infrastructures in the world with documented plans to maintain and expand the urban green space and form a green network were reviewed to extract their strategies and investigate the main concern of the green network in them, the main goals of the green network formation and the general approaches pursued in them, as summarized in Table 3. The case studies included green networks in London (England), Hamburg (Germany), Baltimore (Maryland), Sydney (Australia), Stockholm (Sweden), Dublin (Ireland), Vitoria-Gasteiz (Spain), Glasgow (Scotland), Edmonton (Canada), Bristol (England), Halifax (Canada), Whangarei (New Zealand), Darlington (England), Dundee (Scotland), Essen (Germany), Ljubljana (Slovenia), Nijmegen (the Netherlands), Canterbury, Liverpool, and Sheffield (England), Lisbon (Portugal), Copenhagen (Denmark), Nantes (France), Oslo (Norway), and Nazhvan (Isfahan, Iran).

Table 3. Examining Case Studies of the Green Network; (EGNS[1]), (UGIVG[2]), (WBGNS[3]), (SCP[4]), (DGS[5]), (BGSS[6]), (HGNP[7]), (BGN[8]), (ALGG[9]), (GSGG[10]), (GCV[11]), (HGN[12]), (SNH[13])

Green Network	London-England	Hamburg, Germany	Baltimore, Maryland	Sydney, Australia	Nazhvan, Isfahan, Iran
Concern	Becoming the most dynamic city in the world	Connected green network and creation of active urban trips	Improvement of vacant lot maintenance standards	Expansion of green infrastructure for the future city	Limiting the development of the city and creating an urban air filter
Main Goals	Development of green infrastructure; Climate change adaptation; Enhancing the quality of existing green space; Enhancing the quality of existing green space; Spatial relations and encouragement to travel on foot	Creating an active green network for people and wildlife; Flood reduction and resistance to climate change; Improving health and well-being; Creating an urban green network	Supporting the growing population; Removal of worn-out and abandoned blocks; Encouraging people to invest in urban projects	Increasing access to open spaces in and around the city; Creating an active urban pedestrian network and limiting the transportation network; Improving air quality and mitigating the effect of heat islands	Protection, expansion, improvement, and promotion of green space; Creation of a recreational use while protecting nature and resources; Directing and organizing urban development; Protection and maintenance of natural capitals
Approach	Protecting and promoting the city's natural heritage, such as the Thames River, as a global example	Connecting two urban green rings and creating landscape axes	Connecting urban green spaces with active green routes and improving the quality of urban vacant lots	Supporting the active urban pedestrian system and enhancing access to open spaces and ecological sustainability of the city	Preservation of gardens and agricultural lands in the west of Isfahan city and adding public functions to them

Green Network	Stockholm Sweden	Vitoria-Gasteiz, Spain	Halifax, Canada	Edmonton, Canada	Bristol, England
Concern	Creating a coherent and sustainable city and planning how to expand the city	Connecting urban green infrastructures to take advantage of ecosystem services and preserve biodiversity	Maintaining and promoting the long-term sustainability of the region in the field of green space	Maintaining and improving the natural environment of the city to meet the needs of the growing population of the society	Providing high-quality, attractive, eye-catching, and available green spaces to meet the diverse needs of all citizens and visitors.
Main Goals	Creating a coherent city Improving the quality of public spaces Attention to the future needs of a growing city Resistance to climate change Improving network access	Climate change adaptation, mitigating urban heat islands Promoting the biodiversity of the city Development of environmental and aquatic network Increasing recreational and employment opportunities Preservation of cultural heritage, traditional landscapes, sense of belonging, and identity	Preservation of important environmental, aquatic, and cultural systems Promoting the sustainable use of natural resources and economically important open spaces Investigating, defining, and designing suitable lands for creating parks and urban corridors	Modifying Edmonton's urban form Using public transportation and active walking trips and cycling tours Improving liveability Preservation of the natural environment Improving economic sustainability Diversifying the city's economy	Preserving green space from development Expanding public access to green spaces and enhancing social sustainability Improving landscapes Encouraging public participation and promoting a healthy lifestyle Creating diverse green spaces
Approach	Creating a developed plan for sustainable city development and paying attention to maintaining and improving urban and environmental services	Creating an interconnected green space network where each space has a specific role and supports other roles.	Creating an urban green network to take advantage of ecosystem services and create diverse functions	Urban park management and developing a strategic plan for their natural connections and creating multi-functional spaces	Improving and enhancing urban green space and increasing security in it

Green Network	Glasgow, Scotland	Whangarei, New Zealand	Dublin, Ireland	Darlington, England	Dundee, Scotland
Concern	Improving the quality of the environment, improving people's health and well-being, and connecting urban and rural areas	Expanding the blue and green network and benefiting from ecosystem services	Improving recreational resources for the community	Protecting, planning, managing, and maintaining the quality of green infrastructure	Strengthening and connecting open space and habitats
Main Goals	Creating attractions to attract capital Creating attractive places for people to work and live Increasing educational opportunities Active, healthier workforce Creating a protected natural environment for wildlife Reducing damage caused by severe weather events and improving its quality	Increasing recreational facilities in urban and rural areas Improving health and physical vitality by creating a bike network and increasing green space Increasing the connection between green spaces and residential spaces Protection of historical and cultural areas and their connection with natural heritage	Strengthening key streets and social spaces Improving and expanding existing green spaces and creating roadside green corridors Taking measures to improve the connection between patches and enhancing legibility in the network - Balanced distribution of urban and recreational facilities	Providing places for sports, recreation, and outdoor games Providing spaces for people to connect with wildlife Improving air quality and climate change adaptation Food Production Development and revitalization of green spaces	Connecting green networks Protecting and strengthening green spaces Improving energy efficiency Expanding pedestrian network, bike network, and public transportation Waste Management Climate change adaptation
Approach	Increasing the connection between residence places and recreational places	Improving ecosystem services and ecological communications, providing economic opportunities, and protecting the city from natural hazards	Creating a connected green landscape, creating a legacy of accessible green spaces, and renovating green spaces and playgrounds	Enhancing public participation to improve, manage, and maintain the local environment and identify local potential	Adopting a strategic approach in green infrastructure to achieve sustainable development patterns

Green Network	Essen, Germany	Ljubljana Sloane	Nijmegen, Netherlands	Canterbury, England	Liverpool, England
Concern	To become an example of an industrial green city	Creating a green, clean, safe, and friendly city	Resistance to climate change and use of clean energy	Assessing needs, opportunities, and strategic priorities, and adjusting future actions	Supporting a safe, all-inclusive, sustainable, and enjoyable city
Main Goals	Protecting and strengthening nature and biodiversity Resistance to weather changes Improving air quality Waste Management Implementation of public green projects Improving the quality of life	Improving the quality of life, safety Renovating the traffic network Encouraging citizen participation Creating a connected landscape Protecting nature around Ljubljana	Becoming a smaller city with enough green space Preservation of the surrounding nature Expanding the bike network and public transportation system Investing in the local and regional economy	Strengthening human-nature contact Protecting and strengthening natural assets Creating a green economy Facilitating local measures to protect and improve nature Connecting communities with health, welfare, and accessible green infrastructure	Supporting jobs, and reconstruction and growth of housing within the limits of the living environment. Improving physical and mental health To become a green city with biodiversity Planned green infrastructure
Approach	Benefiting from the help of citizens and changing their attitude towards the success of urban goals	Strengthening teamwork and innovative solutions to promote the city's brand and enhancing public awareness	Involving citizens, and entrepreneurs in the city plan as much as possible to become a healthy and prosperous city	Protecting, strengthening, and managing biodiversity networks and green infrastructure	Sustainable urban and rural development in various infrastructure areas

Green Network	Sheffield, England	Lisbon, Portugal	Copenhagen, Denmark	Nantes, France	Oslo, Norway
Concern	Green and quality open spaces for all generations	Making Lisbon one of the world's greatest cities to live in	A green city with a prerequisite of high quality of life	City development and environmental excellence	Transforming Oslo into a greener, fairer, and more creative city
Main Goals	Access to available safe sites Achieving quality by design Valuing local character and heritage Realizing economic value	Installing new sustainable equipment Housing renovation Creating public green space Expanding a specific path for pedestrians and cyclists Improving public transport infrastructure	Creating green promenades Adaptation of the city to climate change Reducing carbon emissions Expanding pedestrian network, bike network, and public vehicles Expanding urban agriculture and diverse urban green spaces	Protecting the environment to improve daily life and converting it into a resource for activities and jobs Protecting water resources and biodiversity Climate change coping Developing public transportation Waste recycling and processing Expanding tourism infrastructure	Climate change coping Promoting zero-carbon transportation and improving environmentally-friendly cycling and public transportation infrastructure and waste management Maintaining and strengthening water and green infrastructure Sustainable urban development and innovation in creating new jobs
Approach	Funding and providing investment along with attracting public participation and improving standards	Sustainable mobility through limiting the vehicle network and prioritizing walking, cycling, and public transportation	Solving environmental challenges by focusing on innovative and sustainable solutions	Creating a long-term strategy in the field of social, economic, and environmental infrastructure	Coping climate change with an integrated set of actions

To examine the extent to which the extracted effective components in the formation of the green network and the provision of services by it, were considered and addressed, a table (Table 4) was developed and each case study was scored based on a 5-point Likert scale and considering the frequency of strategies presented in the infrastructure categories shown in Figure 7.

Table 4. Scoring the Role of Urban Infrastructure and Ecosystem Services in the Studied Case Studies

			Hamburg, Germany	London, England	Baltimore, Maryland	Sydney, Australia	Nazhvan, Isfahan, Iran	Stockholm Sweden	Dublin, Ireland	Vitoria-Gasteiz, Spain	Glasgow, Scotland	Edmonton, Canada	Bristol, England	Halifax, Canada	Whangarei, New Zealand
Ecosystem Services (S)	Habitat-related Services (ec)	Biodiversity	5	5	5	5	3	4	5	4	5	5	5	5	3
		Creating Active Ecosystems in Cities	5	4	5	5	3	5	5	5	5	4	4	5	3
	Regulatory Services (a)	Regulating Local and Global Weather Conditions	4	5	5	5	5	5	5	5	5	5	5	5	5
		Reducing Noise and Air Pollution	4	4	5	5	5	5	5	5	5	5	4	5	4
		Resistance to Climate Change	4	5	5	5	3	5	5	5	5	5	5	5	5
	Provisioning Services (i)	Energy Saving	3	3	4	2	1	5	5	2	2	3	1	1	1
		Providing Fresh and Low-Cost Food	3	5	5	5	3	5	1	4	4	5	2	2	2
		Protection and Expansion of Urban Agricultural Plots	4	4	5	3	5	5	5	5	5	4	1	4	2
	Social Services (e)	Recreation and Ecotourism	5	5	4	5	5	5	5	5	5	4	5	5	4
		Improving Social Cohesion	5	4	5	5	3	5	5	2	4	3	4	4	3
		Providing Educational Opportunities	2	5	5	5	2	5	4	5	5	5	5	5	3
		Increasing Access to Nature	5	5	5	5	5	5	5	4	5	4	5	5	3
		Providing Job Opportunities	5	5	5	3	3	5	2	5	5	4	5	5	4
		The Possibility of Creating Social Relations	5	5	5	5	3	4	5	4	4	5	4	4	3
		Improving the Sense of Belonging and of Place Identity	5	5	5	3	5	5	5	5	3	5	5	5	2
		Human-Nature Contact	5	5	5	5	5	5	5	5	5	5	4	5	4
		Improvement of Health	5	5	5	5	3	5	3	5	5	5	2	5	3
		Enhancement of Security	4	4	5	3	1	1	5	4	5	5	5	4	5
		Social Participation	4	4	5	3	2	2	5	5	5	5	5	2	1
		Promotion of Aesthetic Values	5	5	5	5	5	5	5	4	5	5	3	5	5
Urban Infrastructure (F)	Land Use (l)	Using Vacant Lots as Part of the Green Network	2	3	5	2	2	1	5	5	5	1	1	1	1
	Access and Transportation Infrastructure (t)	Connected Bike Network in the City	5	5	5	5	3	5	5	5	5	4	5	4	5
		Restricting Vehicle Network	4	5	2	5	3	5	3	3	4	5	5	1	3
		Facilitating Walking Access to Different Places	5	5	3	5	5	5	5	5	5	5	5	5	5
		Improving the Visual Quality of Urban Corridors	5	5	5	5	4	5	3	4	4	4	3	4	4
	Environmental Infrastructure (v)	Surface Water Management	3	5	5	5	3	5	5	5	5	5	3	5	5
		Improving the Quality of Existing Green Spaces	3	5	5	4	5	5	5	5	4	4	5	4	5
		Expanding Green Spaces and Improving the Connectivity of Urban Green Patches	3	5	5	5	5	5	5	5	5	4	4	5	4
		Expansion of Green Roofs and Green Walls	2	5	2	5	1	5	1	4	4	1	1	4	1
		Strengthening and Expansion of Urban Gardens	3	3	5	2	5	3	5	5	4	3	1	5	3
		Protection and Strengthening of Urban Rivers	3	5	5	5	4	5	2	4	3	5	3	5	4
		Waste Management	1	3	5	2	1	3	3	1	1	5	1	1	1
	Economic infrastructure (e)	Establishing Local Retail	2	3	5	3	3	3	2	5	3	1	5	1	5
		Developing Focal Points to Attract Tourists	4	5	3	5	5	4	4	2	4	5	2	4	5
		Strengthening Specific Destinations with Economic Goals	2	5	5	3	5	5	3	5	5	4	4	5	3
	Social infrastructure (s)	Expanding Urban Leisure Space	3	5	5	5	5	5	5	5	5	5	5	4	5
		Creating Interaction Nodes for Citizens	5	5	5	5	5	5	5	5	4	5	5	5	4
		Creating Urban Parks of Different Sizes	3	5	3	5	3	4	5	5	5	4	5	5	5
		Improving Access to Sports Facilities	3	3	5	3	5	5	5	5	5	5	5	5	5

Main Category	Sub-category	Criterion	Darlington, England	Dundee, Scotland	Essen, Germany	Ljubljana Sloane	Nijmegen, Netherlands	Canterbury, England	Liverpool, England	Sheffield, England	Lisbon, Portugal	Copenhagen, Denmark	Nantes, France	Oslo, Norway
Ecosystem Services (S)	Habitat-related Services (cc)	Biodiversity	5	5	5	5	5	5	5	5	5	5	5	5
		Creating Active Ecosystems in Cities	5	5	5	5	5	5	5	5	5	5	5	5
	Regulatory Services (a)	Regulating Local and Global Weather Conditions	5	5	5	5	5	5	5	5	5	5	5	5
		Reducing Noise and Air Pollution	5	5	5	5	5	3	5	2	5	5	5	5
		Resistance to Climate Change	5	5	5	5	5	5	5	5	5	5	5	5
	Provisioning Services (i)	Energy Saving	3	1	5	5	5	1	1	1	5	4	4	5
		Providing Fresh and Low-Cost Food	4	4	3	3	3	4	3	1	5	5	5	4
		Protection and Expansion of Urban Agricultural Plots	5	4	4	5	5	5	5	1	5	5	5	5
	Social Services (e)	Recreation and Ecotourism	5	5	5	5	4	5	5	5	5	5	5	5
		Improving Social Cohesion	5	5	5	4	4	5	5	5	3	5	5	4
		Providing Educational Opportunities	4	4	4	5	5	4	3	5	3	5	5	5
		Increasing Access to Nature	5	5	5	5	5	5	5	5	5	5	5	5
		Providing Job Opportunities	5	1	5	5	4	4	4	5	3	4	5	4
		The Possibility of Creating Social Relations	5	5	4	5	4	5	5	5	5	5	5	5
		Improving the Sense of Belonging and of Place Identity	4	4	3	3	3	5	5	5	4	5	5	4
		Human-Nature Contact	5	5	5	4	5	5	5	5	5	5	5	5
		Improvement of Health	5	5	5	4	5	5	5	5	4	5	5	4
		Enhancement of Security	2	3	2	2	2	5	1	5	5	4	4	2
		Social Participation	4	4	5	4	4	4	5	5	5	5	5	5
		Promotion of Aesthetic Values	5	5	4	4	4	5	5	4	4	4	4	5
Urban Infrastructure (F)	Land Use (l)	Using Vacant Lots as Part of the Green Network	1	1	5	3	1	1	5	3	1	1	3	3
	Access and Transportation Infrastructure (t)	Connected Bike Network in the City	5	4	5	5	5	4	5	5	5	5	5	5
		Restricting Vehicle Network	3	1	3	4	5	3	1	1	5	5	5	5
		Facilitating Walking Access to Different Places	5	5	5	5	4	5	5	5	5	5	5	5
		Improving the Visual Quality of Urban Corridors	5	5	5	5	4	5	5	5	4	5	5	5
	Environmental Infrastructure (v)	Surface Water Management	5	3	5	5	5	5	5	5	5	3	5	5
		Improving the Quality of Existing Green Spaces	5	5	5	5	5	5	5	5	5	5	5	5
		Expanding Green Spaces and Improving the Connectivity of Urban Green Patches	5	5	5	5	5	5	5	5	5	5	5	5
		Expansion of Green Roofs and Green Walls	5	2	1	4	5	3	5	5	3	2	5	5
		Strengthening and Expansion of Urban Gardens	5	4	4	5	5	5	5	5	5	5	5	5
		Protection and Strengthening of Urban Rivers	5	3	5	5	4	4	5	5	5	3	5	5
		Waste Management	1	1	5	5	5	1	2	5	5	5	5	5
	Economic infrastructure (e)	Establishing Local Retail	5	1	3	3	5	4	3	5	2	3	5	4
		Developing Focal Points to Attract Tourists	5	4	3	4	2	3	5	5	5	5	5	4
		Strengthening Specific Destinations with Economic Goals	5	1	2	5	5	5	5	5	5	5	5	3
	Social infrastructure (s)	Expanding Urban Leisure Space	5	5	5	5	5	5	5	5	5	5	5	5
		Creating Interaction Nodes for Citizens	5	5	4	5	5	5	5	5	5	5	5	5
		Creating Urban Parks of Different Sizes	5	5	5	5	5	5	5	5	4	5	5	5
		Improving Access to Sports Facilities	3	3	5	5	4	4	3	5	3	4	5	5

According to the data extracted from the infrastructure factors affecting the formation of the urban green network, the examined cases have mostly focused on social infrastructure factors, creating interaction nodes for citizens, creating urban leisure spaces, and improving access to sports spaces. In the economic infrastructure section, scattered strategies were considered according to the structures of the cities.

The case studies that were tourist attraction centers have mostly focused on earning money through the expansion of tourist attraction centers. These case studies included London in England, Hamburg in Germany, Nijmegen in the Netherlands, Nantes in France, and Sydney in Australia. On the other hand, those cities that were not tourist attraction centers have focused on urban agriculture and creating local businesses to earn money from their urban green spaces. For example, one can refer to case studies such as Baltimore in Maryland and Whangarei in New Zealand. In addition to tourism attraction, some case studies have prioritized urban agriculture, local income, and the preparation of fresh food. For example, one can refer to, Lisbon in Portugal, Copenhagen in Denmark, and Oslo in Norway.

In the environmental infrastructure section, waste management has been given special attention in a few cities and has been considered a strategy for forming an urban green network. Selected European green capitals and small cities such as Baltimore and Edmonton have focused on waste management.

Strengthening and protecting urban rivers and strengthening and expanding urban gardens have received special attention in cities that have these infrastructures. The expansion of green roofs and walls has not even been mentioned in the strategies adopted by half of the cities, but in cities where population growth rate and population density are high, such as London, Sydney, Stockholm, Nantes, Oslo, and Liverpool, this potential has received more attention.

Expansion of green spaces and their continuity, improvement of existing green spaces, and surface water management are the strategies that have been emphasized and paid attention to in most of the studied cases (Fig. 8).

Fig. 8. Radar Diagram of the Role of Infrastructures in Forming the Studied Green Networks

In the access and transportation infrastructure section, the strategies of improving walking access to different parts of the city, creating a connected bike network, and improving the visual quality of pedestrian corridors have been given special attention. The use of vacant lots and improving the visual quality of these places have been more emphasized in cities where the poor quality of these lands has become a challenge. For example, one can mention cities such as Dublin, Vitoria-Gasteiz, Glasgow, and Baltimore. Moreover,

the green network in the city of Baltimore was formed mainly to improve these lands and vacant lots.

As seen in the graph related to the services considered to form the green network in cities, the components related to regulatory services and habitat-related services are the most related, and the least related components are those related to provisioning services and some social services (Fig. 9). Among the social services, the promotion of aesthetic values, the man-nature contact, creating a sense of belonging and place identity, creating social relations and job opportunities, increasing access to nature, recreation, and ecotourism, and improving social cohesion have been included in the majority of urban green network formation strategies. Resistance to climate change, reduction of air pollution, regulation of local weather conditions, creation of active ecosystems in cities, and creation of biological diversity are among the regulatory services that have been specifically considered in many urban green network plans.

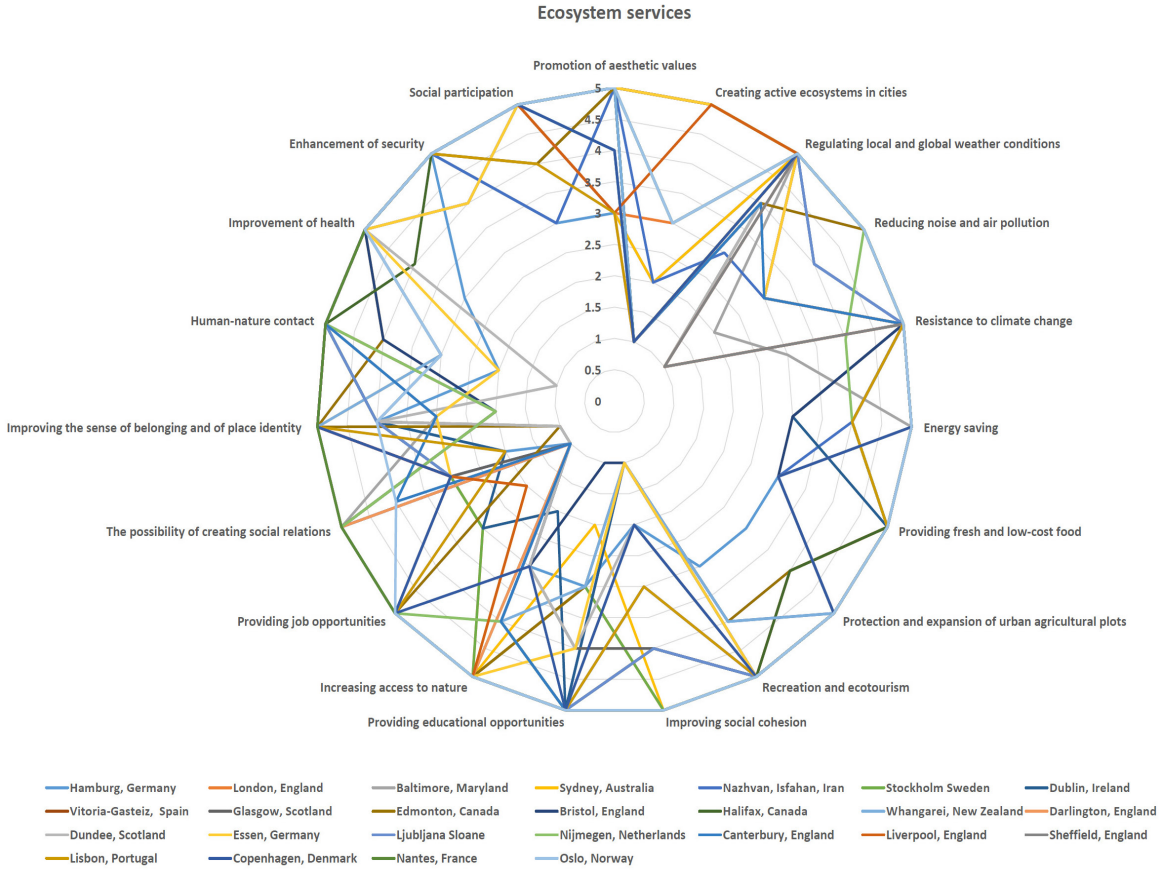

Fig. 9. Radar Diagram of the Role of Ecosystem Services in Forming the Studied Green Networks

According to Table 5, Pearson's correlation coefficient analysis shows that among the infrastructures effective in the green network formation, the highest correlation is observed between economic and environmental infrastructures, followed by environmental infrastructure-land use and environmental infrastructures-access and transportation. The correlation between transportation infrastructure and land use is negative and almost zero, indicating their low correlation with each other and sometimes their opposite effect on each other.

Table 5. Correlation Analysis of Urban Infrastructure

Correlations						
		FS	Fe	Fv	Ft	Fl
FS	Pearson Correlation	1	0.256	0.354	0.076	0.199
Fe	Pearson Correlation	0.256	1	**0.507	0.167	0.015
Fv	Pearson Correlation	0.354	**0.507	1	0.201	0.232
Ft	Pearson Correlation	0.076	0.167	0.201	1	-0.159
Fl	Pearson Correlation	0.199	0.015	0.232	-0.159	1

**. Correlation is significant at the 0.01 level (2-tailed).

According to Table 6, Pearson's correlation coefficient analysis shows that in the examined case studies, among ecosystem services, the highest correlation is observed between social services and habitat-related services with a coefficient of 0.754, and the lowest correlation is observed between regulatory services and social services with a coefficient of zero.

Table 6. Correlation Analysis of Ecosystem Services

Correlations					
		So	Si	Sa	Sec
So	Pearson Correlation	1	0.221	0.000	**0.754
Si	Pearson Correlation	*0.221	1	0.552	0.338
Sa	Pearson Correlation	0.000	0.552	1	0.279
Sec	Pearson Correlation	**0.754	0.338	0.279	1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

According to the regression analysis (Table 7), infrastructure factors were considered independent variables, and green network service components were considered dependent variables. According to this analysis, social infrastructure has the greatest impact on regulatory services with a coefficient of 0.26, and it has a poor and inverse effect on provisioning and habitat-related services with coefficients of -0.29 and -0.01, respectively.

Economic infrastructure has the greatest impact on social services and an inverse impact on regulatory and habitat-related services. Environmental infrastructure has the greatest impact on regulatory services with a coefficient of 0.75, which is natural considering their common context, followed by social services and habitat-related services with coefficients of 0.55 and 0.47, respectively.

Access and transportation infrastructures affect ecosystem services with coefficients ranging from 0.15 to 0.21. Land use affects social services with a coefficient of 1.22, which is the highest correlation between services and infrastructure, followed by the influence of land use on regulatory and habitat-related services with coefficients of 0.84 and 0.61, respectively.

Table 7. Data Regression Analysis

	Fs-Se	Fs-Si	Fs-Sa	Fs- Sec	Fe- Se	Fe- Si	Fe- Sa	Fe- Sec	Fv- Se	Fv- Si	Fv- Sa	Fv- Sec	Ft-Se	Ft-Si	Ft-Sa	Ft-Sec	Fl-Se	Fl-Si	Fl-Sa	Fl-Sec	Ftotal-Stotal
Beta	0.08	-0.11	0.30	-0.03	0.11	0.03	-0.91	-0.17	0.30	0.47	0.35	0.38	0.15	0.51	0.14	0.18	0.28	0.11	0.16	0.21	0.12
B	0.06	-0.29	0.26	-0.01	0.22	0.02	-0.21	-0.23	0.55	0.30	0.75	0.47	0.18	0.21	0.21	0.15	1.22	0.17	0.84	0.61	0.27
Constant	4.44	4.81	3.42	4.71	2.91	3.79	4.89	4.99	1.66	3.03	0.45	1.85	3.59	3.64	3.39	3.69	-2.90	1.86	-1.58	-0.47	2.60

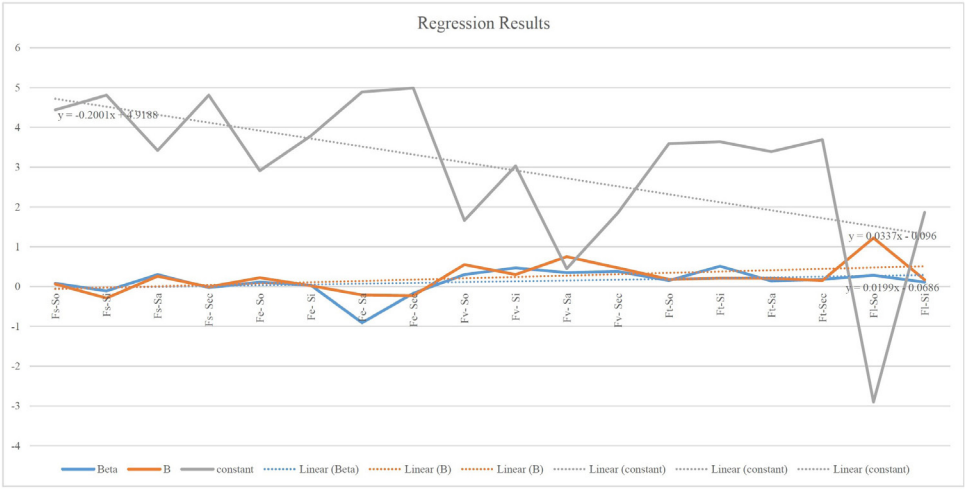

Fig. 10. Variation Ranges of Constants, B, and Beta in Data Regression Analysis

The range of constant variations shows that the influential basic condition in the cause-effect relationship between independent and dependent variables has a wide range, indicating that the basic conditions between the variables are very different and lack a known pattern. The existence of a range of variations between positive and negative values indicates the inverse effect of some independent variables on dependent variables, for example, the impact of economic infrastructure on the provision of habitat-dependent services, as well as the impact of land use on regulatory services. Most of the regression coefficients are between -1 and 1, and the overlapping of the linear diagrams B and Beta indicates that the regression test is standardized (Fig. 10).

Linear regression functions are derived from the statistical data analysis and based on the formula y=constant+Bx, where y is the dependent variable, x is the independent variable, constant denotes the intercept, and B is the impact factor of the independent variable and the slope of the linear graph. The following linear regression functions show the impact of the investigated infrastructures on the ecosystem services provided by them:

Social services = 4.44 + 0.06 (social infrastructure)

Provisioning services = 4.81 - 0.29 (social infrastructure); Regulatory services = 3.42 + 0.26 (social infrastructure); Habitat-related services = 0.01-4.71 (social infrastructure); Social services = 2.91 + 0.22 (economic infrastructure); Provisioning services = 3.79 + 0.02 (economic infrastructure); Regulatory services = 0.21-4.89 (economic infrastructure); Habitat-related services = 4.99 -0.23 (economic infrastructure); Social services = -2.90 + 1.22 (land use); Provisioning services = 1.86 + 0.17 (land use); Regulatory services = -1.58 + 0.84 (land use); Habitat-related services = -0.47 +0.61 (land use); Social services = 1.66 + 0.55 (environmental infrastructure); Provisioning services = 3.03 + 0.30 (environmental infrastructure); Regulatory services = 0.45 + 0.75 (environmental infrastructure); Habitat-related services = 1.85 + 0.47 (environmental infrastructure); Social services = 3.59 + 0.18 (transportation infrastructure); Provisioning services = 3.64 + 0.21 (transportation infrastructure); Regulatory services = 3.39 +0.21 (transportation infrastructure); Habitat-related services = 3.69 + 0.15 (transportation infrastructure).

Based on the linear functions extracted from the statistical analysis, land use has the greatest impact on social services since the intercept is negative and the impact factor is relatively small. After it, environmental and economic infrastructures have the greatest impact on social services.

Regarding provisioning services, land use has the greatest impact on these services with a factor of 0.17 and an intercept of 1.86. Environmental infrastructure and transportation stand on next places. Social infrastructure inversely influences social services with a negative coefficient of 0.29, which is relatively small due to the small factor and large intercept.

Regarding regulatory services, land use has the greatest impact on these services due to the negative intercept, followed by the environmental infrastructure. Habitat-related services are most affected by land use and environmental infrastructure, respectively.

6. CONCLUSION

The urban green network formation depends on the strengths and weaknesses of the city in which it is raised as a concern and targeted to be solved. The direction of planning in the urban green network formation depends on these strengths and weaknesses. According to the review and analysis of 25 case studies in the present research and the considered hypothesis, the main approach to forming a green network and expanding the urban green infrastructure depends on the potentials of the cities and the challenges in them. A full investigation and recognition of these challenges and potential can result in an organized program to improve, promote, and expand green infrastructure in cities.

According to the results obtained from the structural study of green infrastructures, the following can be considered the most influential structural components for the formation of a green network:

1. Creating interaction nodes for citizens
2. Creating urban leisure spaces
3. Improving the quality of existing green spaces
4. Surface water management
5. Improving the visual quality of corridors
6. Facilitating walking access to different parts of the city
7. Creating a connected bike network.

In the presented green network plans, the most attention has been paid to the social and environmental infrastructure in the cities, and the connectedness of the bicycle network in the cities and the provision of a connected walkway are among the items that have been considered in most of the strategies. Although cities need to limit the transportation network in cities, some strategies have not included limiting the transportation network.

Green walls and green roofs have also been emphasized in a few cases. They have been generally considered in cities with high building densities and limited vacant lots.

Regarding ecosystem services, climate-regulating services, and habitat-related services have received the most attention, followed by the social service components. Provisioning services have been given more attention in cities where the required infrastructure is available. The following are the services that have been specifically considered in the majority of urban green network development plans and can be considered the primary service

components in urban green networks:
- Regulation of local and regional weather conditions
- Resistance to climate change
- Creating active urban ecosystems
- Man-nature contact
- Recreation and ecotourism
- Biodiversity.

It seems that the organization of an optimal urban green network requires attention to existing potentials and necessary structural and service components. It should be noted that each structured urban green network requires special attention to the potentials and limitations of the area.

According to the research hypotheses, the provisioning infrastructure can be the only prerequisite for the provision of that service in some cases, and the expected services are not provided just due to the existence of the related infrastructure. For example, social infrastructure poorly influences the provision of social services (coefficient=0.06). As a result, research hypothesis 2 is rejected, meaning that infrastructure does not necessarily lead to a strong provision of services, and they are a necessary condition for providing those services, but they are not a sufficient condition. Also, the impact of ecosystem services on infrastructure is different and there is sometimes an inverse relationship between them.

As a result, by presenting a comprehensive urban strategy, it is necessary to pay attention to the infrastructure factors, in addition to the side factors affecting the provision of ecosystem services, so that the costs spent on the formation of a green network and the urban green infrastructure development lead to the provision of ecosystem services and the constructive performance of the city.

According to the results of the present research and study of the urban green network formation process in all the case studies, in the design of the urban green network, the researchers and designers are suggested to fully recognize all the strengths and weaknesses of the urban green space to preserve and strengthen strengths and functionally redefine weaknesses to form a green network with the ability to provide a variety of services to citizens and have an impact on improving the quality of life in cities while being remained sustainable over time. In addition, it is suggested to study the lateral indirect factors affecting the provision of ecosystem services obtained from the formation of the green network in future research.

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