



Typology of city form and sustainable spatial structure

Majid Karimpourreihan^{1*}

¹Associate Professor at the Department of Earth Science, International Desert Research Center(I.D.R.C.) University College of Agriculture and Natural Resources University of Tehran Karaj, Alborz,Iran

*Corresponding Author: Majid Karimipourreihan

ARTICLE INFO

Received: 20 Sep 2024
Accepted: 26 Oct 2024

ABSTRACT

The form and spatial structure of cities are the important dimensions of cities' knowledge and analysis. A review of the theoretical literature on the concepts of spatial structure, urban form, ossification and shape of the city shows that there is a great variety of thoughts and opinions in these fields by utilizing comparative research methods. Therefore, researchers are looking for genealogy and detailed analysis of the concepts of form and spatial structure of the city. On the other hand, the most important sources of instability are the same mentioned factors. This research aims to use the inductive research method and the K-means clustering model in python software as well as GIS software to analyze spatial data and data gathered from residents' questionnaire for qualitative indicators to identify the relationship between the components of urban form and spatial structure on the factors of sustainability at the scale of Tehran regions. The high overlap of Tehran's pleasant (ideal) areas, based on spatial form and structure indicators as well as sustainability indicators shows the direct influence of urban spatial structure and form on sustainability in Tehran.

Keywords: Spatial Form, Spatial Structure, Environmental Sustainability, Economic Sustainability, Social Sustainability

INTRODUCTION

Rapid urban development has affected various aspects of human life in the last few decades. The intensity of this impact and attention to the role of cities in the consumption of energy and natural resources, the production of waste and pollutants along with the concentration of human activities have turned sustainable urban development into a key element in the future of humanity. Therefore, efforts to understand urban sustainability and its different dimensions continue. The discussion about sustainable urban development as a multifaceted and broad concept also includes the issue of urban form. Examining the theoretical foundations of issues such as urban form, spatial structure, ossification, physical structure, the pattern of the overall shape of the city and the overall pattern of the city's growth show the difference of opinions among experts in these fields. Some of the most important reasons for the disagreement of experts on the definitions of the above concepts are: differences in study scales, diversity of fields, research approaches and the planning or design view of experts. The typology of the definitions of city form and spatial structure of the city, based on the opinion of experts and in various study scales, have caused a more comprehensive understanding of the mentioned concepts, and reveals the differences and overlapping contents of these two terms. On the other hand, the concepts of urban form and spatial structure by including broad axes of issues related to the city and urban planning such as natural appearance, population, density, activity centers, distribution of users, communication networks, etc., as the most important dimensions of city knowledge and analysis play an undeniable role on economic, social, environmental and physical stability. Therefore, achieving a sustainable urban form leading to the development of more efficient ways of living and working in cities has become one of the concerns of urban planners. If Tehran is considered in the three positions of the center of the urban complex of Tehran, the city of Tehran and a complex consisting of 22 regions, some of the axes of form and spatial structure on a macro scale are examined and analyzed. For instance, the examined concepts would be extra-urban communication networks, the share of the population of urban areas, the natural and physical structure and artifacts in the urban complex plan, structural plan and some other forms (such as population densities, public transportation and building densities in the detailed plan of Tehran city areas),

without considering the purpose and systematic effects of these components on various aspects of sustainability. On the other hand, many of the conducted researches have only focused on explaining the effects of a limited number of form indicators (types of urban densities) on some aspects of urban sustainability (sustainability of travel and energy consumption patterns or social sustainability). Therefore, a comprehensive analysis of the relationship between the components of urban form and spatial structure in the scale of Tehran city with sustainability in different dimensions and derived patterns and sustainable urban forms, will be important. The results of the implementation of the mentioned theoretical framework in Tehran and the classification of its regions enable us to better understand the relationship between these concepts.

A review of theoretical concepts

Urban form and sustainable urban spatial structure

In the past decades, cities have been seen as sources of environmental degradation and depletion of natural resources (Chen et al, 2008; Zhang et al, 2021). The important goals of sustainable urban development in wealthy countries are to reduce climate change, reduce energy consumption and pollution, protect natural and agricultural areas, and provide a safe and healthy environment for citizens, especially vulnerable groups (Næss, 2014; Hastings, 2015; Medina-Mijangos et al, 2021; Shi & Stevens, 2021). A sustainable city is a place where improvements in social justice, diversity, and the possibility of living with the desired quality are realized. A sustainable urban form is also a form in which less resources such as energy are consumed, the urban networks are efficient and competitive and have a high capacity for human life. Some of the characteristics of a sustainable city are: intergenerational justice, protection of the natural environment, minimal use of non-renewable resources, economic vitality and diversity, an independent and non-dependent society, the well-being of people and the fulfillment of basic human needs (Maclaren, 2004; Chan et al, 2020; Barker, 2023). These dimensions of sustainable development, in addition to affecting the urban ecological space, are also affected by it. In general, the aspects of sustainable artificial environment are given in Table 1. By reviewing the literature on sustainability and sustainable urban development, it can be concluded that resource efficiency in different residential patterns depends on at least two limited natural resources: land resources for residential uses and energy resources for mobile uses. Land consumption directly depends on the relative density of human settlements and residential density. On the other hand, energy consumption is indirectly dependent on the same variables and displacement patterns (Camagni et al., 2002; Capozzoli et al, 2017; Bonacich, 2019).

Table 1. Aspects of sustainable artificial environment

Communications and Transportation	Environmental, Recycling and Reuse	Environmental and Energy Consumption	Land use and Built Form
Light transportation routes, buses and environmentally friendly routes	Gray water system	Combination of heat and electricity - local electricity production	Extensive use of urban land
Cycling facilities	Water recycling for gardening and car washing	Micro power generation	Green networks and corridors
Pedestrian-friendly infrastructure	Water reuse for ecological parks and green spaces	Renewable energies	Self-management
Car parking restrictions	Waste recycling and use for biogas production	Reducing energy consumption	Mixing land use in relatively high densities
	Reducing household waste	High levels of insulation	Affordable housing
	A way of living away from carbon	Intelligent lighting and	local identity

Communications and Transportation	Environmental, Recycling and Reuse	Environmental and Energy Consumption	Land use and Built Form
		integrated security, thermal and information technology systems	
		Assessment of compatibility with the environment	Sustainable building materials
			Flexible design and optimal space standards
			Improved sound insulation

Based on the review of the world literature about the concepts of urban form and urban spatial structure (tables 2 and 3), the issues of density, land use arrangement, distances between urban centers and displacement patterns and some other axes are originated from urban spatial form and structure. Therefore, it can be concluded that the urban form and spatial structure of the city can increase, decrease or stabilize the urban stability by affecting the two sources of land and energy. Therefore, it will be important to explain how the components of the urban form and the urban spatial structure affect the sustainability and infer sustainable urban patterns and forms.

According to Tables 2 and 3, in some of the definitions about the concepts of city form and spatial structure of the city, common indicators have been occasionally used under different titles. This difference in approaches is completely evident and understandable according to the planning or design view of the experts. One of the reasons for the difference in opinions can be found in the lack of distinction between the concepts of urban structure and urban spatial structure, which has been overlooked by some people. Urban forms cannot be considered sustainable if they are not acceptable to people as a place for life, work and interactions, or if they are unstable and inefficient societies (Bramley et al., 2009; Tonkiss, 2014; Manzini, 2015). Efficient spatial planning can become an incentive and support for economic dynamism and, finally, competitiveness of the city. A sustainable spatial structure is the result of applying sustainability criteria and different conditions that are formed over time. The development of a sustainable spatial structure depends on conditions such as providing ease of movement and access along with the justification of public transportation, the justification of mixing of uses and the degree of adaptation and flexibility, environmental quality and compliance with the distance between activity centers and residences (Meijer et al. , 2011). What leads to urban sustainability includes the efficient way of using land, creating the best access and transportation to all parts of the city with minimal use of polluting motor vehicles, efficient use of resources, lack of pollution and environmental waste, proper use of natural resources, the possibility of renewing its cycle, building desirable houses and creating healthy neighborhoods, establishing a sustainable ecological system, sustainable urban economy, the possibility of the presence and activity of city residents in social partnerships and urban decisions, eliminating slums and unsanitary housing, and finally preserving environmental culture, based on the conquest of common sense and wisdom (Wheeler, 2004; Wagner & Hayes, 2017). These issues are directly related to the spatial structure of the city. The spatial structure of the city shows the order and relationship between physical elements and uses in the city (Cheng et al, 2006; Taylor & Derudder, 2015; Liu et al, 2022; Nasution, 2022). The discussion about whether specific urban forms can affect the sustainability of cities has a relatively long and rich history (Williams, 2005; Williams, 2017; Stead & Vaddadi, 2019).

Table 2. Summary of the components and components of the urban form based on the review of the world literature

Row	Components	Sources
1	Spatial distribution of people who are engaged in an activity, spatial flows resulting from the movement of people, goods and information and physical characteristics that make the space important for those activities.	Lynch, 1981
2	The pattern of spatial distribution of human activities in a certain period of time: the spatial pattern of land use and their density, as well as the spatial design of transportation and infrastructure	Anderson, 1996
3	Artifact form related to a specific historical period; It is the result of the activities that are carried out in it and is designed to accommodate them.	Kropf, 1996
4	Combining features related to land use pattern, transportation system and urban design	Handy, 1996
5	Physical pattern of land use, population distribution and communication networks	Ibrahim, 1997
6	Including the components of density, open space, size, compactness and population	Banister et al, 1997
7	Land use patterns, transportation infrastructure, water and energy infrastructure and physical form of development	Smith, & Marquez 1999
8	Including indicators such as 1- distance of the residence from the city center 2- size of the settlement 3- mix of uses 4- provision of local facilities and facilities 5- density of development 6- proximity to the main transportation networks 7- access to residential parking 8- type of network Roads 9- type of neighborhood unit	Stead & Marshall, 2001
9	The pattern of streets, plots of land, blocks and land use characteristics	Wheeler, 2003
10	Metropolitan size and population density	Giuliano & Narayan, 2003
11	Street design and circulation systems, density, mixing of land use, access, pedestrian access	Song & Knaap, 2004
12	Showing the effects of human actions on the environment inside and outside the city	Alberti, 2005
13	the built body of the city; Placement (structure and graining), density, scale (height and massing), appearance (materials and details) and development perspective	Cowan, 2005
14	Density, size, topography, road network syntax	Williams, 2005
15	Transportation (access), land use characteristics and density	Muñiz & Galindo, 2005
16	Features of land use, density, location in relation to the city center, access to public transportation	Holden, 2004
17	Metropolitan size, density, unequal distribution, centrality, continuity	Tsai, 2005
18	The result of the gathering of several concepts and elements such as street pattern, block size and shape, street design, plot design, parks and public spaces.	Jabareen, 2006
19	The relationship between a city and its surrounding areas	Grimm et al., 2008

Row	Components	Sources
20	Type and height of housing, percentage of land allocated to each user, density, distance to the city center, access to gardens, and percentage of separate settlements.	Bramley et al., 2009
21	Size, shape, scale, density, land uses, construction types, urban block syntax and green space distribution	Jenks & Jones, 2009

Table 3. Summary of the components and components of the spatial structure of the city based on the review of world literature

Row	Components	Sources
1	The main organizing force of the city as the determining factor of communication networks and main buildings	Bacon, 1974
2	Construction of the settlement in accordance with the plan in which all the networks, accesses and spaces necessary for the main uses and activities are specified.	MC Connel, 1981
3	Form composition, density, diversity, connections and communication	Alberti, 1996
4	Urban form, urban interactions and a set of organizing principles that define the relationship between them.	Anderson, 1996
5	The degree of spatial concentration of population and urban employment	Anas et al, 1998
6	Land use patterns, transportation infrastructure, water and energy infrastructure and physical form of development	Smith, & Marquez, 1999
7	Daily travel pattern, average built density, density profile and slope percentage	Bertaud, 2002
8	The general form includes features such as land use as a monocentric versus multicentric form, centralized versus decentralized patterns, and continuous versus discontinuous developments.	Tsai, 2005
9	Order and relationship between physical elements and uses	Chenge et al., 2006
10	A set of communications resulting from the urban form and the gathering of people, transportation, the flow of goods and information	Rodrigue et al, 2009

In general, the views presented about sustainable urban patterns can be divided into several groups of supporters of urban concentration, supporters of urban decentralization, supporters of a compromise view between urban concentration and urban decentralization, or planned expansion. Each of the experts have measured the stability of the form and spatial structure of the city with different criteria, and each of them has focused on a part of the positive and negative aspects of the issue. For example, Jabareen introduces the compact city as the most sustainable urban form by considering the criteria of compactness, sustainable transportation, density, mixed land use, diversity, design using solar energy and green design (Jabareen, 2006).

Wheeler proposes five principles of sustainable urban form: intensive development, interconnected development, connected development, diverse development and ecological development (Wheeler, 2003; McCollum et al, 2018). To measure the sustainability of various urban forms, Echenique proposed evaluation variables with components such as resource component, environmental component, social component and economic component (Echenique et al., 2012; Ladi et al, 2021; Liang et al, 2022). Macro visions have introduced a set of models for a sustainable city. However, a single form cannot be introduced as a stable form of the city. Choosing a planning and design solution for an existing city or urban area depends on the characteristics of that city or urban area and therefore may be different in each case. In addition, there is no common conceptual framework that allows comparison of these approaches, planning propositions and policies (Jabareen, 2006). On the other hand, instead of focusing and emphasizing the results of a solution, people who plan or manage sustainable cities should consider that a variety of urban futures can coexist within the framework of a single city. In other words, there can be many and different ways to achieve a sustainable future within a city, and these

solutions are competing with each other and will be controversial at the local level and according to the environmental conditions.

Urban form, spatial structure and social stability

In the recent decades and in the extensive literature on sustainable development, only attention to environmental concerns has been abandoned and sustainability with economic and social approaches has also been taken into consideration. This is while there are still few agreements about what it is. In addition to the lack of relative agreements regarding the concept of social sustainability, the relationship between urban form and sustainability is still one of the most discussed issues of international environmental guidelines, which has attracted the most attention in the literature due to its social effects. Experts have not yet reached an acceptable consensus regarding the most stable urban form from a social point of view; but from their point of view, density is one of the aspects of the urban form that can affect the social stability of the city in different ways. While relatively limited literature is specifically focused on the issue of social sustainability, there are broader theoretical foundations related to social capital, social cohesion, and social participation. It can be said that the basic premise of all these concepts is that society members need to cooperate and interact with each other in order to achieve socially sustainable societies. Social networks have clearly set the common chapter among the above three concepts. These concepts show the importance of people getting involved in a society and pursuing their interests, so that they have equal access to social benefits.

While, the concept of social exclusion may be distinct due to a greater focus on access to economic opportunities and services, the first and second concepts overlap more (Bramley & Power, 2009; Madanipour, 2015). Social stability is a development compatible with the evolution of civil society, promoting a favorable environment for social life, which is compatible with different cultural and social groups, at the same time encouraging social integration and improving the quality of life of all classes of people (Polese & Stren, 2000; Kaplan et al, 2020; Martin et al, 2021). Among the indicators of measuring social stability are: pride and attachment, interactions, security, environment, satisfaction with residence, stability and stability in the face of displacement, participation in collective and group activities and use of facilities and services of the neighborhood unit (Jenks & Jones, 2009; Banerjee & Baer, 2013; Perry, 2020). One of the problems of efforts related to urban form and social phenomena is the difficulty of separating causal effects from selective effects; where selection effects are the result of different individuals and groups living in different places (Bramley et al., 2009; Gilbert et al, 2018). Therefore, in the evaluation of proposed forms and structures for desirable urban development, one of the challenging issues is social stability, which includes different dimensions. In order to achieve social stability, it will be useful to improve the components of the city's spatial structure and form, which firstly cause social stability, and secondly lead to equal access to services and facilities.

Urban form, spatial structure and economic stability

In addition to the environmental, physical and social aspects, the urban form also affects economic issues and components. The cost of energy consumption, distances between cores and centers of work and activity, costs of residential construction and development, and the cost of building a network of roads and urban equipment and infrastructure are among the parameters of urban form and spatial structure that affect the economic stability of societies. The results of various researches show a significant relationship among different urban forms and public expenses. As mentioned in the previous sections, the scattered development form is one of the forms that has been introduced as a sustainable urban form by some experts. Sprawl has been promoted by many economic analysts. Reducing restrictions on land supply will clearly reduce its price and in turn increase its use. Its effects have more space for living and lower cost of real estate, which in turn reduces the cost of living, labor and production, making the region more competitive and productive in some economic sectors. Some argue that the dispersed form requires more extensive road infrastructure and equipment; But some others argue that with wider networks, the cost of unit installation and setup would be lower (Echenique et al., 2012).

In contrast to the scattered form, there is the intensive development form. In terms of economic stability, supporters of this approach believe that urban forms with higher density support the provision of more diverse local services through local business and more lively units and strengthening the local supply chain; Mixed and dense central areas encourage and support more interactions and networks to promote innovation and creativity and hence endogenous development through economic clusters. Urban integration reduces infrastructure costs through economies of scale and network economies and reuse of existing capacities; at the same time, it raises the value of the land and thus makes the redevelopment more sustainable.

The range and quality of local services are more desirable and higher in denser areas, especially in central locations; but the economic and technological trends of some sectors still consider larger and non-local economic

units as rational and logical. The survival and durability of services depends on income and density, and deprived urban neighborhoods may lack services even in high densities. The supply chain of local goods is weak in many sectors and may be weakened over time. This is while the high value of land may prevent the provision of diverse local services (Jenks&Jones, 2009).

Along with the sustainable city literature and before that, the concept of optimal city size has been proposed since the early 1970s. The logic derived from these arguments is that while the cumulative economies are the driving forces for the development of cities, traffic congestion and air pollution occur in them. This theory indicates that the optimal size of the city is the size where the benefits and costs are equal. The optimal and efficient size of the city is one of the criteria for achieving economic stability. However, the optimal size of the city depends on the manufactured product of the city, how the production process is and how the area functions in the urban economy.

Explaining the role of urban form on various dimensions of economic, social and environmental sustainability shows that the redesign of some neighborhood units in a physically sustainable manner by focusing on the components of land use, public transportation, density, access and others is not a sufficient condition for the stability of the city; Rather, in many cases, socio-economic and demographic characteristics can be more influential factors.

Urban form, spatial structure and environmental sustainability

Among the factors affecting environmental sustainability are: energy and fuel consumption, air quality, ecological footprint, amount of open space and greenhouse gas emissions. One of the factors affecting environmental sustainability is the discussion of travel behavior and the factors affecting its demand, which affect air quality, energy consumption, traffic and environmental pollution. Travel style has profound effects on sustainability.

Environmental, economic and social problems related to urban displacement patterns show that the main core of the debate is the possible impact of urban form on displacement patterns (Muniz & Galindo, 2005; Rapoport, 2016). Planners have paid attention to the influence of urban form on a number of sustainability components such as social equality, accessibility, ecology, economic performance, pollution and health. However, the effect of urban form on transportation, movement and fuel consumption is a topic that has attracted the most attention both in scientific circles and in practice.

Especially, these surveys are on the issue of the best urban form in order to facilitate sustainable transportation solutions, reduce travel length and time, reduce dependence on cars, empower public transportation, encourage walking and cycling, and reduce pollutants and related accidents. It is focused on transportation (Williams, 2005; Ahmed et al, 2020; Nieuwenhuijsen, 2021). Advocating various forms of neo-traditional urbanism, compact cities, rural urbanism and transport-oriented development, all have clearly used land use policy and urban design to promote more sustainable travel patterns (Stead & Marshall, 2001; Houston et al, 2015). Four characteristics of dense and concentrated housing design, a relatively high degree of density in residential areas, the shortest possible distance to the city center and the average size of the residence can produce the best results in reducing environmental impacts (Holden, 2004). Another issue in discussing the form and spatial structure of a sustainable city is energy consumption. Another issue is the ecological footprint, an analytical tool for analyzing the environmental consequences of energy consumption (Holden, 2004; Wiedemann et al, 2020). Also, one of the most important issues raised in the field of environment and sustainability of urban form is the issue of urban air quality. The results of various studies show that the shape of a city and the distribution of land use determine the location of sources of greenhouse gas emissions and the pattern of urban traffic, which affects the quality of urban air (Borrego et al, 2006).

It is also important to mention that the most desirable urban form cannot be deduced only based on environmental issues. In the last decades of the 20th century, due to environmental concerns caused by modernist urbanism, urban planners are looking for new paradigms of sustainable development in search of an ideal form for a sustainable city. Cities are the biggest consumers of energy, and following energy consumption, they cause many environmental consequences. Reducing the consumption of fossil fuels is one of the most important goals of sustainable development. Based on the definitions of urban form and spatial structure in the field of components such as proper urban networks, land use mix, desirable development densities and functional diversity, the form and spatial structure of the city can affect the amount of energy consumption and the state of natural ecosystems.

Theoretical framework: form and spatial structure of a sustainable city

The study and analysis of the thoughts and opinions of different experts show that the concepts of spatial structure and urban form overlap in some components and variables; but they do not completely match each

other. In other words, if we classify the definitions of these two concepts in three levels: macro (metropolitan areas), medium (city and inner-city areas) and micro (neighborhoods and neighborhood units), at the middle level, the themes of these two concepts have commonalities and it has many overlaps. Therefore, in this scale, two concepts can be considered the same. This is while on the macro scale, the components and elements of the urban spatial structure and on the micro scale, the elements and components of the urban form can explain the issue more clearly (Table 4). However, some researchers have used the concept of spatial structure on a micro scale and the concept of urban form on a macro scale. Finally, an analytical model and a precise theoretical framework for measuring the relationship between the components of urban form and spatial structure with sustainability in the city of Tehran are compiled by combining and overlapping the elements and components of urban form and spatial structure and sustainability components. This relationship is shown in Figure 1.

According to table 4, the two concepts of urban form and spatial structure of the city by including the components of natural appearance (including natural effects), artificial appearance (including the sub-components of infrastructure and transportation design, spatial pattern of land use and density) and non-spatial appearance (including human, economic, social and technical factors) in the middle scale of cities have many conceptual and content commonalities; Therefore, these two concepts can be understood in the middle scale of cities.

According to Figure 1, the components of form and spatial structure in the medium scale of Tehran city are divided into eight components of communication networks, public transport systems within the city, pedestrian and bicycle access, spatial ossification, density and spatial distribution of activities, morphology Housing and the size of the residence, natural appearance and non-spatial appearance can be separated. Next, evaluate the relationship between the mentioned components with different dimensions of social, economic and environmental sustainability. In order to evaluate and measure the components mentioned in Figure 1, in Table 5, the indicators and metrics of measurement have been presented and clarified separately.

METHODOLOGY

According to the objectives of the current research and its nature, the research method is a combination of deductive and inductive research methods. In other words, the analysis of the concepts of the city form and its spatial structure is done based on the inferential research method, the exploration of classical ideas and the study of theories, and at the same time, the measurement indicators of these concepts are also deduced and explained at different geographical levels. In the following, using the inductive research method, the 22 districts of Tehran are classified based on the indicators of form and urban spatial structure at the middle level, as well as sustainability indicators, using the K-means clustering model in Python software. The K-means clustering model is a method that can be used to classify sample data into multiple classes; So that the data placed in each cluster are homogeneous and the same, and there is the most difference and heterogeneity between the clusters. The reason for using this model was the classification of similar districts of Tehran in terms of form indicators and stability indicators based on the indicators of the theoretical framework of the research. It should be mentioned that before the implementation of the indicators in the software, the test of the skewness and the tension of the data were done to test whether it was normal or not, and the non-normal indicators were normalized using the fuzzy method. Also, GIS software has been used to analyze spatial data and 2200 household questionnaires based on Cochran's formula and with balanced distribution in different neighborhoods of the regions based on their population to measure the qualitative and subjective indicators of sustainability.

Table 4. The theoretical framework of the research: elements, components and variables of urban form and spatial structure in different spatial scales

	Macro (Metropolitan areas, region-cities)	Mediate (Intra- urban regions and cities)	Micro (Neighborhoods Units)
Urban Form		Natural Images - Natural effects such as water, vegetation, mountains	- Street Design - Streets and main pedestrian routes - Urban landscape system

		<p>Artificial Images</p> <p>a) Infrastructure and transportation design includes:</p> <ul style="list-style-type: none"> - The pattern of streets and communication networks - Intra-city transportation systems - Pedestrian accesses <p>b) The spatial pattern of land use includes:</p> <ul style="list-style-type: none"> - Spatial ossification (axes, edges, centers and signs) - Mixing of uses - Spatial distribution of activities - Housing morphology model - Density <p>Non-Space Images</p> <ul style="list-style-type: none"> - Human, Economic, Social, Technical, Legislative factors 	<p>and cognitive aesthetic components</p> <ul style="list-style-type: none"> - Types of Construction - Details, building materials, facades and windows - Gradation and shaping of part - Height and Weighting - Urban Furniture and Equipment
	The physical form of development		
	Main regional and intercity arteries		
	City size		
Spatial Structure of the City	The amount of development concentrated in several sectors		
	Degree of concentration or lack of concentration		
	Continuity or continuity of		

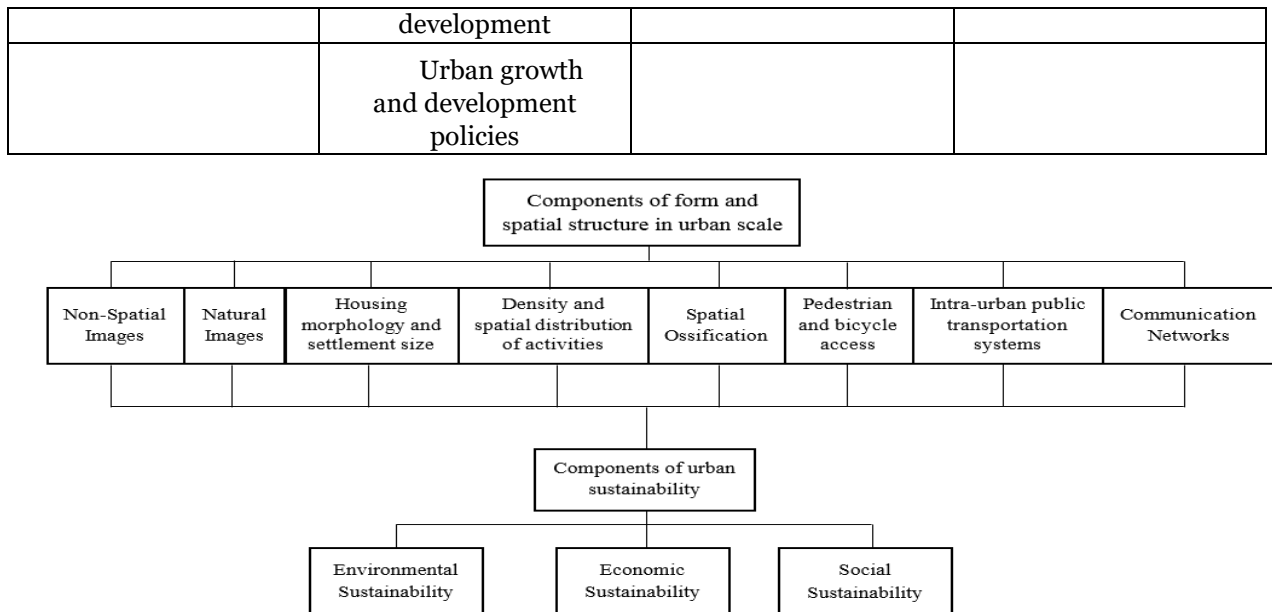


Figure 1. The relationship between the components of spatial structure and urban form with sustainability in Tehran

An overview of the case study and analysis

Based on the research literature and the theoretical framework, the indicators of the form and spatial structure of Tehran city in the middle scale as well as the sustainability indicators were introduced. After collecting the information of the mentioned indicators using information sources and layers as well as spatial analysis, in order to classify the districts of Tehran in terms of form and spatial structure indicators and in terms of sustainability indicators, using clustering methods are necessary. One of the data clustering methods is the K-means algorithm, which is a simple and yet very practical method. In this research, in the first stage, using the K-means algorithm, several regions are considered as the center of the cluster according to the difference in the variance of the indices. Then other districts are also classified according to the degree of proximity to the centers of the clusters. In the second stage, the clustering of the regions according to sustainability indicators is done using the same algorithm, and finally, the overlapping or non-overlapping of the clusters will be evaluated and analyzed.

Table 5. Components, indicators and metrics for measuring the relationship between the spatial structure and the urban form and sustainability of Tehran.

Component	Index and measure	Code	Sources
Communication networks	The length of the main streets available	FV1	Echenique et al, 2012 Souche, 2010 Chen et al, 2008 Vance &Hedel, 2007 Williams, 2005
	Transportation and parking network per capita and percentage share of transportation and storage network	FV2-FV3	Echenique et al, 2012 Thin et al, 2002 Stead & Marshall, 2001
Intra-urban public transportation systems	The percentage of residential land covered by subway and bus stations	FV4-FV5	Souche, 2010 Jenks & Jones, 2009 Vance &Hedel, 2007

Component	Index and measure	Code	Sources
	Number of bus and subway stations	FV6-FV7	Hamin&Gurrán, 2009 Jenks & Jones, 2009 Holden, 2004 Song & Knaap, 2004
Bicycle access	The number of bicycle stations and houses	FV8-FV9	Jenks & Jones, 2009
Spatial ossification	Average distance to the commercial centers of the city	FV10	Jenks & Jones, 2009 Muñiz& Galindo, 2005 Holden, 2004 Stead & Marshall, 2001
	Population concentration and activity (using the Gini coefficient)	FV11	Tsai, 2005
	Centrality and degree of concentration (using Moran's coefficient)	FV12	Tsai, 2005 Alberti, 2005
Spatial distribution of activities	Percentage share of residential use covered by all types of uses	FV13	Echenique et al, 2012 Bramley et al, 2009 Jenks & Jones, 2009 Chen et al, 2008
	Mixing urban functions	FV14	Hamin&Gurrán, 2009 Chen et al, 2008/ Williams, 2005 Song & Knaap, 2004 Stead & Marshall, 2001
Housing morphology and settlement size	Housing per capita	FV15	Echenique et al, 2012 Holden, 2004
	Percentage share of the area compared to the city of Tehran	FV16	Tsai, 2005 Giuliano & Narayan, 2003 Stead& Marshall, 2001
Natural Images	Per capita and percentage share of gardens, open and green lands	FV17-18	Jabareen, 2006 Thinh et al, 2002
Non-Space Images	Net residential density	FV19	Bramley& Power, 2009 Jenks & Jones, 2009/ Hamin&Gurrán, 2009 Chen et al, 2008 Holden, 2004 Williams, 2005 Camagni et al, 2002 Leicester City Council, 1995

Component	Index and measure	Code	Sources
	population density	FV20	Bramley et al, 2009 Hamin&Gurran, 2009 Chen et al, 2008 Muñiz& Galindo, 2005 Giuliano & Narayan, 2003 Banister et al, 1997 Stead & Marshall, 2001
Social Sustainability	The amount of interaction with other residents or social groups	SQ4	Jenks & Jones, 2009 Bramley& Power, 2009 Handy, 1996 Woolever, 1992
	Citizens' access to local services	SQ5	Echenique et al, 2012 Bramley& Power, 2009 Chen et al, 2008 Stead & Marshall, 2001 Handy, 1996
	Satisfaction with housing	SQ6	Bramley& Power, 2009 Jenks & Jones, 2009
	The amount of citizens' access to affordable housing	SQ7	Bramley et al, 2009
	The amount of participation in social and group activities	SQ8	Jenks & Jones, 2009 Bramley& Power, 2009 Woolever, 1992
	The amount of social security (lack of crime and disorder)	SQ9	Bramley& Power, 2009 Chen et al, 2008 Leicester City Council, 1995
Economic Sustainability	Average cost of traveling by private vehicle and public transportation	SQ10-SQ11	Echenique et al, 2012 Souche, 2010 Banister et al, 1997
	Road construction costs	SV21-SV22	Chen et al, 2008 Camagni et al, 2002
	Employment status	SV23-SV24-SV25	Banister et al, 1997
	Approved budget for municipal construction projects	SV36	Camagniet al, 2002 Leicester City Council, 1995
Environmental Sustainability	The amount of noise pollution (in the morning and at night)	SV26-SV27	Bramley et al, 2009 Leicester City Council, 1995
	Access to gardens and green spaces	SQ12	Camagni et al, 2002 Leicester City Council, 1995

Component	Index and measure	Code	Sources
	Air pollution and emission of carbon dioxide and nitrogen oxides	SV28-SV29	Camagni et al, 2002 Leicester City Council, 1995
	Environmental quality of water and sewage projects	SV30	Camagni et al, 2002
	Waste management and soil pollution	SV31-SV32-SV33-SV34	Leicester City Council, 1995
-	The number of passengers served by public transportation	SV35	Jenks & Jones, 2009 Chen et al, 2008

a) Clustering of 22 districts of Tehran city based on form and urban spatial structure indicators using K-means algorithm to increase the significance levels in this article, clustering based on 20 form and spatial structure indicators with different number of clusters. K=1, 2, 3, 4, 5, 6, 7) was implemented with a convergence level of 0.001 and a maximum of 10 repetitions. According to the knowledge of the case sample as well as the outputs of the model, it seems that k=6 can better explain the difference between the current state of the form and the spatial structure of these areas due to the significant difference between the categories. One of the outputs of K-means clustering is the classification of similar samples (Table 6). As can be seen in Table 6, according to the intra-class variance and the distance to the center of different clusters, the 22 districts of Tehran have been clustered. Based on this strategy, considering the similarities of form and spatial structure, districts 1, 4 and 18 in the first cluster, districts 2, 3, 8, 14, 16 and 17 in the second cluster, districts 5 and 20 in the third cluster, districts 6, 7, 10, 11 and 12 in the fourth cluster, districts 9, 13, 15 and 19 in the fifth cluster and districts 21 and 22 can be grouped in the sixth cluster (Figure 3). Variance analysis is another finding of K-means algorithm. In other words, the statistical characteristic (Fisher) F shows the ratio of variance between classes to variance within classes. The higher this ratio is, the greater the inter-class variance will be compared to the intra-class variance, and as a result, the average will have a greater difference between the classes. In the last two levels of Table 6, the status of this analytical statistic is presented for quantitative indicators of form and spatial structure. As it is clear in the last line of this table, the ratio of the mentioned variances in relation to the major part of the indicators is significant and therefore has the necessary precision and accuracy.

Table 6. Clustering of Tehran city districts based on quantitative indicators of urban spatial form and structure

Cluster	1	2	3	4	5	6
Number of districts per cluster	3	6	2	5	4	2
Intra-cluster Variance	116961.615	99340.83	42258.584	1393535.045	233233.122	125776.650
Minimum distance to cluster center	153.313	83.666	145.359	80.654	99.120	250.775
Average distance to cluster center	261.897	260.727	145.359	897.204	347.921	250.775
Maximum distance to cluster center	388.533	424.493	145.359	1682.154	634.857	250.775
Districts of each cluster	1 District	2 District	5 District	6 District	9 District	21 District
	4 District	3 District	20 District	7 District	13 District	22 District
	18 District	8 District	-	10 District	15 District	-

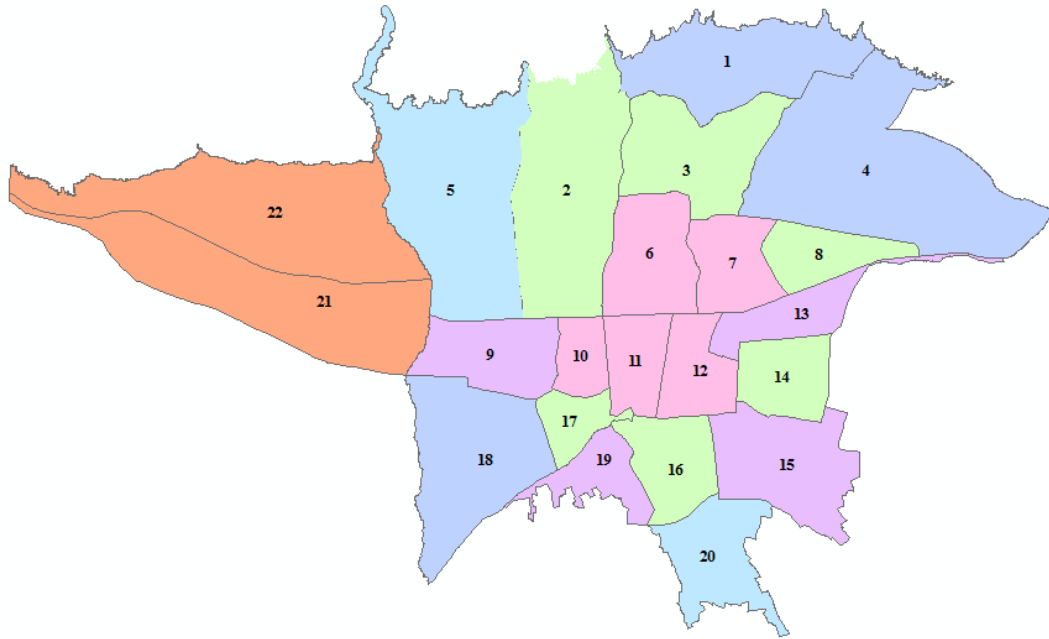


Figure 2. Clustering of Tehran city areas based on quantitative indicators of urban spatial form and structure

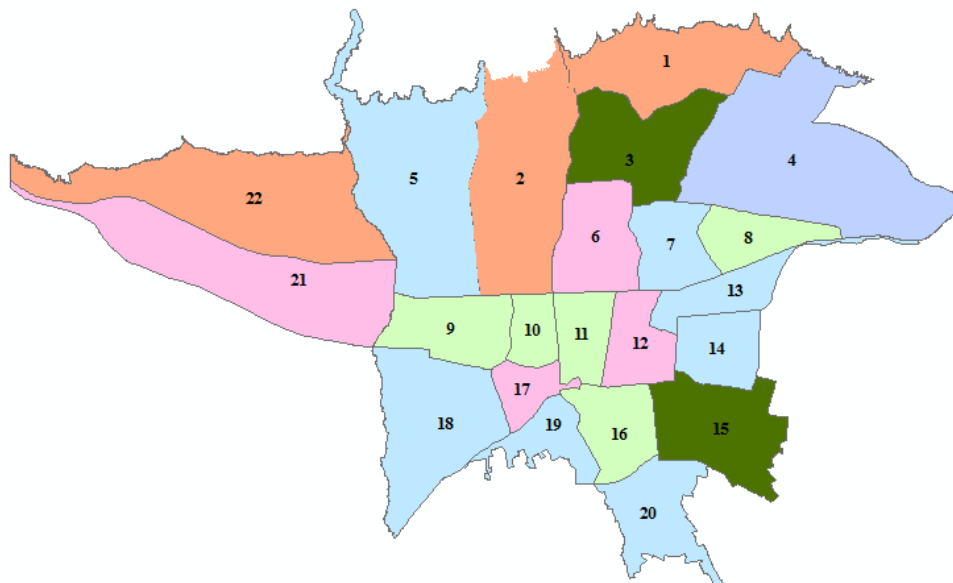


Figure 3. Clustering of Tehran city areas based on objective and quantitative indicators of sustainability

The analysis results show that the clustering of regions based on objective and quantitative sustainability indicators have many similarities and overlaps with their clustering based on form and spatial structure indicators. These overlaps show the direct influence of the features of the city form and the spatial structure of the city on urban sustainability. On the other hand, the very low correlation between the overlap of qualitative indicators and the results of the questionnaires with the urban form indicates the low influence of social components on the elements and components of the urban form. In Table 7 and Figure 3, the results of the clustering of regions based on objective indicators of sustainability are presented. In Figures 2 and 3, respectively, the districts of Tehran are clustered based on the quantitative indicators of urban spatial structure and form, as well as on the objective and quantitative indicators of stability. Similar colors in each figure show the similarity of those areas in terms of the discussed indicators. The districts that are placed in the same class and cluster in both forms represent the relationship between the indicators of form and spatial structure with the indicators of stability and their influence on each other.

Summary

The efficient method of user planning, accessibility and inclusive public transportation, optimal consumption of energy and land resources and the possibility of renewing its cycle, reducing environmental pollution, sustainable urban economy, social interactions, diversity, preserving and creating healthy environments lead to urban sustainability and provides living conditions in cities. These topics are directly related to the components of form and spatial structure in the medium scale, such as communication networks, public transportation systems, pedestrian and bicycle access, spatial ossification, spatial density and distribution, housing morphology and settlement size, appearance, natural and non-spatial, including population density. Therefore, efficient planning and design of urban form and spatial structure in future cities and their modification in the current situation will have an impact on the level of social, economic, physical and environmental sustainability of cities. The results of the research show that it is possible to classify the 22 districts of Tehran into six categories based on the indicators of urban spatial structure and form in the medium scale. The similarities of the form indicators and the spatial structure of the regions of each of these categories make such a classification meaningful. For example, according to the recognition of regions, districts 1, 4 and 18 have significant similarities in terms of form and spatial structure characteristics in the middle scale. Districts 21 and 22, having a wide urban form compared to other districts of the city, and districts 6, 10, 11, and 12, due to having a relatively compact central location in Tehran, are placed in the same category. Also, based on sustainability indicators, Tehran's districts can be classified into six categories. The high overlap of the clustering of Tehran's districts based on spatial form and structure indicators and based on sustainability indicators shows the direct influence of urban spatial structure and form indicators on sustainability in Tehran.

CONCLUSION

In this research, an inferential and exploratory study on theoretical bases was done to identify and compile the components of spatial form and structure in different scales, which was the main focus and innovation of the research. In this way, it was discovered that the components and indicators of urban spatial structure and form can be classified in three scales: macro, medium and micro. At the intermediate level, the themes of these two concepts have many commonalities and overlaps, and therefore, in this scale, the two concepts can be considered the same. This is while on the macro scale, the components and elements of the urban spatial structure and on the micro scale, the elements and components of the urban form can explain the issue more clearly. In the second step, the indicators of urban sustainability should be checked in different dimensions and in the third place, the clustering of the areas of Tehran city based on the set of indicators of form and spatial structure in the middle scale and also based on the indicators of sustainability should be done in order to get an initial understanding and a preliminary view. It can be obtained from the overlaps and the influence of the components of form and spatial structure on urban sustainability. It will be important to measure the extent of this relationship, and test the research analytical model in different case samples in order to generalize the findings in future researches.

REFERENCES

- [1] Ahmed, S., Adnan, M., Janssens, D., & Wets, G. (2020). A route to school informational intervention for air pollution exposure reduction. *Sustainable Cities and Society*, 53, 101965.
- [2] Alberti, M. (1996). Measuring urban sustainability. *Environmental impact assessment review*. 16(4), 381-424.
- [3] Alberti, M. (2005). The effects of urban patterns on ecosystem function. *International Regional Science Review*. 28 (2), 168- 192.
- [4] Anas, A., Arnott, R., & Small, K. (1998). Urban spatial structure. *Economic Literature*. 36, 1426-1464.
- [5] Anderson, W.P., Kanaroglou, P.S., & Miller, E.I. (1996). Urban form, Energy and the Environment, a Review of Issue and Policy. *Urban Studies*. 33 (1), 7-35.
- [6] Bacon, E.N. (1974). *Design of Cities*. New York: The Viking Press.
- [7] Banerjee, T., & Baer, W. C. (2013). *Beyond the neighborhood unit: Residential environments and public policy*. Springer Science & Business Media.
- [8] Banister, D., Watson, S., & Wood, C. (1997). Sustainable cities: transport, energy, and urban form. *Environment and Planning B*. 24, 125-144.
- [9] Barker, T. (2023). A plan for coastal zone integrated resource management in a developing south west pacific island country.
- [10] Bertaud, Alain. (2002). Not on Transition and urban spatial structure. *ABCDE conference*. Washington.
- [11] Bonacich, E. (2019). A theory of ethnic antagonism: The split labor market. In *Social Stratification, Class, Race, and Gender in Sociological Perspective, Second Edition* (pp. 555-568). Routledge.
- [12] Borrego, C., Martins, H., Tchepel, O., Salmim, L., Monteiro, A., & Miranda, A. I. (2006). How urban structure can affect city sustainability from an air quality perspective. *Environmental modelling & software*. 21(4), 461-467.
- [13] Bramley, G., Dempsey, N., Power, S., Brown, C., Watkins, D. (2009). Social sustainability and urban form: evidence from five British cities. *Environment and planning. A*, 41 (9).
- [14] Bramley, G., & Power, S. (2009). Urban form and social sustainability: the role of density and housing type. *Environment and Planning B Planning and Design*. (36), 30-48.
- [15] Camagni, R., Gibelli, M. C., & Rigamonti, P. (2002). Urban mobility and urban form: the social and environmental costs of different patterns of urban expansion. *Ecological economics*. 40 (2), 199-216.
- [16] Capozzoli, A., Piscitelli, M. S., Gorrino, A., Ballarini, I., & Corrado, V. (2017). Data analytics for occupancy pattern learning to reduce the energy consumption of HVAC systems in office buildings. *Sustainable cities and society*, 35, 191-208.
- [17] Chan, E. Y., Lo, E. S., Huang, Z., Kim, J. H., Hung, H., Hung, K. K., ...& Gobat, N. (2020). Characteristics and well-being of urban informal home care providers during COVID-19 pandemic: a population-based study. *BMJ open*, 10(11), e041191.
- [18] Chen, H., Jia, B., & Lau, S. S. Y. (2008). Sustainable urban form for Chinese compact cities: Challenges of a rapid urbanized economy. *Habitat international*. 32 (1), 28-40.
- [19] Cheng, Jianquan, Jan, Turkstra., Mingjun Peng, Ningrui Du & Peter Ho. (2006). Urban land administration and planning in China: Opportunities and constraints of spatial data models. *Land Use Policy*. 23 (4), 604- 616.
- [20] Cowan, Robert. (2005). *Dictionary of Urbanism*. Streetwise Press.
- [21] Crook, Kenneth, F. (2007). *Britannica Concise Encyclopedia*. Encyclopedia Britannica Corp. (Available, at:www.britannica.com).
- [22] Echenique, M. H., Hargreaves, A. J., Mitchell, G., & Namdeo, A. (2012). Growing cities sustainably: does urban form really matter?. *Journal of the American Planning Association*. 78(2), 121-137.
- [23] Gilbert, T., Neuburger, J., Kraindler, J., Keeble, E., Smith, P., Ariti, C., ...& Conroy, S. (2018). Development and validation of a Hospital Frailty Risk Score focusing on older people in acute care settings using electronic hospital records: an observational study. *The Lancet*, 391(10132), 1775-1782.
- [24] Giuliano, Genevieve & Narayan, Dhiraj. (2003). Another Look at Travel Patterns and Urban Form: The US

and Great Britain. *Urban Studies*. (40).

- [25] Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X. & Briggs, J.M. (2008). *Global change and the ecology of cities Science*. 8; 319(5864), 56- 760.
- [26] Hamin, E. M., & Gurran, N. (2009). Urban form and climate change: Balancing adaptation and mitigation in the US and Australia. *Habitat international*. 33 (3), 238-245.
- [27] Handy, S. (1996). Methodologies for Exploring the Link between Urban form and Travel Behavior. Transportation Research. (Part D). *Transport and Environment*. 2 (2), 151-165.
- [28] Hastings, A., Browne, A., Kall, K., & Margaret diZerega. (2015). *keeping vulnerable populations safe under PREA: Alternative strategies to the use of segregation in prisons and jails*. Vera Institute of Justice.
- [29] Holden, E. (2004). Ecological footprints and sustainable urban form. *Journal of Housing and the Built Environment*. 19(1), 91-109.
- [30] Houston, D., Boarnet, M. G., Ferguson, G., & Spears, S. (2015). Can compact rail transit corridors transform the automobile city? Planning for more sustainable travel in Los Angeles. *Urban Studies*, 52(5), 938-959.
- [31] Ibrahim, A. (1997). *Investigation of the Relationship between Urban Spatial Structure and Travel Demand in the GTA*. A thesis submitted in conformity with the requirements for the degree of Master of Applied Science. University of Toronto.
- [32] Jabareen, Y.R. (2006). Sustainable Urban Forms: Their Typologies, Models and Concepts. *Journal of planning Education and Research*. 26 (1), 38-52.
- [33] Jenks, M., & Jones, C. (Eds.). (2009). Dimensions of the sustainable city. (Vol. 2). Springer Science & Business Media. 39. Kropf, Karl. (1996). Urban tissue and the character of towns. *Urban Design International journal*. 1 (3), 247-263.
- [34] Kaplan, M., Thang, L. L., Sánchez, M., & Hoffman, J. (Eds.). (2020). *Intergenerational contact zones: Place-based strategies for promoting social inclusion and belonging*. Routledge.
- [35] Ladi, T., Mahmoudpour, A., & Sharifi, A. (2021). Assessing impacts of the water poverty index components on the human development index in Iran. *Habitat International*, 113, 102375.
- [36] Leicester City Council. (1995). *Indicators of Sustainable Development in Leicester: Progress and Trends*. UK: Leicester City Council.
- [37] Liang, Z., Luo, Z., Yuan, J., Li, M., Xia, Y., Che, T., ...& Liu, J. (2022). Evaluating the Environmental and Economic Performance of Municipal Solid Waste Disposal by All-Component Resource Recovery. *Sustainability*, 14(24), 16898.
- [38] Liu, Y., Meng, Q., Zhang, J., Zhang, L., Allam, M., Hu, X., & Zhan, C. (2022). Evaluation of Urban Spatial Structure from the Perspective of Socioeconomic Benefits Based on 3D Urban Landscape Measurements: A Case Study of Beijing, China. *Remote Sensing*, 14(21), 5511.
- [39] Lynch, Kevin. (1981). *Theory of Good City Form*. MIT press.
- [40] Maclaren, V. (2004). *Urban Sustainability Reporting The sustainable urban development reader*. Routledge.
- [41] Madanipour, A. (2015). Social exclusion and space. In *The city reader* (pp. 237-245). Routledge.
- [42] Marquez, L.O & Smith, N.C (1999). A framework for linking urban form and air quality. *Environmental Modelling and Software*. (14), 541- 548.
- [43] Manzini, E. (2015). *Design, when everybody designs: An introduction to design for social innovation*. MIT press.
- [44] Martin, A. J., Strnadová, I., Loblinzk, J., Danker, J. C., & Cumming, T. M. (2021). The role of mobile technology in promoting social inclusion among adults with intellectual disabilities. *Journal of Applied Research in Intellectual Disabilities*, 34(3), 840-851.
- [45] MC Connel, S. (1981). *Theories for Planning*. London: Heinemann Publication.
- [46] McCollum, D. L., Echeverri, L. G., Busch, S., Pachauri, S., Parkinson, S., Rogelj, J., ...& Riahi, K. (2018). Connecting the sustainable development goals by their energy inter-linkages. *Environmental Research Letters*, 13(3), 033006.

- [47] Medina-Mijangos, R., De Andrés, A., Guerrero-Garcia-Rojas, H., & Seguí-Amórtegui, L. (2021). A methodology for the technical-economic analysis of municipal solid waste systems based on social cost-benefit analysis with a valuation of externalities. *Environmental Science and Pollution Research*, 28, 18807-18825.
- [48] Meijer, M., Adriana, F., Linden, O & Vander, S. (2011). *A Next Step for Sustainable Urban Design in the Netherlands*. New York. Routledge.
- [49] Muñiz, I., & Galindo, A. (2005). *Urban form and the ecological footprint of commuting the case of Barcelona*. *Ecological Economics*. 55 (4), 499-514.
- [50] Næss, P. (2014). Urban form, sustainability and health: the case of greater Oslo. *European Planning Studies*. 22 (7), 1524-1543.
- [51] Nasution, F. R. (2022). A STUDY OF MEDAN HELVETIA SUB DISTRICT MORPHOLOGICAL PATTERNS WITH URBAN DESIGN THEORY APPROACH. *Jurnal Koridor*, 13(1), 1-7.
- [52] Nieuwenhuijsen, M. J. (2021). New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity. *Environment international*, 157, 106850.
- [53] Rapoport, A. (2016). *Human aspects of urban form: towards a man—environment approach to urban form and design*. Elsevier.
- [54] Perry, C. (2020). “The Neighborhood Unit”: from The Regional Plan of New York and its Environs (1929). In *The City Reader* (pp. 557-569). Routledge.
- [55] Polese, M., Stren, R. (2000). *The Social Sustainability of Cities: Diversity and Management of Change*. Toronto: University of Toronto Press.
- [56] Rodrigue, J.P., Claude, C. & Brian, S. (2009). *The Geography of Transport Systems*. New York. Routledge.
- [57] Shi, L., & Stevens, G. D. (2021). *Vulnerable populations in the United States*. John Wiley & Sons.
- [58] Song, Yan & Knaap. (2004). Measuring the effects of mixed land uses on housing values. *City and Regional Planning*. 34 (6), 663- 680.
- [59] Souche, Stephanie. (2010). Measuring the structural determinants of urban travel demand, *Transport Policy*. Elsevier. 17 (3), 127-134.
- [60] Stead, D., & Marshall, S. (2001). The relationships between urban form and travel patterns. An international review and evaluation. *European Journal of Transport and Infrastructure Research*, 1 (2).
- [61] Stead, D., & Vaddadi, B. (2019). Automated vehicles and how they may affect urban form: A review of recent scenario studies. *Cities*, 92, 125-133.
- [62] Taylor, P., & Derudder, B. (2015). *World city network: a global urban analysis*. Routledge.
- [63] Think, N. X., Arlt, G., Heber, B., Hennersdorf, J., & Lehmann, I. (2002). Evaluation of urban land-use structures with a view to sustainable development. *Environmental Impact Assessment Review*. 22 (5), 475-492 and *Transport & Infrastructure Research*. 1(2), 113-141.
- [64] Tonkiss, F. (2014). *Cities by design: the social life of urban form*. John Wiley & Sons.
- [65] Tsai, Y. H. (2005). Quantifying urban form: compactness versus' sprawl. *Urban studies*. 42 (1), 141-161.
- [66] Vance, C., & Hedel, R. (2007). The impact of urban form on automobile travel: disentangling causation from correlation. *Transportation*. 34 (5), 575-588.
- [67] Wagner, W., & Hayes, N. (2017). *Everyday discourse and common sense: The theory of social representations*. Bloomsbury Publishing.
- [68] Wheeler, S. M. (2003). The evolution of urban form in Portland and Toronto: implications for sustainability planning. *Local Environment*. 8 (3), 317-336.
- [69] Wheeler, S.M. (2004). *Planning for Sustainability*. New York, Routledge.
- [70] Williams, K. (2005). *Spatial planning, urban form and sustainable transport*.
- [71] Williams, K. (Ed.). (2017). *Spatial planning, urban form and sustainable transport*. Routledge.
- [72] Wiedemann, S. G., Biggs, L., Nguyen, Q. V., Clarke, S. J., Laitala, K., & Klepp, I. G. (2021). Reducing environmental impacts from garments through best practice garment use and care, using the example of a Merino wool sweater. *The International Journal of Life Cycle Assessment*, 26, 1188-1197.

- [73] Woolever, C. (1992). A contextual approach to neighbourhood attachment. *Urban Studies*. 29, 99- 116.
- [74] Zhang, L., Godil, D. I., Bibi, M., Khan, M. K., Sarwat, S., &Anser, M. K. (2021). Caring for the environment: How human capital, natural resources, and economic growth interact with environmental degradation in Pakistan? A dynamic ARDL approach. *Science of The Total Environment*, 774, 145553.