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Editorial

Mehmet Topçu (Editor in-Chief)

JOURNAL of DESIGN for RESILIENCE in ARCHITECTURE and PLANNING (DRArch) has published Volume 3 Issue 2, which includes up-to-date research problems with qualified articles. DRArch began its broadcast life with the excitement, enthusiasm and assertiveness with clear goals, emerging from need and a strong team. The journal progresses rapidly within its own dynamics. The feedback shows that we are not the only ones who believe in DRArch, but the readers as well.

The articles in In the Volume 3 Issue 2 can be categorized under three different headings. The first group is the studies focusing on Istanbul. Current problems and solution suggestions in Istanbul regarding urban morphology, residential and office buildings are presented. This group also includes articles on energy efficiency in office buildings and high-rise buildings. The second group is articles focusing on innovative facilities and innovations related to materials, conservation, land use/land cover and of geospatial information technologies. The third group is in the field of education, which we attach importance to Drach in every issue.

The first article of the first group is written by Eda Coşkun, Ayşe Sema Kubat. The title of this article is

“Study for a morphological assessment: impact of a new project on the urban form of Galata, Istanbul”. The aim of this study is to determine the change and development of the Galata region over time with the Conzenian approach and to reveal the impact of the Galataport project on the region and the use of the coastline by space syntax method.At the end of this study it is observed that the Galataport project completed together with the morphological structure led to functional changes in the field and caused differences in the characteristics of the use of space. It has affected the area and old trading functions began to transform the leisure and tourism sector.

Another interesting paper deals with İstanbul titled as “Housing typologies from different markets and prices throughout Istanbul” by comes from Evren Ozus. This study focuses on rapid growth of İstanbul due to national and international migration during the last two decades. In addition, multi-center development of the city, and construction of peripheral highways, bridges, and metro systems have affected the economic, cultural and physical structure of the city. The purpose of this paper is to illustrate the changes of the housing types and prices from the center to the periphery.

The article titled as “Dynamic analysis of Istanbul office markets with highest demand and office rent” written by Nesil Aybar, Vedia Dökmeci also addressed İstanbul. This study investigated the growth and decline of office rents in office markets which have highest demand and office rents. According to the results of the study, while office rents in the office markets with growth potential have increased, that of the markets with supply increased dramatically between 2011 and 2016. Emre Ilgın also conveyed important new information about high-rise buildings in this issue. The study called “Use of aerodynamically favorable tapered form in contemporary supertall buildings” will be a basic guide for design and construction professionals including architectural and structural designers, and contractors. This important issue is explored in this article with data gathered from 41 supertall case studies, considering location, function, structural system, and structural material as well as the aerodynamic taper effect.

In this issue innovative approaches to materials, conservation, land use and geographic information technologies contains striking scientific findings. Ayşenur Karakaya and Seden Acun Özgünler’s paper “An evaluation of smart windows in a reference office building in Kayseri” argues the the energy performance of smart window systems has been evaluated comparatively with a traditional window system in a reference office building in Kayseri, Turkey. This study aims to evaluate the energy performances of smart windows and reveal their advantages and disadvantages over the available window system in this climate condition. In this context, smart window systems have been classified and explained their properties. In the simulation part, a reference office building has been modeled with each smart window system to evaluate their energy performances comparatively.

The fascinating piece of work comes from Süha Berberoğlu, Anıl Akin, Onur Şatir, Cenk Donmez, Ahmet Çilek, and Merve Şahingöz with the article titled “Geospatial Technologies for Physical Planning: Bridging the Gap Between Earth Science and Planning”. This study explores how digital technologies are reshaping physical planning and design. While the potential of digital technologies is well documented within physical planning and

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visualization, its application within practice is far less understood. This paper highlights the role of the geospatial information technologies in encouraging a new planning and design logic that moves from the privileging of the visual to a focus on processes of formation, bridging the interface of the earth science and physical planning. Another interesting paper titled "Assessing the performance of machine learning algorithms in Google Earth Engine for land use and land cover analysis: A case study of Muğla province, Türkiye'' comes from Hazal Yalçın-Bayrakdar, Mehtap Özenen-Kavlak, Burcu Yılmazel, Alper Çabuk, in which they focus on the creation of a 4-class LULC map of Muğla province over the Google Earth Engine (GEE) platform by utilizing three different machine learning algorithms, namely, Support Vector Machines (SVM), Random Forest (RF), and Classification and Regression Tree (CART), and on comparison of their accuracy assessments. Sebahat Sevde Sağlam and Seden Acun Özgünler claims that considering the various negative effects of polymers on the environment, biopolymers could be seen as a strong alternative. The study called "An experimental study on production opportunities of biocomposite by using fungal mycelium" is tried to find the most efficient ratio among different mixing ratios by using the mycelium of the genus Pleurotus Ostreatus and the same raw materials.

We believe in the strong relationship between the concept of resilience and education, which is necessary when designing the places, cities, and lives of our future. That is why DrArch try to take place to education in every issue. The article on education in this issue came from Iranian researchers. Shahab Abbaszadeh, Behrooz Khosrowjerdi, Zohreh Sadat Seyedmoradi focused on design process in their article called "To develop a model for design protocol in the research-based design process in architecture education". The aim of this study is to develop a model that can be used in the architecture educational system. We hope this research will be useful to all designer and educator.

I would like to extend my deepest gratitude to all participants and all our readers for the support they provide to the Journal. And I would like to a special thanks to the referees. We look forward to your comments, contributions, suggestions, and criticisms.

Best regards...

Following names that provided valuable contribution as referees of articles in this issue are:

Anahita Zendedelan (Assist Prof. Dr.), Islamic Azad University
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DRArch's objectives are:

- to question how future building technologies are revolutionizing architectural design, city planning, urban design, landscape design, industrial design, interior design and education,

- to catalyze the processes that lean on interdisciplinary and collaborative design thinking, creating a resilient thinking culture,

- to improve the quality of built environment through encouraging greater sharing of academicians, analysts and specialists to share their experience and answer for issues in various areas, which distributes top-level work,

- to discover role of the designers and design disciplines -architecture, city planning, urban design, landscape design, industrial design, interior design, education and art in creating building and urban resilience,

- to retrofit the existing urban fabric to produce resilience appears and to support making and using technology within the building arts,

- to discuss academic issue about the digital life and its built-up environments, internet of space, digital in architecture, digital data in design, digital fabrication, software development in architecture, photogrammetry software, information technology in architecture, Archi-Walks, virtual design, cyber space, experiences through simulations, 3D technology in design, robotic construction, digital fabrication, parametric design and architecture, Building Information Management (BIM), extraterrestrial architecture, , artificial intelligence (AI) systems, Energy efficiency in buildings, digitization of human, the digitization of the construction, manufacturing, collaborative design, design integration, the accessibility of mobile devices and sensors, augmented reality apps, and GPS, emerging materials, new constructions techniques,

-to express new technology in architecture and planning for parametric urban design, real estate development and design, parametric smart planning (PSP), more human-centered products, sustainable development, sustainable cities, smart cities, vertical cities, urban morphology, urban aesthetics and townscape, urban structure and form, urban transformation, local and regional identity, design control and guidance, property development, practice and implementation.

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Editorial Team

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Research Article
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Study for a morphological assessment: Impact of a new project on urban form of Galata, Istanbul

Eda Coşkun[*]
Ayşe Sema Kubat[**]

Abstract

Cities are in a continuous process with the change and re-adaptation of different parts. Cities are deliberately planned under different socio-economic, natural, religious, and political conditions in different historical periods. While cities are growing, new urban projects are planned that will affect urban morphology. Thus, the research problem is that new urban design projects require planning and integrated policy in interaction with the city. One of the aspects of ensuring this is examining the city from the historical point of view and comprehending urban morphology analysis. Within this framework, the Galata Region is chosen as the study area. The main reason for choosing the study area is; that it is thought the planning of the Galataport Project, the characteristics of the district and its impact should be questioned. Therefore, the study aims to first determine the change and development of the Galata Region over time with the Conzenian approach. In this section, historical maps of the area will be examined through the spatial development of the city, and the determination of the areas affected by the planning decisions will be revealed. Morphological region analysis will be done to identify the focus area boundary. Secondly, the aim is to reveal the impact of the Galataport Project on the region and on the use of the coastline by space syntax method. In this part, the effect of the Galataport Project will be explained comparatively by axiality, convexity, integration and intelligibility, and synergy concept through the 1980 and 2020 maps. As a result, it is seen that the study area has its spatial characteristics, cultural values, and historical process. In the general analysis of the area, it is seen that the old city center is seen as a high potential area for transformation due to its central location. The old city center plays a central role in the marketing of the city because of its economic potential. New design projects are done in the study area because of the transformation potential. It is observed that the Galataport project together with the morphological structure led to functional changes in the field and caused differences in the characteristics of the use of space. It has affected the area and old trading functions began to transform the leisure and tourism sector. Lastly, recommendations are given according to the results.

Keywords: Conzenian approach, Galata region, Galataport project, urban morphology, space syntax methodology.

1. Introduction

From past to present, urban form and structure have been one of the major research topics in urban studies. Thus, morphological analysis is the main method effective in examining the city's form and structure. Also, planning and design decisions developed for cities have been issues of strategic importance in terms of understanding the history of cities, understanding their present and future planning approaches, and fictionalizing their future.

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As industrialization and urbanization increase, settlements begin to lose their historical, cultural values, and identity. Cities are facing major challenges because of the rapid rate of population growth and economic development, which require comprehensive strategies to protect the environment and sustainable development. For these reasons, examining the settlements through their forms and morphological characteristics to their dynamic structures stand out as themes that should be emphasized. Also, understanding the physical complexities of various scales and the spatial configuration of cities helps us to understand how towns have grown and developed. While cities are growing new urban projects are planned. Each plan decision and project should be harmonious and integrated. Istanbul, as a port city, includes many port projects. In the region's growth phase, the ports which are integrated with the city need to expand due to increased traffic and urbanization. As a result, ports that grow in parallel with the growth of the city maintained their port city appearance while on the other hand, the ports that are stuck in the city that cannot integrate with the city shrink and become dysfunctional.

Galata Region, which is considered the historical core/port of Istanbul, has also been affected by many planning and design decisions throughout history. A new project like Galata Port Project is planned and done in the area. Galata Port is located in a position that can be described as the entrance gate of Istanbul. Anatolia is rich in architecture and urban structure, reflecting its geographical location and the influence of several civilizations (Kubat,2010). These kinds of planning decisions belong to various historical periods and these planning decisions led to alterations in the morphological framework of the region.

A brief explanation of the emphasis on the research problem is that new urban design projects require planning and integrated policy in interaction with the city.

Accordingly, the main aim is *to analyze the change and development of the Galata Region over time by analyzing the physical layout and syntactic characteristics through historical periods and to reveal the impact of the Galataport project on the coastline use and the region.* Sub aim of the study can be stated as *synthesizing two different morphological approaches (Conzenian morphology and space syntax methodology) to investigate the change and development of the study area.*

Based on the aims the research questions can be summarized*: Is Galataport Project (new port project) effective within the spatial structure and is it a characteristic feature of a region?*

2. Urban Morphology as a Discipline in Urban Studies

A great number of scholars have put forward the definition of urban morphology throughout history. Urban morphology concepts in the literature are presented in Table 1.

Table 1 Definitions of urban morphology by scholars.

The Definition of Urban Morphology	Scholars
"The study of the layout and build of towns viewed as the expression of their origin, growth, and function"	(Dickinson, 1948, p.232)
"A method of analysis which is basic to find(ing) out principles or rules of urban design"	(Marshall & Çalişkan, 2011)
"A method of analysis which is basic to finding out principles or rules of urban design or 'the study of the physical and spatial characteristics of the whole urban structure"	Gebauer & Samuels (1981, cited in Oliveira 2016, p.3)
"The study of the physical (or built) fabric of urban form, and the people and processes shaping it"	(Urban Morphology Research Group, 1990)
"The science of form, or of various factors that govern and influence form"	(Lozano, 1990)
"The study of the physical (or built) fabric of urban form, and the people and processes shaping it"	(Larkham & Jones, 1990)
"The study of the city as human habitat".	(Moudon, 1997, p.3)
"The study of the evolution process of a particular place over time"	(B. Scheer & Scheer, 2002)
"The study of urban form"	(Cowan, 2005)

A "method of urban analysis used to find out basic principles of urban formations and aiming to describe the process of urban formation defined period within a hierarchical order"	(Mıhçıoğlu Bilgi, 2010)
"Morphology claim to be the instrument that connects organically sustainable technologies and formal needs."	(Maretto, 2013)
A study identifying "the repeating patterns in the structure, formation, and transformation of the built environment to help comprehend how the elements work together, notably to meet human needs and accommodate human culture"	(Kropf, 2014, p.41)

As a consequence of these definitions, it can be said that urban morphology is known as the structure of the city. As can be seen from the study of urban morphology, the contributors who have worked in this field have so far studied the city's evolution from history to the present. Thus, the formation of the cities, the transformation process, and the characters of the cities emerge. It can provide a general structure for a deeper analysis of decision-making.

2.1. Different approaches to urban morphology

Kropf (2009) attempts to clarify the methods and elements of urban morphology. He studied the work of some scholars on aspects of urban form and developed principles and techniques for urban form study. He defined four techniques for urban morphology, which are "spatial analytical," "configurational," "typological method" and "historic-geographic". These techniques together provide a comprehensive understanding of the built space (Gokce, 2018) (Figure 1).

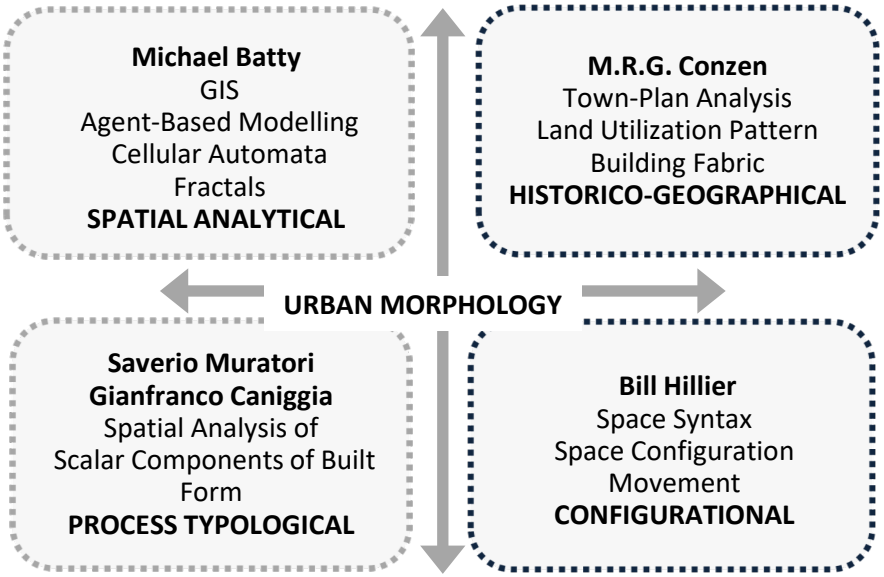

Figure 1 Approaches to urban morphology (adopted from Kropf, 2009).

In the spatial analytical approach, cities are considered to be ordered, but complex entities, and this complexity question can be solved through the study of their spatial structure and dynamics by understanding their emergence and evolution method (K. Kropf, 2009).

In the configurational approach, space syntax is the main method used in urban morphology to analyze the connections between form, function, and perception (K. Kropf, 2009).

The typological approach is rooted primarily in the work of Saverio Muratori, inspired by Giuseppe Pagano (Marzot, 2002). This perspective examines how the built environment develops and what future developments can benefit from its physical structure's evolution over time (K. Kropf, 2009).

The historical-geographical approach is seen as the analysis of the town plan of Conzen, which systematically analyzes the features of the city and its growth through periods to assess the spatial structure and character of the city (K. Kropf, 2009).

Table 2 Similarities and differences among three schools, compiled by the author.

	HISTORICO-GEOGRAPHICAL	PROCESS TYPOLOGICAL	SPATIAL ANALYTICAL	SPATIAL ANALYTICAL
	British School	**Italian School**	**French School**	
Year	The 1950s	The 1950s	The 1970s	The 1970s
Founder	Geographers	Architects	Different Disciplines	Different Disciplines
Adherents	Conzen Whitehand	Saverio Muratori Giafranco Caniggia Aldo Rossi	Michael Batty Lefebre Paneria Caste Depauri	Bill Hillier Julienne Hanson and their colleagues
Focus	Urban morphogenetic process	The design of the urban form	Relationship between urban form and various social phenomena	Relation between space and activity
Intention	How cities are built and why?	How cities should be built?	What should be built and what has been built?	How to predict movement and land use from spatial structure?
Data	Diachronic	Synchronic and diachronic	Synchronic	Synchronic and diachronic
Patterns	Plan units Morphological frame Plot series	Building types Building tissues	Classification of different urban patterns	Syntactic maps
Explored Linkages	Land use, land value, historical periodicity	Cultural region	Social practices	Land use, land value, historical periodicity, Social practices

Thus, the historical-geographical and configurational approach is selected as the methodology of the study. It is aimed to use both of these urban morphology approaches to detect morphological elements and morphological change. By bridging the two approach, better understanding of the region and the applicability of the two methods have been tested.

3. Historico-Geographical and Configurational Approach

3.1. Historico-Geographical Approach

Townscape is "the physiognomy of the urban landscape" (Conzen, 1969). It looks at the changing urban patterns and their contribution to the regional character.

Morphological regions

Conzen uses the concept in townscape analysis as morphological regions that describe the boundaries or regions of the land utilization, building type, and plan unit and place them in hierarchical order. A morphological region is an area that has a unity in respect of its form that distinguishes it from surrounding areas. Boundaries between regions vary in strength (Conzen, 1988).

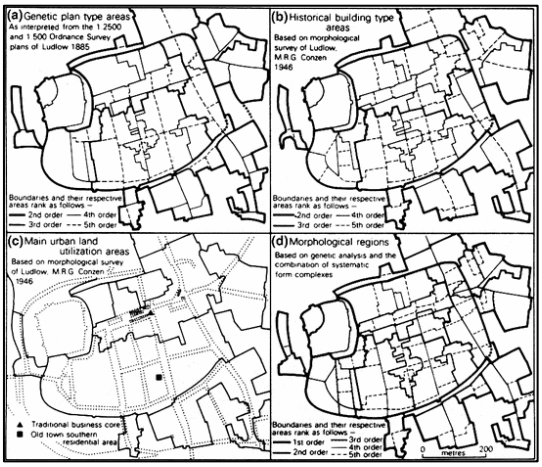

Figure 2 Morphological regions of Conzen's Ludlow map (Whitehand, 2001).

The five-tier hierarchy of boundaries is described in the Ludlow analysis of Conzen, seen in Figure 2. The elements of urban morphological regions are urban land use, the form of building, and the type of plan divided into four hierarchical ranks.

First-order: the old district as a whole represents the first order. Also, basic historical elements and developments are involved.

Second-order: major plan units, urban districts, or small residential dwellings are involved.

Third-order: intermediate plan units, street units, or land utilization are involved.

Fourth-order: minor plan units, building fabric cells, morphotypes, or the new planning areas are involved.

Plan unit can be conducted at various scales from layouts to individual morphotypes and refers to any region showing internal homogeneity and morphological discord with adjacent plots (Conzen, 1960, p.5).

Land utilization pattern is the order or spatial development of land use. Conzen identified that "the elements of the pattern are the individual units of land utilization occupying discrete plots. Classification of uses is based on the single criterion of purpose" (Conzen, 1988).

Building type is defined as "the elements of the urban land utilization pattern, that is the individual units of land utilization occupying desecrate plots" (Conzen, 1981).

3.2. Configurational Approach

Space syntax theory from the urban morphological tradition perspective was developed between the late 1970s and the early 1980s by Professor Bill Hillier[1] Julienne Hanson and their colleagues at University College London's Bartlet Institute. This special morphological theory—provides a demonstrable frame to understand the urban system and its physical evolution (Kubat, 1999). Answers to such questions were sought. How can space be described? How to predict movement and land use from spatial structure? How to assess an area's design?

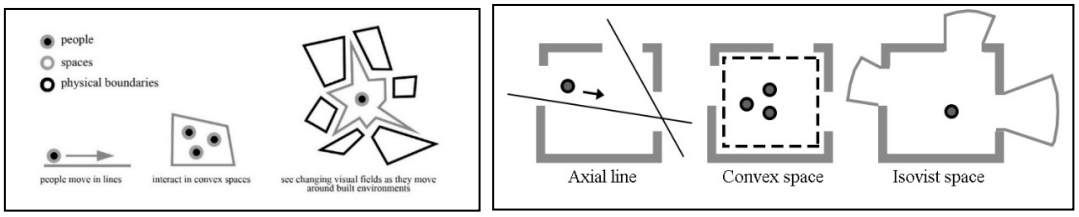

Figure 3 Relation between space and activity: Space is not a background of activity but an intrinsic aspect of it (Hillier, 2004) (left); Axial line, convex space, and isovist space (Hillier, 1984) (right).

The spatial specification allows the social structure to be mapped to itself in space syntax. For example, Figure 3 shows two different types of spatial configuration; building structure and space structure, although in adjacency and number of cells they appear to be similar, underneath topology they are completely different (Hillier, 1996).

The spatial structure measuring is represented by using syntactic maps. These syntactic maps are comprised of axial, convex, and isovist spaces. These are the representation of spaces as shown in Figure 4. These components constitute different types of measurement to detect the configurational properties of urban settlements.

[1] Bill Hillier got his BA and MA in Architecture at the University of Cambridge, in 1961 and 1964. He received his DSC in Built Environment at the University of London in 2003 (Oliveira, 2016).

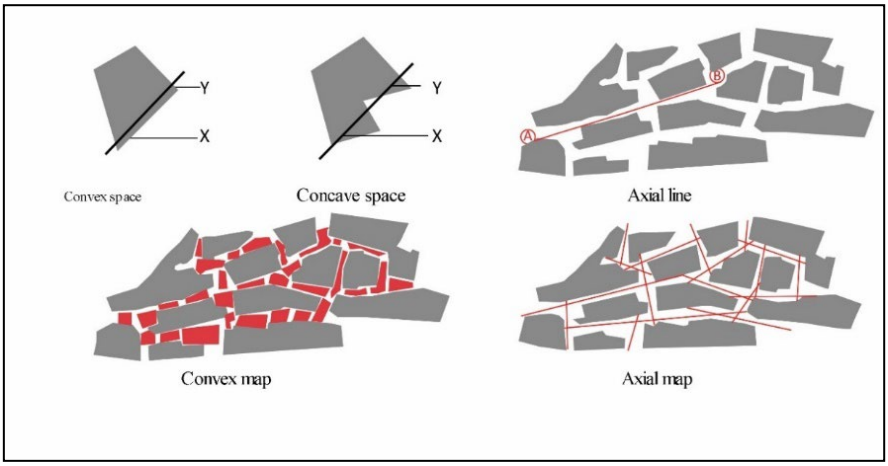

Figure 4 Space syntax tools (Hillier, 1984).

3.3. Measures of space syntax

Since the 1970s, a significant body of researchers has been using the "space syntax" approach to analyze the morphology of the physical city and its relationship with the functional city.

Table 2 summarizes ten related mathematical definitions of measures that are used in the spatial structure of the case studies.

Table 2 Mathematical definitions of measures, complied by (Hillier, 1984; Kubat, 1997).

TERMS	DEFINITIONS	FORMULAE[2]
Axial articulation	Axial integration is a measure of the integration of axial lines. Low values mean an axial line with a high degree of integration. It is measured by dividing the number of axial lines by the number of buildings.	L/number of buildings
Convex articulation	The degree to which the open space of an urban system is broken up into convex space is indicated by the convex articulation value.	C/number of buildings
Axial ringiness	Axial ringiness is a measure of rings in the axial map.	½L−5
Convex ringiness	The ringiness of the convex system R convex is the number of the rings in the system as a proportion of the maximum possible planar rings for that number of spaces.	I/2C−5
Grid axiality	The value is between 0 and 1, a high value indicates a strong approximation to a grid, and a low value a greater degree of axial deformation.	2I1/2 + 2/L,
Grid convexity	This formula compares the convex map to an orthogonal grid. High values indicate little deformation of the grid and low values indicate higher deformations of the grid.	(I1/2 + 1)2/c,
Convex deformation	The degree of convex deformation of the grid can be measured by dividing the number of convex spaces by the number of islands.	C/I
Axial integration	Axial integration is a measure of the integration of axial lines. Low values mean an axial line with a high degree of integration.	L/C
Mean connectivity	Connectivity is a significant measure of an axial map that describes the number of lines connected to or intersecting a given line.	Lower is attributed to a nonorthogonal
Mean global integration	The highest number is the most integrated space in the system, the lowest is the most segregated space in the system.	Integration

3.3.1. Measuring axiality through space syntax

The simplest of all morphological measurements that can be taken from the axial map is the length of any street or space along the longest possible axis. Axiality means the maximum global or

[2] L is the number of axial lines; C is the number of convex space; I is the number of islands.

axial extension of space, as a point, in a straight line (UCL Space Syntax). The axial map is therefore a series of axial lines which are the longest lines in the spatial structure that can be drawn from a random point. (Benech, 2007). Four main measurements are analyzed in the thesis shown in the table. They are axial articulation, axial integration, grid axiality, and axial ringiness.

Axial articulation is the number of axial lines per urban block. About urban blocks, this shows the granularity of a spatial structure. A higher degree of axiality is suggested by a lower axial articulation value and a higher value by a greater axiality breakup.

Axial integration is the reciprocal of the real relative asymmetry (RRA) value of an axial line, which is a function of the mean depth (MD) value of the line. A higher RRA value indicates greater segregation, and a lower value indicates a higher integration of a node with the other nodes in the entire graph. Therefore, a higher integration value, which is the reciprocal of an RRA value, indicates greater accessibility, and a lower value indicates lower accessibility of a node wiconcerninghe other nodes of a graph (Sevtsuk & Davis, 2019).

Grid axiality, or the degree of axial deformation of the grid, is measured by comparing the number of axial lines in a spatial system with the number that could exist in a regular grid with the same number of islands or blocks. According to (Hillier and Hanson, 1984), in general values of 0.25 and above indicate a grid-like system, while values of 0.15 and below denote a more axially deformed system.

Axial ringiness is the number of rings in the axial map of a spatial system as a proportion of the maximum possible planar rings for that number of axial lines. This value may exceed 1 since the axial map is nonplanar. However, in practice values greater than 1 is unusual (Hillier and Hanson, 1984). Axial ringiness is a measure of restrictions indicating how freely one can move in an area.

3.3.2. Measuring convexity through space syntax

The degree to which any space can be extended into two dimensions is described by convexity. There are four main measurements: convex articulation, convex deformation, grid convexity, and convex ringiness.

Convex articulation can be measured by dividing the number of convex spaces by the number of buildings. Grid convexity compares the convex map to an orthogonal grid. High values indicate little deformation of the grid and low values indicate higher deformations of the grid. Convex ringiness of a convex system is R convex is the number of the rings in the system as a proportion of the maximum possible planar rings for that number of spaces and the degree of convex deformation of the grid can be measured by dividing the number of convex spaces by the number of islands (defining an island as a block of continuously connected buildings surrounded by open space).

3.3.3. Measuring intelligibility and synergy through space syntax

“The correlation between connectivity and global integration is an important indicator of how clear an urban system is for its users; and this is referred to as Intelligibility” (Choudhary, 2012). In practice, the value of intelligibility is evaluated by the degree of linear correlation between connectivity and the global value of integration (Hillier and Hanson, 1984). The greater a correlation, from its measurable local relations, the more global configuration of a space can be inferred.

Synergy is similar to intelligibility. The concept of synergy, like the parameter of intelligebility, has been defined as a second-degree value emerging as a result of correlation (Topçu, 2019). The connection between the global value of integration and the value of local integration explains the city's synergy (Thilagam, 2015). Hillier suggests that this is a measure of how the local street network is a reliable indicator of the global configuration. (Dalton, 2010). Synergy's definition is in several respects related to that of intelligibility. Hillier argues that this is also a measure of the correlation between the grid's local structure and the grid's global structure (Dalton, 2010).

3.3.4. Measuring integration through space syntax

Integration is the most significant measure among syntactic measures when applied to the axial and segment maps of space syntax. A static global measure is an integration. As Peponis et al (1997) state: “Integration measures the relationship of each line to the network as a whole”. Space integration is defined as a valindicativeion of the degree to which space is integrated or separated from a system as a whole (global integration) or a partial system consisting of spaces a few steps away (local integration)' (Choudhary, 2012). Integration is not only a structured function but can also help identify how urban structures operate (Hillier, 1996).

4. Historical Evaluation of the Galata Region

Galata region is chosen as the study area for this study. The selected area is chosen based on six parameters. First, in the selected study area, there is a rich historical and cultural history. Second, is the existence of documentation (pervititch maps, historical photographs, aerial photographs, GIS software, etc.). Thirdly, the selected study area has a varied degree of urbanity. Fourth, the selected area has a rich urban pattern that includes apart from each period of urbanization. Fifth, the area is affected by numerous planning and design decisions throughout the historical development and the effects in areas that make up the city's unique character showed themselves. Lastly, the planning of the Galataport Project is also a situation where the characteristics and impact of the district should be questioned.

The Galata region plays a vital role in the spatial structure and operation of the municipality. We can see the strategic importance of the selected area through the introduction of new urban design projects such as the project Galataport project.

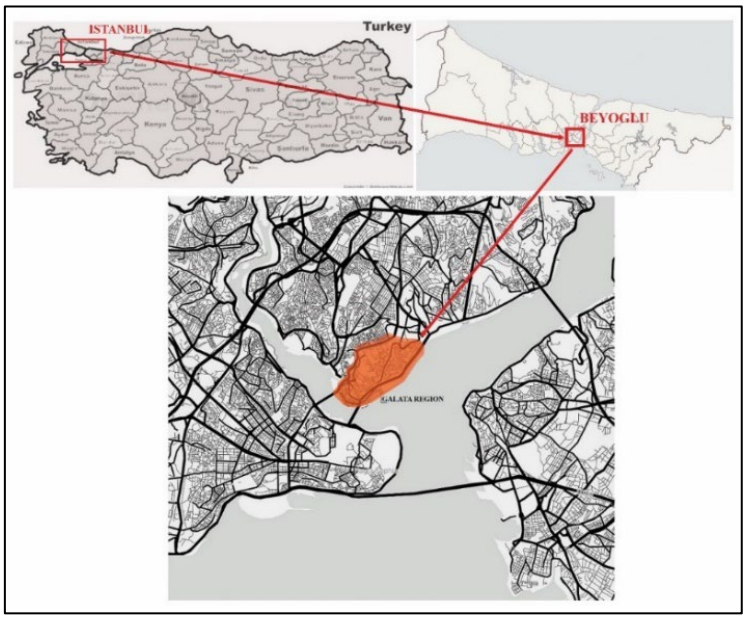

Figure 5 Location of the study area in Istanbul.

It is seen throughout history, that variations of Galata Road systems have been documented. Galata’s corporate image and port accessibility reached a high level of activity as part of this metropolis (Agirbas & Ardaman, 2015).

By the historical maps, the study area reflects the traces of each period and has reached the present day with important historical buildings belonging to each period.

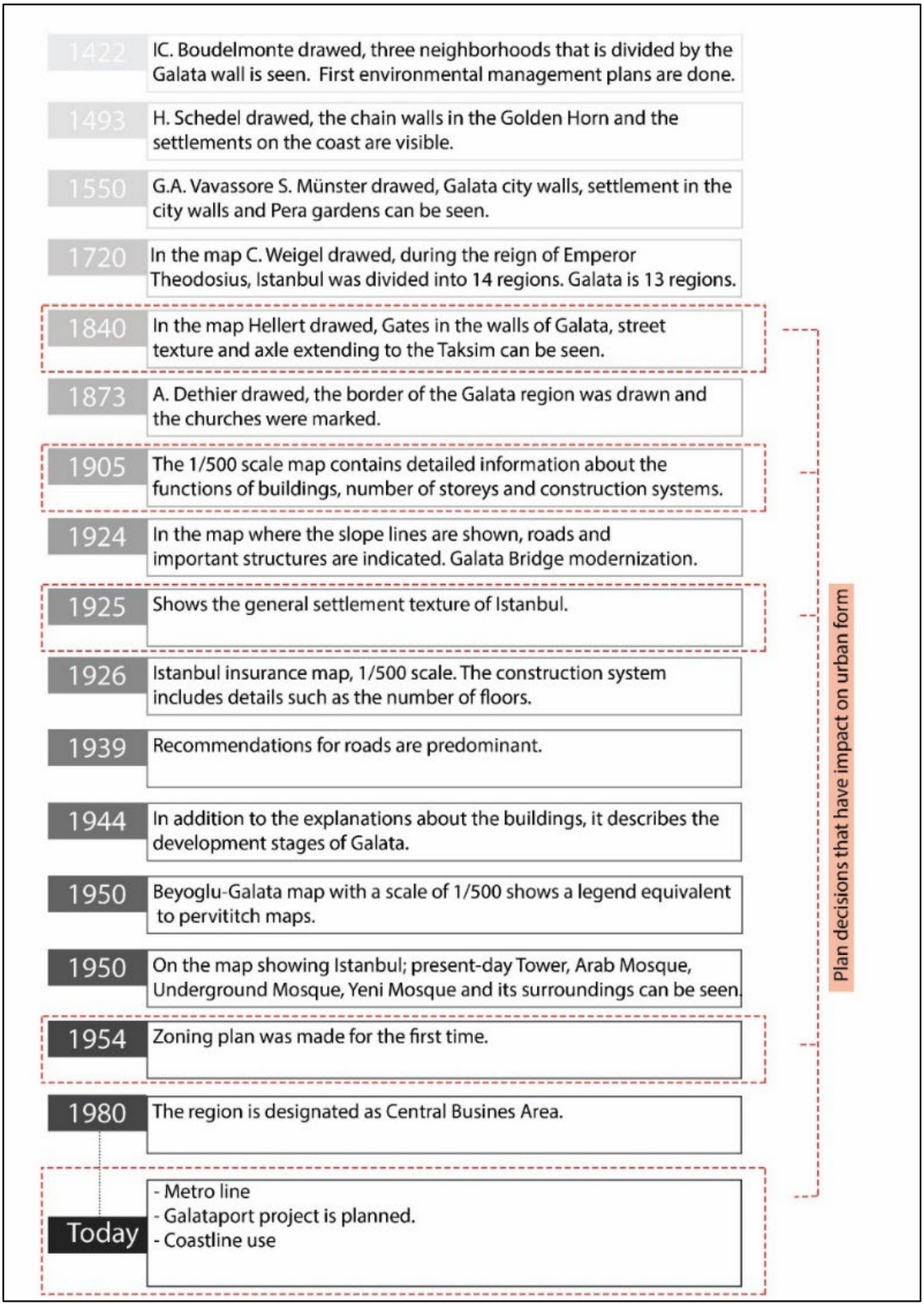

Figure 6 Major developments in the historical process of the Galata region, compiled by the author.

At present, one of the most important developments seen on the 2018 map is the metro line that connects the Historical Peninsula and Karaköy. Karaköy square and the port area have been thought through different planning approaches throughout history. Today, the coastline is planned for pedestrian use with the new projects. The area between the two bridges where the square and the port are located is considered a recreational area. It is seen in the 2020 map, that since the beginning of the 2000s, the approach of marketing in the area has led to megaprojects (Galataport and Haliçport) with port functions which causes morphological transformations in the area.

Figure 7 shows that when historical maps are examined through street patterns, the city walls were demolished after 1453. Afterward, the Pera fire destroyed many houses, shops, and streets including Yüksek Kaldırım Street 1860. We can see in the 1887 map that the grid plan was widely applied to urban regulations after the Pera fire. Later on, in 1913 German map that Yüksek Kaldırım street was enlarged, and some arrangements were made. On the map in 1945, Kemeraltı Street and Bankalar Street became the main roads that connect the main artery which comes through the Galata Bridge. In the 1980 map, we can see that the coastal zone of the region is an important planning area. Important buildings have preserved their importance throughouth history, but it can be said that 1945 was a breakdown. Although fires have greatly affected the urban texture of Galata, surrounded by city walls, the region has preserved its features for many years. In a conclusion, the research showed and made it possible to analyze the increased number of streets and significant structures, as well as the change and the development of the region.

Figure 7 Development of the street pattern for examined periods studied, marked with important changes.

Also, the physical patterns of the study area are seen in Figure 8. It's seen in the street pattern that the main axles that existed till 1887 are Yüksek Kaldırım Street, Kemeraltı Street, Tersane Street, and Bankalar Street. The importance of these streets has been going on for many years. These roads were used as main roads in the past. The core of the region is planned as a traditional organic pattern that can be seen in many historical city centers. But when we look at the edges, we can see a grid pattern. This pattern is also seen in the new project area.

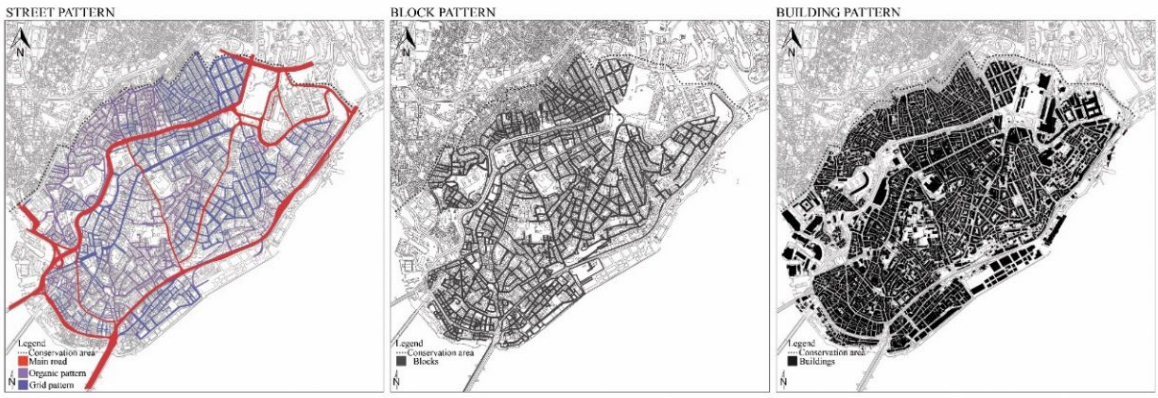

Figure 8 Physical patterns of the study area.

Galata Port from Past to Present

Galata port, which is seen as the gateway of Istanbul to the world, did not have a modern dock until the 19th century. For this reason, the ships that stopped during the period, anchored in pontoons and buoys off Galata.

19. the century that began in the Ottoman Empire in the century also affected the urban life of Istanbul. In fact, in the last years of the century, it was decided to modernize the Port of Istanbul. The main reason for this decision is that the current capacity of the port has been insufficient in the face of the growing volume of trade and technological developments.

Construction of the first modern dock in the port of Galata began in 1892. But due to reasons such as rising flow rate, disease outbreaks, and the formation of some collapses during construction, the construction process has been very difficult. Despite all the difficulties, the Galata pier was completed in 1895. But when it became clear that it was not strong enough, and as a result of various collapses, the dock was repaired again in 1898, and the renovation work was completed in 1900.

In the 20th century, as a result of non-investment, the port of Istanbul started to lose its importance. However, with the Soviet Revolution, the port of Istanbul lost its most important source of income in the Black Sea. Galata docks company was nationalized in the period between 1933 and 1934 and was connected to the General Directorate of sea roads and ports. Since the 1980s, the port in the city center has become unusable due to increased ship traffic and heavy tonnage trucks. Because of these situations, Galata port has started to be used for tourism purposes.

Currently, different planning decisions have been made and implemented for the port. Now, Galataport project is a project covering 1.2 kilometers of coastline from Karaköy Quay to Mimar Sinan University Fındıklı Campus. As part of the project, it is planned to repair or demolish the structures located in this area of the tourist concept of the port and open up space for new facilities. Hotels, restaurants, and all other commercial enterprises to be built in the coastal areas of the port are intended to preserve the historical fabric of the port area and transform the area into a full tourist attraction. With the project “Galataport”, it is thought that the area will gain different functions and become a cultural, tourism, and trade center, thus adding new value to Istanbul.

The entire coastal line is reserved for cruise port use. Functional changes are also planned within the scope of the project. In the region, the historic package Post Office is functioning as a fair and exhibition hall, while the historic inn buildings on the coast are functioning as hotels. On the Tophane side, the Square and the proprietary historical structures and spatial elements behind it are preserved. But new uses such as hotels, office buildings, sales areas, and a marina have been added to the waterfront line. The functional distribution of the coastal band is planned as semi-private uses such as hotels, terminals, and congress centers, where public use is not included.

When analyzed visually, it is seen in Figure 9, that there is no public open space in the area other than Tophane Square. Semi-private uses of hotels and restaurants can be seen in small-scale openings between buildings. The only point in the project that changes the silhouette and creates a public open space is Tophane Square. However, Tophane Square, which is a coastal Square is not fully met with the sea. The Square is again located behind the shoreline and there is a structure planned as an aquarium in front of it in the western direction. Although the rest of the area appears clear in the foreground, the use of the harbor makes the square lose its coastal position. The cruise ships that will dock onshore are the size that completely closes the square and prevents sea–shore perception. The structures planned to replace the four existing warehouses as terminal buildings are larger in scale than the existing ones and they completely covers the shoreline. This means the reproduction of physical tissue on the coast on a larger scale and the formation of a new morphological character in the city.

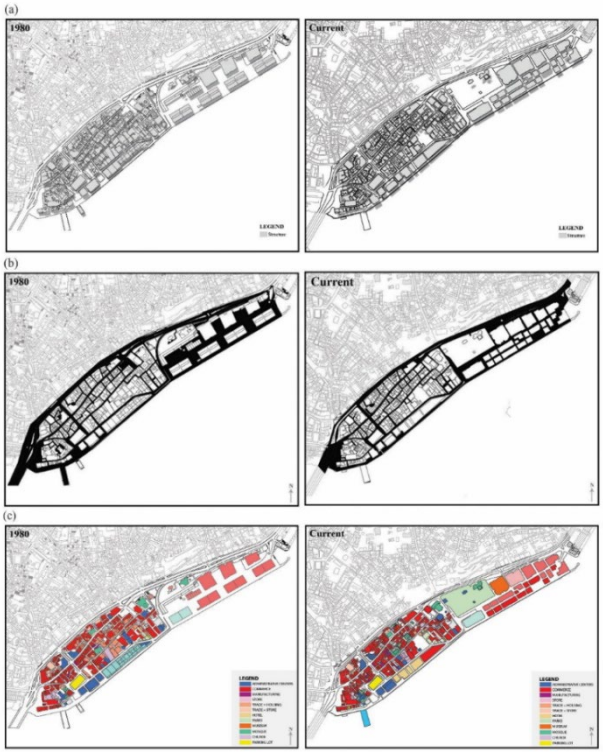

Figure 9 Maps of the area in 1980 (left) and 2020 (right): (a) spatial change; (b) street pattern; (c) land use.

Figure 10 Cruise ships and their impact on the silhouette (Tepeli, 2015).

Figure 11 Impact of the project from the coastal area to the silhouette, the 1900s (top) and 2020 (bottom) (Url, 1).

5. Morphological Change in Galata Region

5.1. Historico-Geographical Analysis

Galata's old city wall comprising the old settlement area is indicated as a first-order, due to its persistence as a multi-level urban fabric from Byzantium to the present. In the second-order, major structural divisions, historical processes, and regions within definite identities are considered according to the direction of urban development. It is seen in the plan unit the region started to parallel the sea. Determining the second-order land utilization of the study area is differentiated as which are residential, commercial, industrial, and community service functions. It is seen that the historical core contains centrally the commercial functions. This is also seen in the planned new design project (Galataport project). Additionally, to determine the second-order, significant buildings from each period are determined. In this analysis, building types and groupings are divided based on six different building periods (Figure 12). It is seen that the region preserves buildings from each period and most of these buildings are clustered regionally.

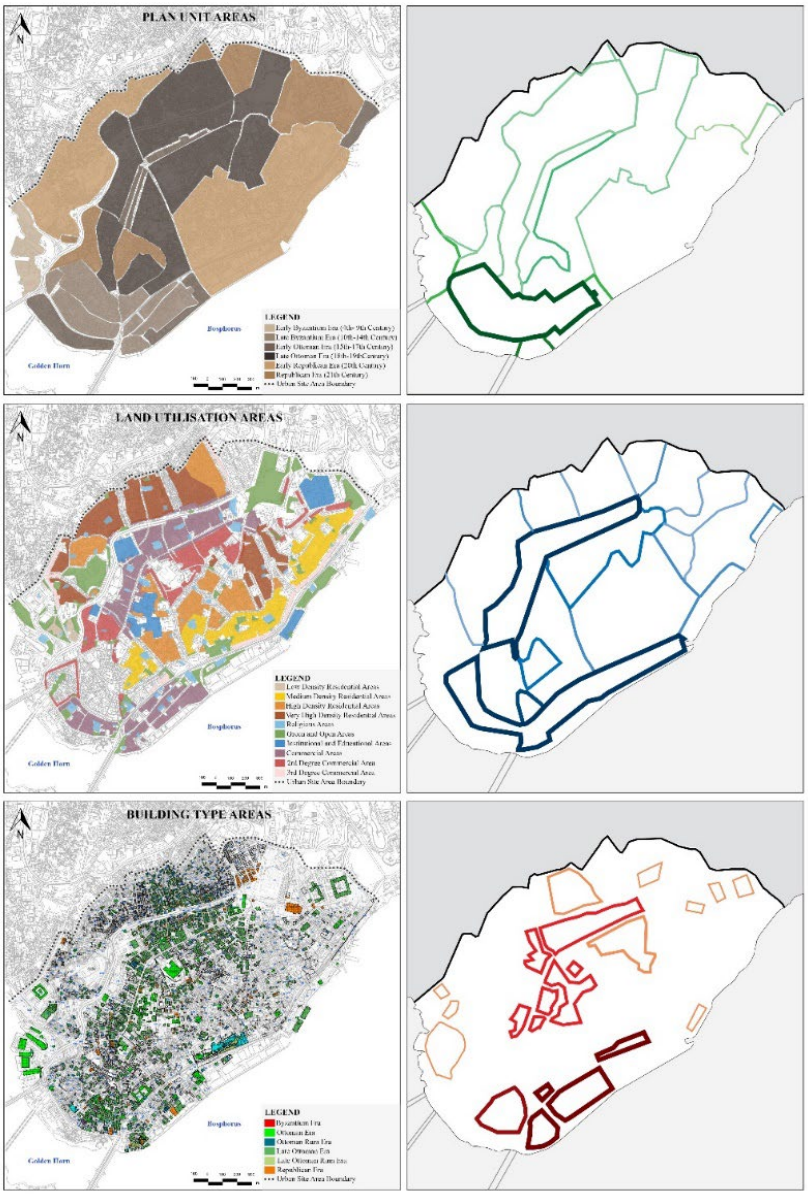

Figure 12 Plan unit, land utilization, and building type regions of Galata Region.

Figure 13 Plan units of Galata district showing general urban fabrics with 2019 aerial photos (first and second orders).

Consequently, according to all of the research, the region is mainly divided into 24 regions with its historical process, land use, and building pattern considered (Figure 13). One of these provides the division containing the Galataport project.

By looking at Figure 13 specific focus area can be determined. It is seen that the selected focus area plays a vital role in the spatial structure as a commercial and transportation zone of the municipality. Based on the boundaries of the area where the author will apply space syntax analysis have been determined.

5.2. Configurational Approach Analysis

Necessary inputs have been created and analyzed for morphological analysis by space syntax. After the determination of these data by applying the necessary formulas the morphological characteristics of the chosen sample area can be ascertained by a comparative analysis of the syntactic measures.

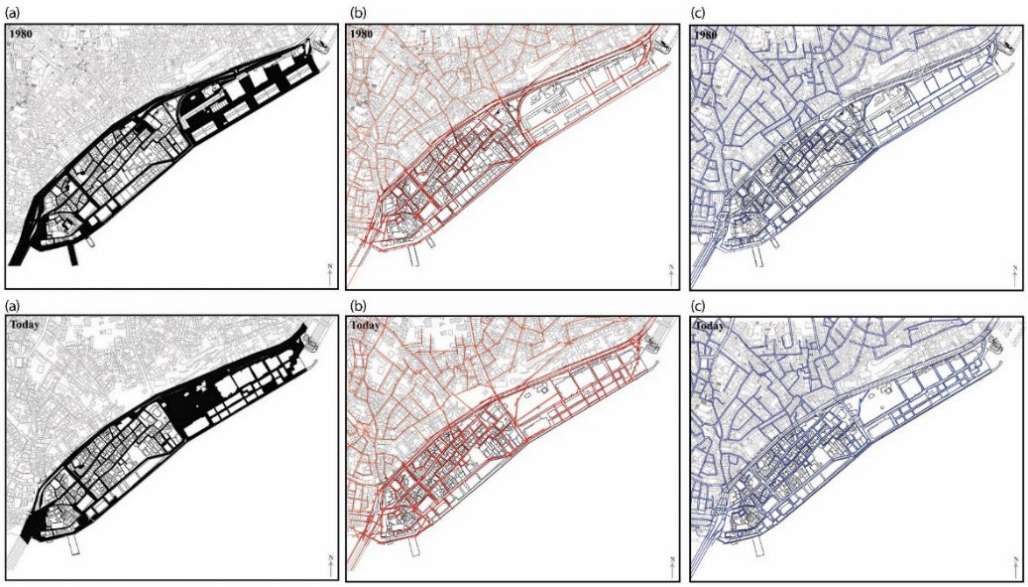

Figure 14 Maps of the area in 1980 (top) and today (bottom): (a) open space map (shown in black); (b) transcription of the plan into the convex map; (c) transcription of the map into an axial map, prepared by the author.

With these findings, the impact of the project on the region and the coastal band can be predicted and interpreted from the findings on whether the new physical tissue that will form on the coast will work as a coastal band that is integrated with the urban fabric, easily accessible and available to the urban people, as mentioned in the project. This comparison will be done by 1980 and the map of 2020.

Table 3 Mathematical values of the study area before and after the Galataport Project, complied by (Kubat, 1997).

Properties	1980	2020	Mean Values
L= Number of axial lines	106	116	111,00
C= Number of convex spaces	231	257	244,00
I= Number of islands	36	48	42,00
B= Number of buildings	316	362	339,00
Measures of convexity			
Convex articulation (C/B)	0,7310	0,7099	0,7205
Convex deformation (C/I)	6,4167	5,3542	5,8854
Grid convexity $((I^{1/2}+1)^2/C)$	0,2121	0,2446	0,2283
Convex ringiness (I/(2*C-5)	0,0788	0,0943	0,0865
Measures of axiality			
Axial articulation (L/B)	0,3354	0,3204	0,3279
Axial integration (L/C)	0,4589	0,4514	0,4551
Grid axiality $((I^{1/2}*2)+2)/L)$	0,1321	0,1367	0,1344
Axial ringiness (I/(2*L-5)	0,1739	0,2115	0,1927
Measures of integration			
Integration	1,1980	1,3970	1,2975
Measures of intelligibility			
Intelligibility	0,4044	0,3344	0,3694
Measures of synergy			
Synergy	0,4589	0,4787	0,4688

Measurement of axiality

Axial articulation can be calculated by dividing the number of axial lines by the number of buildings. Axial articulation value represents the open space structure's curves and angles. This value also shows a higher degree of urban axiality. Axial articulation values for the 1980 map and current map are 0.3354, 0.3204 and the mean value is 0.3279. The area in the 1980 map has an axial articulation value higher than the mean value due to its fragmented and organic urban texture. It clearly shows the growth of non-axial cities. But after the project, it is seen that the area with its low values exhibits a higher degree of axiality and high values show break-ups in the settlement. It gives the conclusion that the deviations in transportation are reduced and that transportation will be provided in the area through more linear moving axles.

The axial integration of convex spaces can also be determined informatively. Axial integration allows us to compare the number of axial lines with the number of convex spaces. Low values indicate a higher degree of axial integration in convex space. Axial integration values for the 1980 map and current map are 0.4589, 0.4514 and the mean value is 0.4551. Values lower than average value indicate a high level of integration of convex space. Today axial integration value indicates that the degree of axial integration of convex spaces is higher and it is seen in previous maps that the regions in the past showed low axial integration consisting of various twists and angular junctions.

Grid axiality is a result between 0 and 1, but higher values suggest a better grid approximation and a higher degree of axial deformation at low values. The mean grid-axiality level of both of the cities is 0.1344, and both the year comparisons are close; nevertheless, close observation of urban patterns shows the fact that these structures are not axially deformed. In the contrast, in the

current map grid, the axiality value (0.1416) which is higher than the mean value means a grid layout that follows a simplified pattern by replacing the intersection of streets with more T-junctions, providing a more symbolic and formal spatial pattern for the important buildings in the area. But in the past, the region mainly presents a highly symbolic nature of the street pattern.

To measure the distributed news of the open system, it is necessary to calculate the values for the ringiness in the convex space (Kubat, 1997). Axial ringiness values for 1980 and current map value is 0.1739, 0.2115 and the mean value is 0.1927. This value shows that the connection between the axles is strong in the overall assessment. But to make a prediction, the fact that this value is higher compared to previous periods indicates that the connection between the axles will weaken after the project. These high values also indicate the grid pattern in the project.

Measurement of convexity

Convex articulation can be calculated simply by dividing the number of buildings by the number of convex spaces. Convex articulation values for 1980 and the current map values are 0.7310 and 0.7099 and the mean value is 0.7205. Values lower than the mean value shows fewer breakup and therefore more synchrony in the convex spaces of the area. 1980 map value for convex articulation (0.7310) confirms the asymmetrical and organic pattern with many twists, turns per unit length, and variations in the widths of convex spaces. This causes more breakups and less spatial synchrony (asynchronous) in the open space structure. But the current map value (0.7099) shows fewer breakups and synchrony in the urban structure and also the existence of a continuous linear major axis. This causes more breakups and less spatial synchrony (asynchronous) in the open space structure of the study area.

Convex deformation can be calculated by dividing the number of islands by the number of convex spaces. Convex deformation values for 1980 and the current map are 6.4167 and 5.3542 and the mean value is 5.8854. Higher convex deformation values suggest a more irregular open space network. It can be said that the values are close but in past, the area had more irregular open space. But by looking at a bigger scale., The Galata region's historic heart has the highest value and therefore has the most unusual open space structure. This is also the cause of steep topography and the curvilinear street layout in the neighborhoods.

The grid convexity formula compares the convex map to an orthogonal grid where convex spaces stretch in one direction across the network, while convex spaces fit in the interstices in the other direction (Hillier & Hanson, 1984). According to Hillier & Hanson, this formula should give a value between 0 and 1, with high values that indicate less grid deformation and low values that indicate a lot of grid deformation. Grid convexity values for 1980 and the current map value are 0.2121, 0.2446, and the mean value is 0.2283. The low syntax value of the study area implies a high deformation of the grid, which means that the city's open space layout is not geometric and the high syntax value for a current map with a higher value shows little deformation of geometrical grids that were applied in historical periods.

Convex ringiness is the number of rings in the system as a proportion of the maximum possible planar rings for that number of spaces (Hillier & Hanson, 1984). 1980 and the current map convex ringiness values are 0.0788, 0.0943 and the mean value is 0.0865. After the project the area has a higher value this shows no bends or curves in the open structure and confirms the more grid-like urban structure observed in this area. But before it is seen from the values and also the maps the area confirms the organic open space structure with gradual curves.

Measurement of integration

Another important way of analyzing the pattern of settlements is integration values. Integration is the key concept of space syntax. The approach allows integration to be represented in numerical values.

Integration shows the degree to which a line is more integrated, or segregated, from a system as a whole. The mean integration values for 1980 and the map of 2020 are 1.1980, 1.3970, and the mean value 1.2975.

From the integration value obtained after the Galataport project and the resulting integration map, it can be read whether the density, accessibility, and relationship with the surrounding texture of the Post-Project region, especially the coastal band, has increased. As it is seen on a global scale the project will indicate a more integrated settlement. But when it is looked at on a local scale it is seen that the value is lower than in the previous period. This indicates that the project is not in a structure that will strengthen the relationship between the coastal zone and urban fabric. On the contrary, in the coastal band, it is seen that the degree of integration of the entire coastal region and the connections reaching this region is low. The low level of integration of the coastal region, where the Galataport project is located shows that this area will be a place that will work indoors, with a weak connection to its environment. In terms of access to the coast and coastal use, access to the coastal band is also seen as low and the intensity of use is predicted to be poor. This results in the fact that the production of an easily accessible urban coastal space open to public use, where the sea-human relationship is strengthened, as targeted in the project, will not occur.

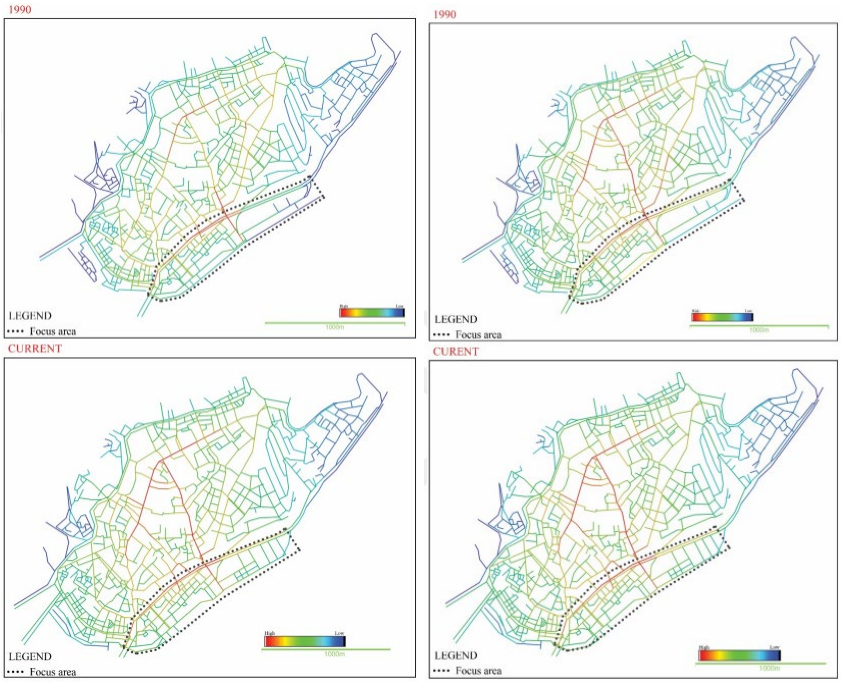

Figure 15 Global integration (Rn 1200) (left) and Local integration map (Rn 800) (right) of the study area.

Figure 16 Detailed representation of local integration map (Rn 800) of the area in 1980 (left) and 2020 (right).

Integration value will also be used to detect major urban spaces or major building interactions with the district.

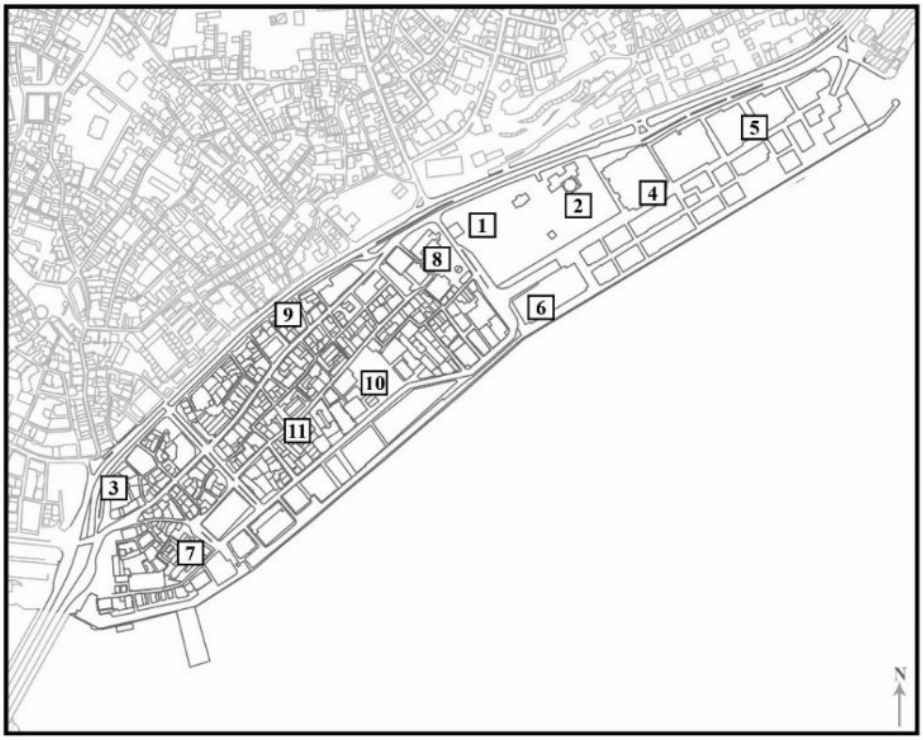

Figure 17 The rank ordering of the major urban space and urban elements of the study area.

Table 4 The rank ordering of the major urban space and urban elements of the study area by the value of global integration.

Rank	Principal urban elements	Global Integration value
1	Tophane Square	2,0160
2	Nusretiye Mosque	1,9105
3	Karaköy Palas	1,6669
4	Museum	1,4720
5	Galataport Project	1,4439
6	İstanbul Modern	1,4120
7	Yeraltı Mosque	1,3981
8	Kılıç Ali Paşa Mosque	1,3585
9	Surp Krikor Church	1,3421
10	French Gateway	1,1915
11	Aya Nikola Church	0,7098

By locating various urban elements on the map, the society-space relations can be analyzed. For this analysis, only major buildings or major urban spaces termed as 'principal elements of the city' occupying a predominant role in the city's history are documented.

It is seen that after the construction Tophane Square has the highest rank, followed by the Nusretiye Mosque which is also affected by the new project. Another significant aspect of the urban structure is remotely located also with the new project; the museum and Istanbul Modern building with a low integration value (Table 4). We can also see that the Galataport Project integration rank is low.

Measurement of intelligibility and synergy

The syntactic intelligibility of an urban system is defined as the degree of correlation between the connectivity and integration values in the system (Topçu & Kubat, 2007). Logically, this means that information about local connectivity in a highly intelligible layout allows a person moving through the system to understand the configuration's overall structure.

The area's low intelligibility shows that it is not comprehensible for city users, and it's not easy to find and walk through it. High intelligibility reveals the areas with higher global integration that are at the same time the city center with inner integration. An intelligible system in another word means well-connected spaces in an urban system. Mostly, economic activities and services in these areas would become denser in the long term.

According to the results of syntactic analysis, the spatial structure of the current map (0.3344) lacks structure and is found to be less intelligible when compared with the past (0.4044) which is more intelligible according to the value higher than the mean value (0.364). This means that the Galataport project will not be intelligible to users.

Synergy is similar to intelligibility. The correlation between the global integration value and local integration value describes the synergy of the city (Thilagam, 2015). Hillier suggests that this is a measure of how much the local street system is a reliable predictor of the global configuration (Dalton, 2010).

The synergy values for 1980 and current map is 0,4589, 0,4787 and the mean value 0,4688. High correlation is explained by two situations: first, according to Medeiros (2006), “to synergy, the larger the system, the smaller the value”; so, for a small system, the synergy value will be higher. Second, the regular orthogonal mesh results in a high convergence of global and local integration scales (Geremia, 2017).

6. Conclusion and Recommendations

In a conclusion, both morphological and land use findings were revealed, such as how the new physical structure of space will work and the impact of space on the urban fabric. With these findings, the impact of the project on the region and the coastal band can be seen and interpreted. It can be analyzed whether the new physical tissue that is formed will work as a coastal band integrated with the urban fabric, easily accessible and available to users as mentioned in the project.

It is believed that it will be helpful in new planned urban studies, especially for the reconstruction of the historical and cultural regions of the cities damaged by industrialization effects and accelerated cycles of urbanization. This is also an important system for new urban design projects. The author wanted to draw attention to the use of these approaches as input in new projects. It is believed that a comparative examination of the historical core conducted in this study would contribute to research on urban morphology, urban design, and urban planning.

As a recommendation, in this context;

- According to the report of the project, it is stated that the project will be an image of the city. But quantitative findings obtained from space syntax analyses showed that the area of the urban shoreline requires a coastal reorganization.
- Looking at the morphological character of the area, the prediction that the new spaces produced in the project do not have the effect of reinforcing the historical texture of the coast, the coastal location of the Square, and the public use of the coast are revealed. It is observed that cruise ships will dock on the 1.2 km coastal line, and this will cause a morphological formation that acts as a wall on the shore.
- The structures planned to replace the four existing warehouses as terminal buildings are larger in scale than the existing ones and are in a size that completely covers the

shoreline. This means the reproduction of physical tissue on the coast on a larger scale and the formation of a new morphological character in the city. It is seen that the physical texture of the port function, which is maintained on the coast, is an obstacle to both public use of the coastal line and the comprehensibility of the coast. By moving the port to another area, solutions can be provided to the problems of the region (such as access to the coast, perception of the sea, and the acquisition of a public dimension of the coast).

- Therefore, based on the historical maps examined, Henri Prost's proposal to move the port area from the coast in the city center to the Marmara coast should be considered in the next planning decisions.
- It is proposed that land use in this area should be regulated for recreational use after moving the port to another area.

As a recommendation for further studies; a certain area was analyzed as a result of morphological region analyses. But it is also possible to select a different study area boundary. The entire coastline of the Galata region which also contains the historical core can be re-worked as a focus area. Therefore, both the impact of the Project on the historical core and as well as the impact on the continuation of the coast will be determined in more detail. Secondly, Galataport is a completed project and the author would like to outline that in the renewal of Haydarpaşa Port or Haliçport Projects these inputs should be considered. In the context of globalization, the renewal of port sites should be planned with urban farsightedness, taking account of the needs of existing social roles, and approached in a format that supports each other without contradicting historical, cultural, or national values.

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Housing typologies from different markets and prices throughout Istanbul

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Abstract

During the last two decades, Istanbul experienced rapid growth due to national and international migration. In addition, multi-center development of the city, and construction of peripheral highways, bridges, and metro systems have affected the economic, cultural and physical structure of the city. The purpose of this paper is to illustrate the changes of the housing types and prices from the center to the periphery. While some of the fashionable neighborhoods lost their importance through time, some new neighborhoods became fashionable due to their modern buildings in the green areas. The great impact of Bosphorus and Marmara Sea shores amenities on the type and price of housing was emphasized. Economic development, globalization, restructuring and strategic locations have contributed to improve the quality of housing and to increase their prices. Due to increasing income gap, there is a widening difference between the types of low-income and upper-income housing.

Keywords: housing types, location, housing prices, restructuring, Istanbul

1. Introduction

During the last two decades, rapid growth of Istanbul, globalization, modern housing projects in the periphery, restoration of historical neighborhoods and restructuring of squatter areas resulted in a large spectrum of neighborhoods with different urban life characteristics in the city (Oruc et al., 2017). Globalization has provided construction with advanced technologies and international business services that enable a new way of working within an international framework. Because this process is based on advancing the global economy and is realized through the international market, the globalization of the architectural practice is sensitive to economic conditions (Stiglitz, 2002). In addition, the national and international migration changed not only the physical characteristics of urban structure but also their political, cultural, and social life of the city as well as its buildings and their prices (Jones and Leishman, 2006). It would be interesting to examine the nature and extent of the urban transformation with its corollary changes in demographic, economic, and social structures. It is possible to display the results of economic development, globalization, and changes in lifestyles by detailed spatial examination of the response of distinct housing markets within Istanbul (Keyder, 1999; Ozus et al, 2011; Islam and Sakizoglu, 2015; Oruc et al, 2017). The purpose of this paper is to illustrate the different housing types and their prices in these neighborhoods with different historical, economic, technological, cultural and social characteristics in order to see the re-shaping the geography of opportunities, in other words, place effects in global perspective as already illustrated by Briggs (2003).

There are several studies which study housing typologies in Istanbul. Bozdogan (2013) investigated residential architecture and urban landscape in Istanbul since 1950. This date is the

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preface of the intensive rural migration as well as the development of large squatters near the industrial sites which played an important role for shaping the landscape of the city and politics. Another comprehensive analysis was made by Gur and Yuksel (2019) about urban housing typologies in Istanbul starting from the most luxurious seashore mansions to the squatters as a large spectrum of housing types.

On the one hand, social polarization in Istanbul as gated towns as a result of globalization (Akgun and Baycan, 2011) and country-side mansions, on the other hand restoration of historical neighborhoods, providing lofts as housing (Ozker, 2014) and transformation of large squatter areas into high-rise housing complexes have enlarged the already existing large spectrum of housing segments in Istanbul. While high-status individuals who are strongly attached to the global economy and have benefitted from global integration prefer to live in gated towns (Genis, 2007), continuous rural migrants are obliged to work on low-paid jobs and can only afford to live in squatters.

Despite the large segments of housing in Istanbul, it is observed that smaller amount of housing segments was taken into consideration by the American authors, such as Chandler et al. (2010); the detached house, the row house and other low-rise housing, the mid-rise housing. Higher economic levels and the importance of individual life for the American people keep housing segments limited.

At the same time, economic and demographic changes play an important role on the housing typology which is produced. During the second half of the last century, in European countries housing was greatly subsidized by the governments until the post-modern period when subsidies were decreased. For instance, in Sweden, after 1960s, more multi-family housing was built than single family housing. However, after 1990s, only single-family housing was built to a smaller amount due to economic and demographic changes despite the population increase (Terner Center, 2017).

Differences between the spatial organization of modern urbanized societies in terms of the proportion of detached houses as against apartments are quite dramatic, especially between North America/Australasia and continental Europe. Seventy percent of dwellings in Greater Stockholm comprise apartments, compared only 22 percent in Greater Sydney. The overwhelming majority of dwellings in Australian cities are houses and moreover, detached houses, while the majority of dwellings in Swedish cities are apartments. In England, only 45 percent of Greater London are apartments and not similar to Swedish cities. The difference this makes to the socio-spatial organization of the cities, of these countries is profound, yet almost unsearched (Kemeny, 2001).

In the developing countries, similar to Istanbul, there is a large spectrum of types of housing due to wide income gap starting from villas, security apartments to squatters, such as in Mexico City (Gilbert and Varley, 2002), Rio de Janeiro (Pino, 1997), Sao Paulo, and Cairo (Harris and Wahba, 2002). This is a neglected research issue and there is need to do more research on this problem.

The organization of this paper is as follows: Background information is given about population and physical growth of Istanbul and its multi-center and transportation development in section two. In the third section, selected housing segments are given with different social, economic, aesthetic, technological, cultural and social background to show the wide income gap between the rich and the poor in the city as in other large cities of developing countries. The final section is devoted to a conclusion and suggestions for further research.

2. Background

Population growth and changes in demographic composition are important factors to effect demand for housing. While many cities in Europe and North America face urban decline (Alden, 1996), between 2010-2018, Istanbul's population grew from 13,255,685 to 15,029,231 due to national (Yazgı et al. 2014) and international migration (Toksoz, 2006) from different parts of the country as well as different parts of the World. This is a general trend for the third world large cities in the periphery of the world system (Lyman, 1992). In addition, the rise of living alone and the

number of small size families have contributed to fuel the demand for housing as in some of the other European countries (Ogden and Hall, 2000; Ogden and Schnoebelen, 2005). Both the population and its density are unequally distributed among the metropolitan region's 39 districts. At the same time, Istanbul is an old city whose long history has been reflected in its interesting spatial development with multi-cultures inherited from three empires. Population growth caused traffic congestions and thus stimulated suburbanization. Multi-center development of the city has contributed to decentralization of jobs and population with the help of construction of peripheral highways and bridges over the Bosphorus and metro system (Dokmeci and Berkoz, 1994). In order to answer to the housing demand as a result of population growth, large modern housing projects were built around multi-centers which display a new way of life as in the other post-modern cities (Clark and Kuijpers-Linde, 1994). Mass housing was greatly supported in this period of time. Gated towns were developed in the periphery of the city as a result of globalization impact (Baycan-Levent and Gulumser, 2007) which is also observed in other developing country cities such as Metro Manila (Shatkin, 2008), Santiago (Salcedo and Torres, 2004) and Beijing (Wu and Webber, 2004). Especially, during the post-modern period, the aesthetics, design and styles of consumption became increasingly diverse, as the marketplace became even more sophisticated as regards to what it knew and what it wanted to know about its consumers (Lee, 1993). Gentrification of the historical neighborhoods has contributed to improve the living quality of the building and their environment (Yetiskul and Demirel, 2018; Gur, 2015). In addition to planned housing areas, illegal housing was also developed by the low-income migrants on the government land. Planned and unplanned housing areas are the two main segments of the Istanbul housing areas. Planned housing areas represent 70% of the total whereas unplanned housing areas represent 30% of it (Alkay, 2008). Later, in order to improve the quality of housing and environment of squatter areas Transformation Law 6306 was implemented. This housing development process results in different types of housing in different neighborhoods with various economic, social and aesthetic characteristics (Oruc et al, 2017). As a result of globalization and economic development many shopping malls, entertainment places and fast-food restaurants were opened and spread throughout the city (Keyder,1999; Terzi et al., 2006; Ayatac, 2017).

Thus, the long-established high income and social disparities have been aggravated by the deterioration in conditions for the working poor and improvement in the wealth of the new rich, especially those associated with the partisan economy similar to other developing countries (Richardson and Bae, 2006). This situation has reflected in the spatial distribution of housing quality, form and style as a wide disparity between the high- and lower-income neighborhoods which is also increasing in the US (Dong, 2018).

3. Housing Types from Different Housing Markets in Istanbul

Housing market in Istanbul is very heterogeneous due to long history of the city, long seashore amenities, different cultures, dynamic topography, globalization and a wide gap of income distribution.

In Istanbul, the residential landscape was shaped by industrialization and migration forces and expressed the economic and demographic structure of the city developed under laissez faire approach to urban planning and housing production (Genis, 2007). Especially, during the recent government relaxing density regulations resulted in haphazard development in the third dimension caused terrible traffic congestions.

Data for this study is obtained from study by Dokmeci and Erdogan (2021) which is based on 840 neighborhoods in 36 districts and collected from internet advertisements in October 2018.

Although there are several housing segments in Istanbul, in this study, as a method, only eight housing segments are taken into consideration based on the study by Oruc et al., (2017): Sea-shore summer residences, hill-side mansions, city apartments, restored apartments, mass housing, gated towns, luxurious villas and farm housing, squatter and restructured squatter buildings in order to illustrate wide gap between the income and living conditions of different social groups. Underlying

each typology there will often be a thesis that explains how the types comprising the typology are generated and sustained.

The first group of housing segments consists of seashore summer residences along the Bosphorus shores (Dokmeci and Erdogan, 2021). Their high-quality design and antic quality increase their value. They were built during the Ottoman period by wealthy businessmen and administrators as summer resorts (Eldem, 1993; Koramaz and Dokmeci, 2008). Now, they are habited by the wealthy industrialists and oil riches of the Arab world. Their advertised prices are between 30- 150 million dollars.

The second group of housing segments consists of konaks (hill-side mansion) located on the hills of Bosphorus, on the Marmara Sea shores and, on the Princes, Islands. They are multi-storied, usually wooden historical buildings with high-quality design and antic value. While konaks have significantly diminished by the changing family structure from extended to core family type and for the sake of modern building comfort in the second half of the twentieth century (Karaosmanoglu, 1920), modernized and restored konaks have been preferred nowadays as Istanbul housing market has become open to the global markets. Their asked prices vary between 30 and 45 million dollars. They are preferred by the upper-income people also because they fulfill the conspicuous consumption characteristics of the post-modern lifestyle (Breitung, 2012).

The third group of housing segments consists of villas (Oruc et al, 2017) and recently 10+ rooms villas are mostly located on the Bosphorus as well as countryside mansions. They are higher-income residential units surrounded by green areas and they are isolated from the other residential areas with middle or lower income. Istanbul has a larger villa type housing market than its own capacity since the owners of the industries in the surrounding provinces prefer to live in Istanbul. Some of these villas was designed in order to express conspicuous consumption of new rich owners. On the other hand, some of them were especially designed with more than 10 rooms according to the social needs of Arab families with multi-wives.

The fourth group of housing segments consists of city apartment flats in modern style as observed in traditionally in Sisli and Nisantas and later in all the districts. In place of 1-2 storey traditional houses, multi-story apartment buildings were built to maximize rent of urban land at the expanse of increasing demand for urban facilities, infrastructure, transportation and social services from the local authorities (Gur and Yuksel, 2019). Their prices change according to their locations such as proximity to the Bosphorus had been the determining criterion of status distinction between middle- and upper-class apartments (Dokmeci et al., 1996). Location, view, size and especially living room size play an important role for their prices (Ozus, et al.,2007). Their sizes and the number of rooms were increased as also illustrated in the US (Altshuler, 2005).

The fifth group of housing segments consists of the revitalized neighborhoods in the historical districts and they have quite high housing prices, for instance in Beyoglu district, Gumussuyu and Cihangir neighborhoods due to having a strategic location in the center of the city, beautiful historical buildings, being near the Istiklal Street which is the most important shopping and entertainment area of Istanbul (Dokmeci and Ciraci, 1999; Dokmeci, et al., 2007; Ozus and Dokmeci, 2005; Ergun, 2004). It is interesting to note that restored historical apartment flats which are more expensive than the new flats with the same size in the same neighborhoods. They offer a new lifestyle enriched by the history, and culture of the higher-life style of new inhabitants (Uzun, 2013). However, some studies claim that gentrification increases the inequality in the neighborhoods (Lyons, 1996; Christafore, 2019) while some others argue that local contextualities render the gentrification process to have a relevant degree of place specify (Carpenter and Lees, 1995).

The contributions of historic preservation and restoration to housing and economic development were illustrated also in other countries (Liskotin et al., 1998).

Lofts are a recent trend to build at the top floor of apartments (historical or new) as doublex flats. Their prices are higher than the lower flats since they provide wider view than the surrounding buildings which is already illustrated by the previous studies (Ozus, et al., 2007).

The sixth group of housing segments consists of large housing projects which include all the necessary cultural facilities, swimming pools, tennis courts, shopping markets, restaurants and coffee shops. They have first started with the Italian architect, Prost's proposal in Atakoy, in the 1960s. After 1980s, the public and private sectors constructed large housing projects extensively at the metropolitan level to meet the shelter needs of high-density population. Although the prices of large housing projects change according to their location, they are mostly occupied by the upper middle class and middle class such as in Atakoy. The results of the study by Ozus et al., (2007) suggest that planned housing developments have higher apartment flat prices than the developments on a piecemeal base.

The seventh group of housing segments consists of gated towns. Starting in the 1980s, gated towns were the result of neo-liberal urbanism which has accompanied neo-liberal economic restructuring, seek to expand the role of market forces in the housing and real estate sectors, privatize the provision of urban and social services, and increase the role of elites in shaping urban landscape (Genis, 2007; Breitung, 2012). Inward investment of FDI becomes interested in not only cheap labor for manufacturing industries but also cheap land with a high potential for value increase. Developers wanted to produce community and lifestyles isolated from noise, pollution, and traffic congestion of the city for the upper-class families of Istanbul. However, cultural facilities, clubs swimming pools, and tennis courts socially nourish the development of community concept in these establishments, their isolation from the rest of the city may cause psychological problems in the future. In addition, homogenous socio-cultural profiles of gated towns is not only outcome of market forces, but also they are the results of careful design of traditional wealthy detached suburban housing identity such as in Fenerbahce and Erenkoy (Oruc, et al., 2017). This can be to protect traditional cultural pattern from the erosion of globalization.

The earlier examples of gated towns are so successful that they worked as a trendsetter in the market for many following their leaders (Genis, 2007) and they contributed urban fringe development. Thus, post-modern landscape of diffused urbanity has been made feasible and promoted by improvements in transport infrastructure and the development of high-technologies permitting electronic access to information, services and facilities (Gospodini, 2006).

The eighth housing segments consists of squatters which usually located in the periphery of the city and were built illegally by the urban poor and rural migrants, on the public land without any infrastructure (Tas and Lightfoot, 2005).

While the squatters were single level at the beginning, in the following period, they have transformed into apartkondus. The main reason is two-fold: to meet the spatial needs due to demographic increase of existing families; to gain extra income by renting the extra space. Some solidarity might have been obtained in the meantime so that at least the neighborhood has received the basic urban services (Gur and Yuksel, 2019).

Earlier main reason of migration was industrialization. During the last two decades, other reasons of high migration to Istanbul were the government policies to close down public factories in the Anatolia and to relax the restriction of importation of agricultural products which caused unemployment in the countryside (Yazgi et al., 2014; Koramaz, et al., 2017).

Although earlier squatters consist of homogenous social characteristics, in the 1970s, declining wages of working classes and government employees resulted in heterogeneous squatter areas (Erder, 1996). In 2012, development of high-rise residences in the squatter areas at the strategic locations with easy access to transportation arteries and job locations, according to the implication of Transformation Law No. 6306 income and cultural gap was increased among the different social groups as well traffic congestions since density increase was not calculated by taking into consideration road capacity in their surroundings. Maximum benefits of the entrepreneurs were the primary purpose of the government for these projects (Kuyucu and Unsal, 2010). Finally, public participation should be taken into consideration for the success of these development projects.

Thus, the review of different housing segments reveal that their production are decided mainly not according to the housing need of different income groups but to maximize the profits of the entrepreneurs. Even in the case of public-private partnerships, the real housing need of the community stays unanswered. While low-rise residential buildings are preferred in the countries which have earth-quake risk, such as Japan and California, US, high-rise residential buildings are built even in the transformation areas of the squatter areas in Istanbul for the seek of profits despite the earth-quake risk of these zones. In addition, transformation cannot be a solution to lower income housing without solving their economic problems, since the squatters simply will be relocated to another area which is prone to become another squatter area. Also, haphazard development of metropolitan areas resulted in unsolvable traffic problems which is an economic burden to people as well as to the economy. Many researchers suggest (O' Regan and Quigley, 1996; Quigley, 1998) that crime and victimization increases with urban scale. Finally, without making plans at the metropolitan and country level for the better distribution of population, under the pressure of global forces and income inequality, housing problems cannot be solved at the metropolitan level which are beyond the economic capacity of developing countries (Sassen, 1994). Moreover, there is need to decrease income inequality in order to have more integrated and socially healthy cities.

4. Conclusion

During the post-modern era, integration with the world economy resulted in social polarization and polarization of income and thus a large spectrum of housing segments. Following this trend, population growth due to government policies which encouraged migration, economic development and globalization fueled demand for housing as well as types of housing varies according to the increasing multi-cultural characteristics of the city. In Istanbul, the number of housing segments is increasing while expanding through changing actors in the urban market, restoration, revitalization, easing density restrictions and planning regulations as well as transformation policies. The restless urban landscape is the result of migration, economic, socio-cultural and technological change and the transformation of the metropolitan Istanbul.

Great differences in the housing types exist between neighborhoods due to historical and socio-economic conditions, seashore amenities, real estate prices, provision of services and facilities, dynamic topography differences and unbalanced provision of transportation systems. As the income, education and cultural gap increases, housing segments variety increase also. Especially, its strategic location contributes to enlarge the type of housing demand at the international level.

The present study investigates the different types of housing taken from different housing segments. Although there are several housing segments in Istanbul developed throughout the history according to the changing socio-economic conditions, culture and demand of people and policies of the governments, here, only eight segments were chosen. Analysis start with the most luxurious sea shore residences, continues with historical konaks, 10+ room villas or country mansions, city apartments, restored apartments, large housing modern complexes, gated towns and squatter housing. The results of the analysis reveal that there is tremendous differences between the top and lower quality housing segments which reflects the large difference between the income, education and culture of the housing groups.

The review of the spatial distribution of housing types reveals that geographically the most luxurious housing locations were on the Bosphorous Sea Shores which benefit from seashore amenities associated with existing upper income neighborhoods, near the new CBD of the city and traditional beautiful housing as it is also illustrated by Bitter (2014) in the US. Low-quality housing is located in the transition zone and in the squatter areas in the periphery of the city.

As a new trend, 10+ room villas are mushrooming as a result of desire of nouveau rich family's conspicuous consumption as well as in order to answer to the need of oil rich Arab families with many wives. They are mostly located on the hills of Bosphourus or as country mansions in the periphery of the city near the forests with sea or lake view.

Lofts are another new concept which take place at the top of the apartment buildings, as dublex flats with wider view and high prices. They can be found even in the squatter areas since the owners hope to charge higher prices than their vicinity.

Large modern housing projects represent another group of housing segment which are stimulated by the multi-center development of the city as well as they contribute to the development of these sub-centers. Residences are mostly upper- or middle-income people. They offer all the necessary cultural and shopping facilities, services and transportation required by the modern urban spaces and globalization. They usually provide well-kept landscape amenities for the residences.

Restored historical apartments represent another group of housing segment which are preferred by the wealthy families as a result of post-modern movement in the urban development and revitalization of the historical neighborhoods which offer more entertainment and social activities than modern neighborhoods. At the same time, this trend can serve the preservation of the historical atmosphere of the old neighborhoods.

Under the influence of globalization, although gated towns provide all the luxury with respect to building comfort, necessary facilities and services and environmental amenities as well as security for upper class families, they are isolated from the city's social life. It is already illustrated by the previous studies that this isolation can be the cause of certain psychological problems in the future.

Despite the enormous support of the government for the transformation of the squatter areas by implementing the Transformation Law, the results were mostly for the benefits of the entrepreneurs rather than their inhabitants. Although better quality buildings were built in the squatter areas based on this law, their residents were obliged for relocation since they cannot keep up with their continuous expenses and despite nothing is done to improve their low-income status.

The results of the study can contribute to investigate the urban dynamics, landscape transformations, density and morphology of the city. They help to understand the emerging housing markets and the development of the metropolitan structure. Finally, the results can be useful for the urban planners, architects, sociologists, realtors, entrepreneurs and policy makers. To analyze the urban impact of haphazard development of different housing segments and to solve the socio-economic, political and traffic problems caused by them are left for further research.

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Resume

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Dynamic analysis of Istanbul office markets with highest demand and office rent

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Vedia Dökmeci**

Abstract

From the 1980s onwards, restructuring of economy and globalization has increased the size and number of companies in Istanbul and demand for modern office space which cannot be provided in the old CBD due to construction restrictions. Thus, multi-center development has started in the city in order to answer to the growing demand for modern office markets. The present study investigated the growth and decline of office rents in office markets which have highest demand and office rents. According to the results of the study, while office rents in the office markets with growth potential have increased, that of the markets with supply increased dramatically between 2011 and 2016. On the other hand, while office rents in all of the office markets were sharply declined in 2021 due to devaluation of Turkish Lira against USD. Although the pandemic has made Work from Home (WFH) and Hybrid working models a global trend, A class office demand stayed strong due to well-being requirements on office area. Thus, it is expected to have a positive impact on the economy of the city.

Keywords: Istanbul office market, Turkiye economy, rent analysis

1. Introduction

After 1980's, post-modern urban planning trends stimulated multi-center developments in large metropolitan cities throughout the World. Following this trend, Istanbul's urban structure was transformed from monocentric (Dokmeci and Ciraci, 1988) to a polycentric form as a result of rapid population growth (Dokmeci and Terzi, 2008), globalization (Dokmeci and Ciraci, 1999), being in a strategic location, economic restructuring and development of transportation and communication systems, change in lifestyles between 1960-1990 (Dokmeci and Berkoz, 1994; Dokmeci, 1996; Dokmeci and Berkoz, 1996). This situation has been already investigated by several studies such as by taking into consideration the spatial distribution of shopping malls (Ertekin et al., 2008), banks (Dokmeci and Evcil, 1995), hotels (Dokmeci and Balta, 1999), spatial distribution of physicians' offices (Dokmeci, 2002) and public and private hospitals etc. in Istanbul. The purpose of the present study is to illustrate the growth and decline of office rents in the office markets with highest demand and highest office rents.

There are several studies which investigated the changes in office rents with respect to location and building characteristics. One of them is given by Gloscock et al. (1990) which illustrates that rents vary across classes of buildings and also change according to geographical locations. Mills (2002) analyzed Chicago office market by using 543 observations included most of the market's larger buildings. He found that the rent price per square foot varies positively with building size, location and nearby amenities. Bollinger et al. (1998) applied office rent models by using data from

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Atlanta that span the years 1990-1996. As a result, they found that variables measuring locational differences in wage rates, transport rates and proximity to concentrations of support services and office workers play an important role in explaining spatial variation in office rents. Mourouzi-Sivitanidou (2002) investigated office rents across 18 office markets during 1986-1995. The empirical results reveal office employment factors, construction cost interest rates amenities and zoning in shaping inter-area differences in the equilibrium components of office rents. Dunse and Jones (1998) showed in their study that age and location as principal determinants of office rents in the city of Glasgow. According to the results of the study by Koster et al. (2014) Dutch firms are willing to pay an average about 4% more for a building that is 10 m taller, implying a substantial Premium associated with tall buildings.

Nagai et al. (2000) investigated the rental office market in the Tokyo CBD for the 1985-1994 fiscal years. They found that the characteristics related to transportation conveniences are less effective in explaining office rents than the characteristics related to the agglomeration of offices and the amenities of the office buildings themselves.

The review of the studies on office rents reveals that while there are extensive amount of studies in the developed countries, there are only few in the developing ones. One of the earlier studies on the subject is given by Dokmeci et al. (2000) on office rents distribution in Istanbul. According to their results, the growing companies which cannot find sufficient space in the old CBD, they establish themselves in Maslak which has good connection to the Airport, to the suburbs and to the industrial sites. Therefore, it had the highest office rent at that time. In a further study, Oven and Pekdemir (2006) proposed a factor analysis model to investigate the office rent determinants in Istanbul. Later, Ozus (2009) proposed a hedonic price model for the analysis. The results of the study illustrate that number of floors of the buildings, vacancy rate in the vicinity, social facilities in the buildings, aesthetics of the buildings, rental office floor, banks in the vicinity, and accessibility are the most important characteristics to affect the office rents. After the 1980s, globalization, economic restructuring, economic growth of the country and locational advantage between Europe and Asia played an important role in demand increase for office market in Istanbul (Berkoz and Turk, 2010).

Since the previous work does not investigate the changes in office price in Istanbul through time, the present paper analyses the changes in office rents in the offices markets with highest office rents and highest demand in Istanbul through time. The organization of the paper is as follows. Background information about office markets is given in the second section; changes in the office rents through time in major office markets with highest demand and office rents; and final section is devoted to a conclusion and suggestions for future research.

2. Turkiye Economic Overview

The Turkish economy is the 21st largest economy in the world and the 11th largest by GDP at PPP in the world with 802 billion USD according to recent data published in 2021.

In the era of COVID-19 pandemic, partial rebound in the economy has started to be recorded in the last quarter of 2020 in line with the increase in retail sales, industrial production and credit payments whereas consumer sentiment remains cautious. In 2021 GDP growth was recorded as 11% y/y. According to the latest data, GDP realized $802 billion and $9,539 per capita.

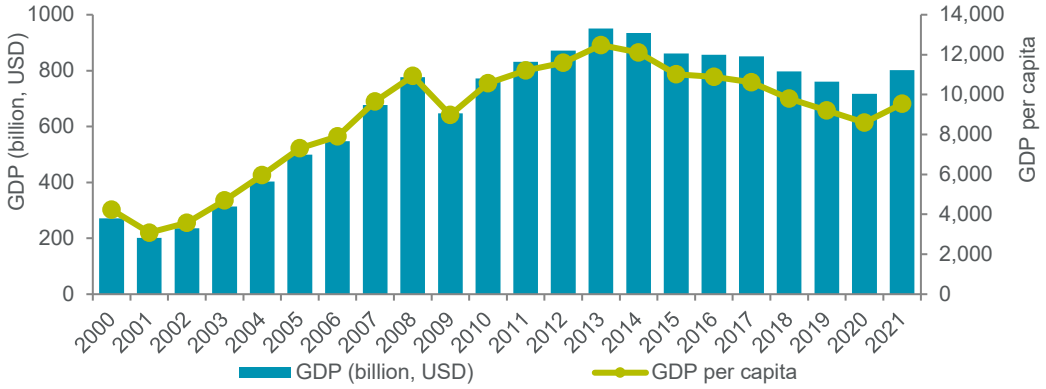

Figure 1 Turkish GDP and GDP Per Capita (TURKSTAT, 2022 (The data is based on 2009 series))

Following the CPI inflation hike starting from the second half of 2018, which fluctuated within a band of 17.9% – 25.24%, headline inflation rate sharply fell to its lowest rate in almost three years and recorded at single digit level, 9.26% in September 2019, for the first time since July 2017. However, inflation re-accelerated and recording double digit levels again at 11.84% by the end of 2019. Starting from 2020, inflation level was recorded in the level of 11.0% - 12.0%. In 2021, inflation exceeded the 15-18% band recorded in the first half of the year and remained in the 19-36% band in the second half of the year. At the end of 2021, inflation increased above the seasonal trends with the negative impact of the pandemic on the economy and fluctuation in FX; was recorded as 36.08%. In line with the forecasts, it is expected to decrease and remain again at double-digit levels in 2022. The annual D-PPI also rose throughout 2021 in parallel with the CPI and was recorded as 79.89% at the end of 2021, with a significant increase compared to the same period of the previous year.

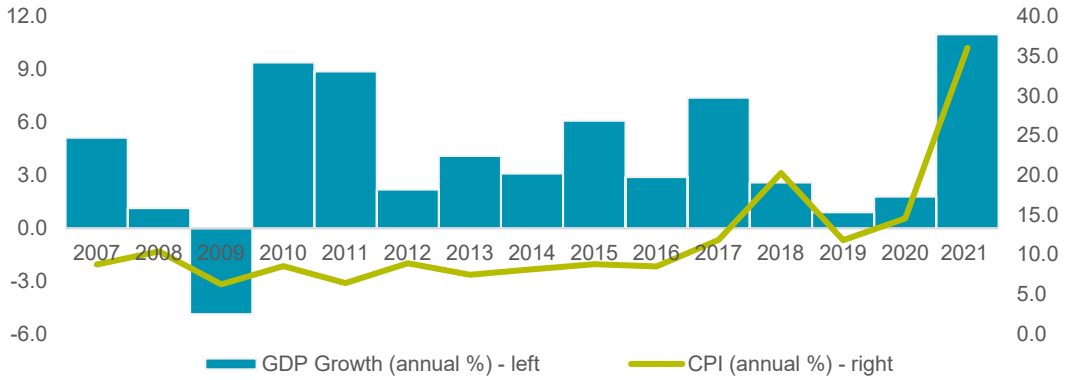

Figure 2 GDP and CPI (inflation) Growth, TURKSTAT, 2022

The unemployment rate fluctuated around 10% in the last decade, with an exception in 2008 and 2009 where it increased to around 12% as a result of the economic slowdown. A declining trend observed in the following periods. However, the unemployment rate started to increase especially in the second half of 2014 and kept increasing. Seasonally adjusted unemployment increased to 13.1% and 13% by the end of 2019 and 2020, respectively. In 2021, the unemployment rate indicated a decrease starting from the second half of the year comparing the first half by removal of Covid-19 restrictions in the third quarter and recorded as the lowest rate in 2 years. The seasonally adjusted unemployment rate slightly decreased to 11.4% in November and closed up with 11.2% in December 2021. According to the recent data unemployment rate is 12.0% for 2021. Yet, it is expected to decrease by year end and Moody's Analytics forecast for unemployment rate are respectively 10.71% and 10.27% for 2022 and 2023.

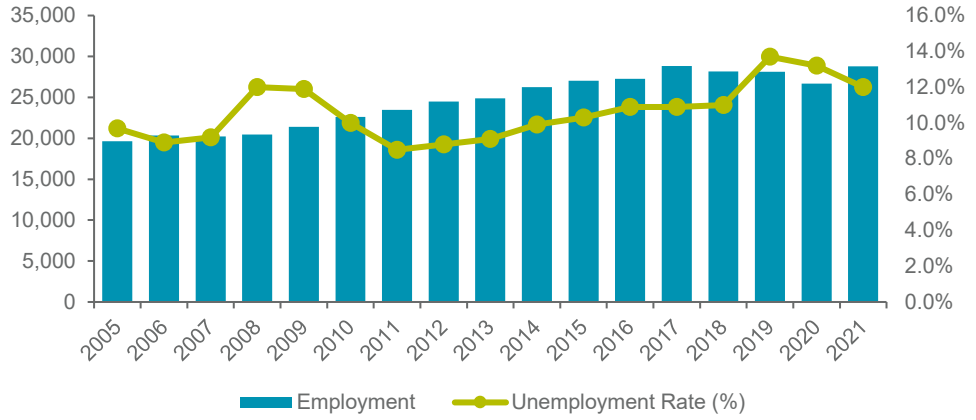

Figure 3 Employment (2005-2021) TURKSTAT, 2022

As end of 2021, total foreign trade volume reached USD 496.7 billion, which was USD 398.2 billion in year before. Turkey's exports increased to USD 225.3 billion by the end of the year in 2021 due to the effect of the reduction of pandemic concerns and the initiation of vaccination. Import trade volume reached at USD 271.4 billion while the proportion of import to cover export was 83.0% in 2021. In addition, Turkey's foreign trade deficit was recorded as USD 46.1 billion with a decrease of 7.5% compared to previous year. After the increase in export and import trade volume recorded in 2021, export trade volume increased by 32.8%, while imports increased by 23.6% in 2021.

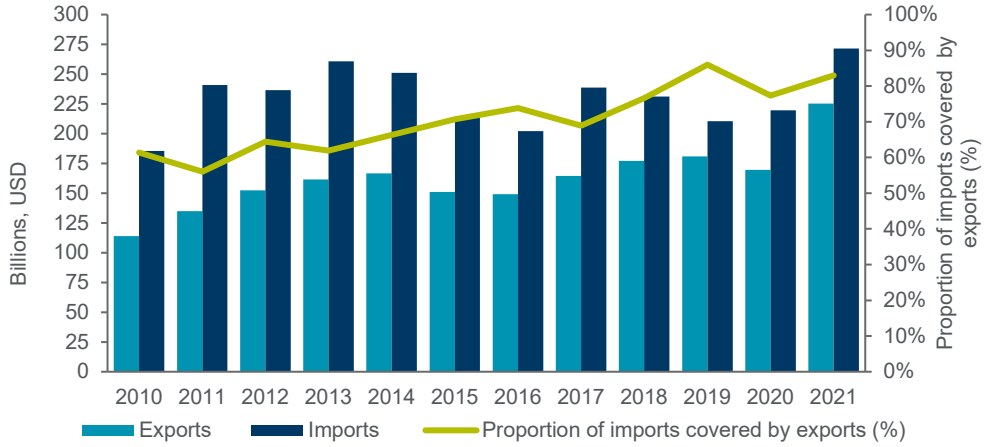

Figure 4 Foreign Trade (2010-2021), TURKSTAT, 2022

Net foreign direct investments, which have exhibited a weak performance since 2011, performed better during 2015. However, foreign direct investment recorded a decline in 2017 and 2019, total FDI inflow reached USD 9.57 billion with a decrease of 23.5% compared to the year before. By the end of 2021, foreign direct investment was limited to 7.8 billion with a decrease of 18.2% compared to the previous year. Real estate share of foreign direct investment in 2020 is 50.5%. Moreover, recovery has been observed on foreign direct investment increased by 80.7% in 2021 and recorded as USD 14.1 billion. Real estate share of foreign direct investment in 2021 is 40.8% with a value of USD 5.8 billion, while the share of real estate investment decreased 19.2% compared to the year before.

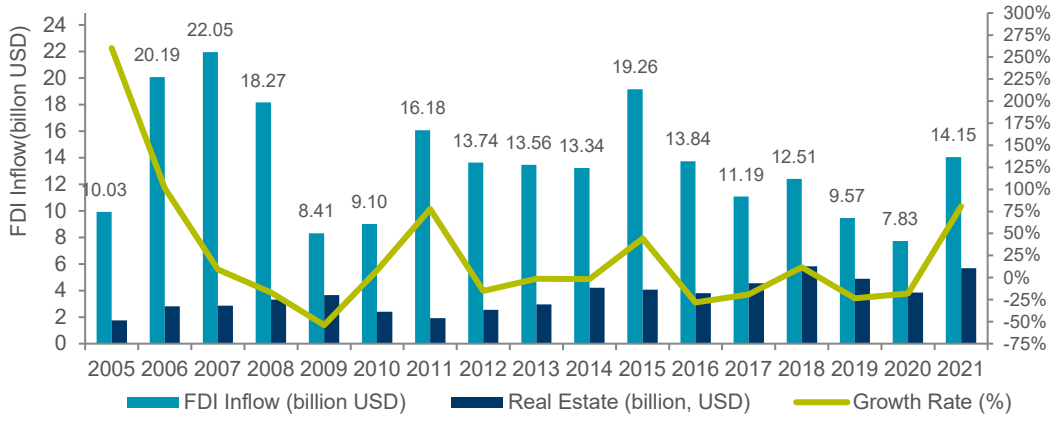

Figure 5 Foreign Direct Investment (2005-2021), Economy of Trade, 2022

The CBRT (Central Bank of the Republic of Turkey) has adopted a floating FX rate regime with the primary objective of achieving price stability, after the 2001 banking crisis in Turkey. It is observed that exchange rates increased gradually reacting to change in domestic and global markets, however a declining trend followed each time after a significant increase. Since the beginning of 2016, unexpected period of political uncertainty has intensified the downward pressure on the exchange rate. As of second quarter of 2018, Turkish currency has collapsed and highly devaluated depending on the many reasons such as the deterioration of political relations with US government, increase of the risk perception towards developing countries, the US Central Bank Fed's interest rate hikes and slowdown of the international capital flows. Indeed, the Turkish Lira depreciated by around 40% against USD and 34% against the EUR from the date of December 2017 to December 2018. The exchange rate remained to accelerate in 2019. Starting from 2020, FX continued to increase, and USD/TRY recorded at 7.20 in Q3 2020, while it was accelerated to 7.86 in Q4 2020. 2020-year average of USD/TRY and EUR/TRY recorded at 7.00 and 8.03, respectively, while Turkish Lira depreciated by around 30% against USD and 43% against EUR from the date of December 2019 to December 2020. At the beginning of 2021, USD/TRY was recorded at 7.38 with a slight decrease in Q1, after that USD/TRY begin rising accelerated again recorded at 8.38 in Q2. In Q3, it was recorded as 8.54 on average and continued its upward trend. USD/TRY rose sharply in the last quarter of the year and tested 18.38 in December. After the government announced a new financial system called "Foreign Exchange-Protected Turkish Lira Deposit", the Turkish Liras gained value against USD and the average of Q4 was recorded as 11.08. Thus, in 2021 average USD/TRY was recorded as 8.90. At the beginning of 2022, USD/TRY continued to upward trend.

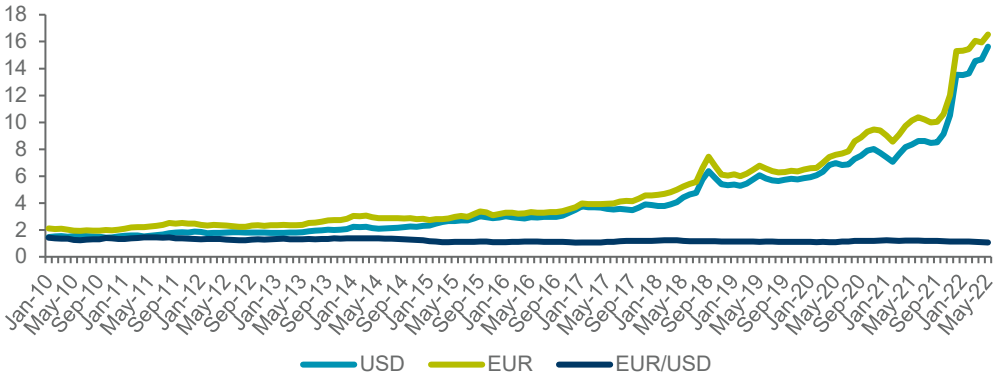

Figure 6 Exchange Rates (2010-2021), CBRT, 2022

Starting from 2014, the CBRT had decided to implement necessary measures at its disposal to contain the negative impact of these developments on inflation and macroeconomic stability. In this respect, policy rate has been decreased gradually from 10% to 7.50% between 2014 January to 2015 February and the same rate continues to October 2016. CBRT raised the upper bound of the interest rate corridor and late liquidity window lending rate in first nine months of 2017 and

increased from 8% to 24% from 2018 May to 2018 September and keep unchanged until the end of June 2019. As of July 2019, the policy rate has been gradually decreased to 19.75% in July and August, 16.5% in September and 14% in October 2019. The CBRT pressed on with its easing cycle in May 2020 delivering a ninth straight cut in order to support the post-pandemic recovery, bringing the policy rate down to 8.25% in May 2020, while it is increased to 10.25% in September, then 15.0% in November 2020 to ensure a stronger real rates buffer. Furthermore, the CBRT sharply hiked the policy rate by 200 basis points to 17.0% in December 2020, within the aim of cooling the inflation. The CBRT increased the policy rate from 17% to 19% in March 2021, and this rate remained stable until the end of September. Afterwards, the interest rate cuts were made 4 times as of September, and the interest rate was reduced to 14% in December. Until August 2022, the interest rate was held constant at 14%.

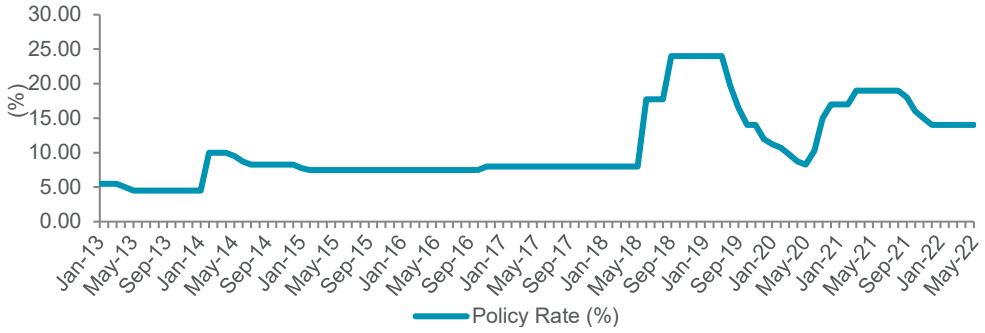

Figure 7 Policy Rate CBRT, 2022

Starting from January 2021, the method used in the business tendency surveys for determining enterprises to apply the surveys has been updated. Economic confidence index increased to 96.7, amid increase in confidence among service providers 121.7 from 114.7 and retail trade 121.5 from 119.4 m/m in May 2022. Only construction confidence index decreased 81.7 from 83.45 m/m in May 2022. Furthermore, confidence among consumers increased to 67.6 from 67.3 m/m in May 2022. The economy is likely to observe some rebound in 2022 along with the expected improvement in external position within partial recovery in foreign trade and tourism revenue.

The historical trends in sectoral, consumer and real sector confidence index are indicated below:

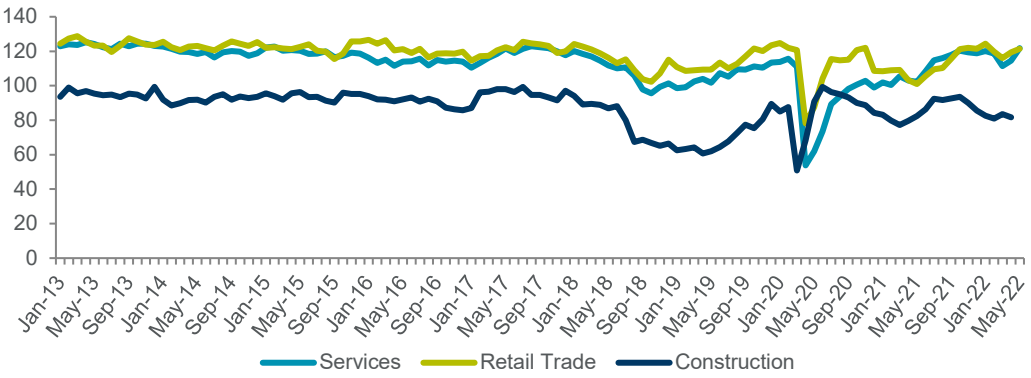

Figure 8 Sectoral Confidence Index, TURKSTAT, 2022

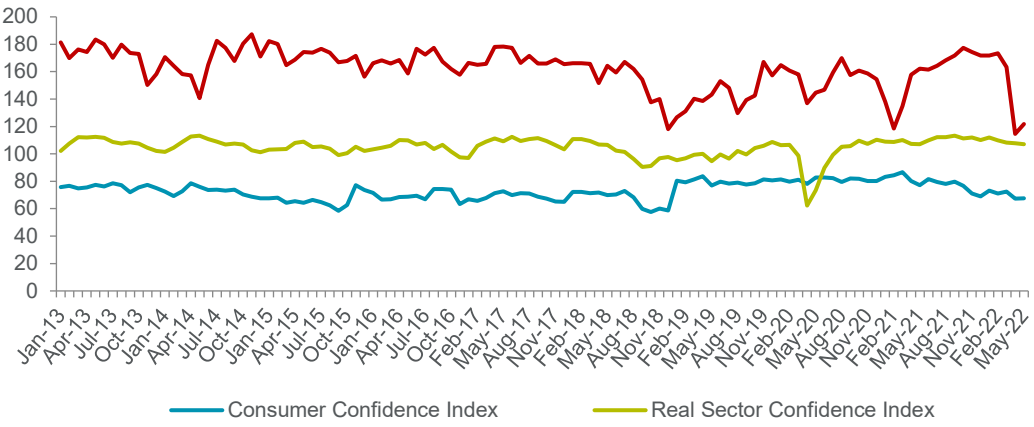

Figure 9 Consumer / Real Sector Confidence Index, TURKSTAT and CBRT, 2022

The table below shows the economic summary of Turkey, with forecasted indicators.

Table 1 Economic Summary, TURKSTAT and CBRT, 2022 F: Forecast Source: Moody's Analytics

Economic Indicators	2017	2018	2019	2020	2021	2022F	2023F
GDP Growth (y/y, %)	7.4	2.6	0.9	1.8	11	3.5	4.0
FDI (y/y, %)	-20.3	17.3	-30.5	-16.2	-12.1	-	-
Fixed Investment (y/y, %)	8.3	-0.3	-12.4	7.2	7.2	0.23	2.02
Industrial Production (y/y, %)	8.7	1.6	-0.6	1.6	17	8.34	2.71
Unemployment Rate (%)	9.9	12.7	13.1	13.2	12.2	10.7	10.3
Consumer Price Index (y/y, %)	11.9	20.3	11.8	14.6	36.08	68.04	20.31
€: ₺ (Average)	4.14	5.69	6.31	8.04	10.49	17.51	21.83
$: ₺ (Average)	3.64	4.84	5.66	7.02	8.90	15.80	18.07
Monetary Policy Rates (Average)	8	15.5	20.6	10.2	17.6	13.97	12.9
Interest Rates: 10-year (%)	11.1	15.9	15.8	12.8	17.1	25.13	19.90

3. Background

Istanbul population grew from 8 to 16 million between 2000-2020 by being the major destination of migration (Yazgi et al. 2014; Koramaz and Dokmeci, 2020) and being the most important business, education, and cultural center of the country. This result in population and employment growth of the peripheral districts and the multi-center development of its structure (Dokmeci, 2009) and on the other hand, the decline of the old ones due to their old structure which are not convenient for the new businesses requirements with respect to lack of space and lack of quality of buildings and construction restrictions (Dokmeci and Ozus, 2005). Afterword, although some revitalization projects were implemented to deal with this problem, they were successful to some extend (Ozus et al., 2011) but they could not provide space for large scale modern office buildings due to conservation restrictions in the historical centers (Dokmeci et al., 2007 Arslanlı et al., 2017). Thus, this results in multi-center development in the North and in the periphery of the city. Their optimum number and location were investigated by Dokmeci (1996) in another study.

After 1980s, economic restructuring, increase in service sector as in other countries, development of transportation and communications systems and globalization which all played an important role for the development of office markets in Istanbul as in other large cities of the World

(Ozus, 2009). Increase in the amount of foreign investment due to restructuring of regulations for foreign investments also played an important role for the development of office markets. In addition, Istanbul's strategic location between Asia and Europe has contributed to the growth of its office markets (Dokmeci and Berkoz, 1994; Berkoz and Eyupoglu, 2007; Berkoz and Turk, 2010). Finally, total office area reached to 6.474.381 m^2 as of beginning 2022 while it was 3,2 million m^2 as of 2012.

With the increase of supply, the average vacancy rate reached 10% as of Q4 2014 and it reached to 26% as maximum in 2019 in overall Istanbul. New development activities have slowed down and vacant areas have been absorbed during the period, current vacancy rate is 21% in 2022.

After the construction of the Bosporus bridge in 1975, Sisli, which has relatively more modern buildings than Beyoglu(old business center) became the most important office market between 1975 and 2000. Later, as a result of economic development and globalization, there was need for larger and more modern office buildings which resulted in further development of office market toward the North in Levent area. Now, between Levent and Maslak area is the backbone of the major business area of Istanbul. Majority of the headquarters of prestigious banks, and well-known industrial companies, research and development, advertisement, real estate and insurance companies, shopping malls and hotels are congregated in this axis supported by the modern housing projects in nearby. As an extension of this business axis, new office markets were developed such as in the European side, Gayrettepe/Zincirlikuyu, Barbaros and Kagıthane/Cendere; in the Asian side, Atasehir, Kozyatagi, Altunizade, Kavacik and Umraniye as the most demanded and with the highest rent office markets.

In 2018, due to devaluation of Turkish Lira against foreign currency, foreign currency use in rental contracts has banned by law. Moreover, recent dollar crises caused the decline of office rent in USD basis to the lowest level during the last 15 years. On the other hand, this situation has stimulated heavily occupier demand by local and international firms in this market areas.

4. Dynamism of Office Markets with Highest Demand and Rents between 2011-2021.

From the 1980s onwards, restructuring of economy and globalization has increased the number and size of companies and demand for office space accordingly. Indeed, Istanbul has become an attractive location for the international business firms due to its strategic location between Europe and Asia. Since the old CBD did not have sufficient space for the modern office buildings, they were established themselves in different locations as a leapfrog of the old CBD or a new sub-center. Each location has different office rent and the reason of difference is investigated by a previous study by Ozus (2009). The present study investigates the changes in office rents between 2011 and 2021 in different locations with highest demand and with highest rent price in Istanbul through time (Table-2).

Table 2 Istanbul Prime Office Areas Unit Rent 2011-2021($/m2) (Cushman&Wakefield, 2022)

	2011	2016	2021
Levent	38	41	22
Gayretepe/Zincirlikuyu	32	27	12
Kağıthane/Cendere	-	-	10
Barbaros	29	22	-
Maslak	24	28	13
Airport	13.5	14	8
Kozyatağı	20	26	16
Altunizade	21	23	12
Kavacik	19	17	10
Umraniye	20	21	12

Table 3 Istanbul Office Market Summary (Cushman&Wakefield, 2022)

	2019	2020	2021	2022 q1
Supply (sq.m)	6,46	6,46	6,46	6,46
Vacancy (%)	24.8	22.7	21.5	20.0
Take-up (sq.m)	316,000	329,000	304,507	123,424
Prime Rent (CBD, sq.m/mo)	$32	$25	$22	$23
Prime Rent (CBD, sq.m/mo)	₺170	₺170	₺240	₺320
Prime Yield (CBD, %)	7.75	7.75	7.75	7.75

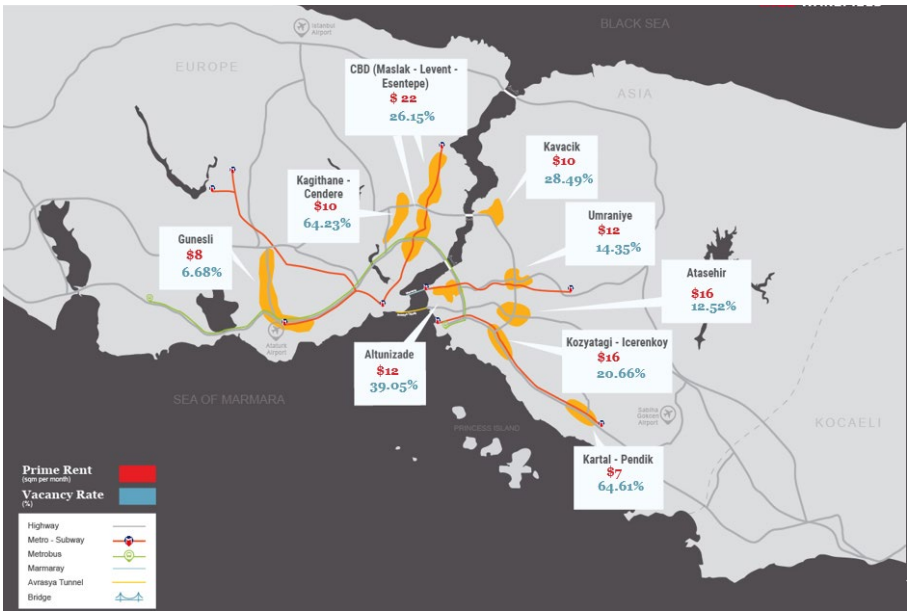

Figure 10 Istanbul Prime Office Areas Map- Rent and Vacancy Rates (Cushman&Wakefield 2021)

Levent office market is the most important office area in Istanbul. Levent office market was developed in the 2000s, as an extension of Sisli business center which was the major office market of Istanbul between 1975-2000 (Dokmeci, 2009). Industrial buildings owned by the major companies were transformed into office buildings by these firms or office developers. Currently, Levent has the highest office rent and is the most demanded office market in which office rent was increased from $38/m^2 in 2011 to $41/m^2 in 2016 while it decreased to $22/m^2 in 2021 due to dollar crises (Cushman & Wakefield, 2021). The reason for the highest demand for this area is the existence of large, modern and prestigious office buildings and easy access to the airport and other centers.

While Gayrettepe/Zincirlikuyu Office market had the second highest office rent price ($32/m^2) in 2011 due to recently built modern office buildings, its price decreased to $27/m^2 in 2016 due to limitations of expansions. Finally, its price was decreased to $12/m^2 due to dollar crises in 2021. Although Barbaros Avenue had the third office rent price ($29/m^2) with its modern office buildings and easy accessibility in 2011, its rent price was decreased to $22/m^2 in 2016 due to construction restrictions.

Maslak had the fourth office rent price ($24/m^2) in 2011, it increased to the second place ($ 28/m^2 in 2016 due to its highest demand and constantly development of new modern office buildings with locational advantages such as being in front of a well-known university and easy access to the airport. As a result of dollar crises its office rent price decreased to a third place ($13/m^2) in 2021.

Altunizade office market started to develop in the 1980s as a leapfrog expansion of the European side CBD to the Anatolian side after the construction of Bosporus Bridge in 1975. In 2011, its office rent price ($23/m^2) was the fifth one due to height limitations in this zone. Its office price increased to $23/m^2 in 2016 due to increasing demand for office space in the Anatolian side and easy accessibility of its location. Its office rent price decreased to $12/m^2 due to dollar crises 2021.

Kozyatağı started to develop in the 1980s as a result of construction of a new town (Ataşehir) with 100,000 population together with two large shopping centers, offices, hospitals and hotels. Its office rent price ($20/m^2) was sixth one in 2011. Its office rent price increased to $26m^2 in 2016 due to high demand for offices in the Anatolian side and its high accessibility at the intersections of highways. Although its office rent decreased to $16/m2 due to dollar crises, it increased to the second place in ranking in 2021 among the highest priced office markets.

After 1960s, Umraniye has started to develop as a squatter settlement nearby an industrial site. After the construction of peripheral highways, its population growth was increased by being at the intersection of these highways and by having easy accessibility to different sites of the city. These advantages have contributed to its formation as a sub-center in the Anatolian side. Its office market was increased as a leapfrog expansion of the European side office market area. Its office rent was increased from $20/m^2 in 2011 to $21/m^2 in 2016 due to its higher accessibility to the different parts of the city. However, its office rent decreased to $12/m^2 due to dollar crises in 2021.

Kavacik office market was developed as a leapfrog expansion of Maslak Office market area to the Anatolian side of the city. Although Kavacik was originally a squatter area, construction of the second bridge and the peripheral highways stimulated its growth highly demanded as office market area. However, while its office rent was $19/m^2 in 2011, it decreased to $17/m^2 in 2016 due to lack of appropriate urban structure. Furthermore, office rent was decreased to $10/m^2 in 2021 due to dollar crises.

Airport office market serves especially textile, communication and international companies (Ozus, 2009). It could not be developed much due to height restrictions. Its office rent was $13.5 /m^2 in 2011 and it increased to $14/m^2 in 2016. This price was reduced to $8/m^2 due to dollar crises in 2021, which is the lowest among those considered. With the closure of the Ataturk Airport in 2019, the occupier profile of the region is expected to be changed in the future.

Cendere/Kağıthane office market area is a new development as an extension of Maslak office market toward the West. Its office rent was $10/m^2 in 2021.

Thus, the results of the study illustrate that while office rents decline in the office markets without growth potential between 2011-2016, office rents increase in the office markets with growth potential such as in Maslak and Kozyatagi.

Although these are the highest demand and highest rent price office markets, their trend is the lowest if we take into consideration their situation during the last fifteen years. Thus, this situation stimulates heavily local and international companies to occupy in these markets.

5. Conclusion

During the post-modern era, the number of office buildings increased as a result of restructuring of economy, globalization and growth of service sector in Istanbul which is the largest and the most important socio-economic and the cultural center of the country. Moreover, development of transportation systems in order to answer to the increasing traffic needs contributed to the decentralization of CBD activities resulted in multi-center development of the city. In addition, improving telecommunication systems has also contributed to this trend as in many other countries. Development of these new office markets has great impact on the distribution of demand for office space and office rents. Thus, in this study, the trend of office markets with the highest demand and rent price are investigated in Istanbul between 2011and 2021. Each sub-center has different locational and transportation characteristics. New sub-centers provided opportunity

to be built large and modern office buildings with necessary infrastructure with international standards. However, haphazard development of some of the office markets are not functionally and physically efficient. Thus, they are evaluated under their real estate value. In addition, it is observed that the office rents of markets in strategic locations with growth potential have increased between 2011 and 2016, on the other hand the ones which does not have it they decreased during the same period. Although Altunizade and Umraniye are in strategic locations, but their office rents are not increasing much due to building height restrictions, and by having squatter background. Atasehir where white collar workers prefer to live hosts under construction Istanbul International Finance Center (IIFC) Project with 1,5million m^2 leasable area will enter the office market by end of 2022 of which at least 50% are expected to be occupied by state banks and financial authorities.

Therefore, there is desperate need for planned development of new office markets sub-centers in order to prevent transportation congestions, to create life quality, to use efficiently land potential and to protect their real estate values. In terms of the future development of office market in Istanbul, the location of the new sub-centers should be determined by using comprehensive research methods, not only for the benefits of the private sectors as it is today, but also for the economic benefits of the city. Otherwise, in the free market economy, private investor would use the land for the sole purpose to get maximum net return over a period of time but creating almost unmanageable problems for generations to come.

After Covid 19, stay at home restrictions accelerated remote working trends with work from home and hybrid working models. In a post-pandemic environment, meaning of the offices has been changing, and the purpose of the office will likely be for more collaboration, connectivity, socializing, innovation activities. New office occupiers desire convenience, functionality and wellbeing. This situation ensures that the A class office demand remains strong post pandemic period.

The results of the study can be useful to the investors, real estate agents, architects, urban planners and policy makers. Using GIS and spatio-temporal analytical methods with larger data sets. Time-series analysis of office rents and hierarchical economic impact analysis of office markets over each other can be other extensions of the study.

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Resume

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Use of aerodynamically favorable tapered form in contemporary supertall buildings

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Abstract

Today, supertall buildings can be constructed in unusual forms as a pragmatic reflection of advances in construction techniques and engineering technologies, together with advanced computational design tools for architectural design. As with many other buildings, architectural and practical principles play a crucial role in the form of a supertall building, where aerodynamic behavior shaped by wind-induced excitations also becomes a critical design input. Various methods are used to meet the functional needs of these towers and reduce excitations, including aerodynamic modification methods directly related to the building form. Tapered forms are one of the most frequently used and most effective methods in today's skyscrapers, which significantly affect architectural design. To date, no study has been conducted in the literature that provides an understanding of the interrelationships between tapered building forms and main planning criteria, considering the aerodynamic design concerns of the tapering effect in supertall buildings (≥300 m). This important issue is explored in this article with data gathered from 41 supertall case studies, considering location, function, structural system, and structural material as well as the aerodynamic taper effect. The main findings of the study highlighted the following: (1) Asia was where tapered towers were most favored, with a wider margin in all regions; (2) mixed-use was the most preferred function in selected supertall buildings with tapered form; (3) outriggered frame systems were mainly used; (4) tapered supertall cases were mostly built in composite; (5) the sample group included 17 cases that used the tapering effect with aerodynamic design concerns, some of which were accompanied by corner modifications. It is believed that this study will be a basic guide for design and construction professionals including architectural and structural designers, and contractors.

Keywords: supertall building, tapered form, aerodynamic design consideration, structural system, function, location, structural material

1. Introduction

Due to the ongoing urbanization and technological developments, the number of tall and supertall buildings (≥300m high) in the world is increasing exponentially (Karjalainen et al., 2021; Tulonen et al., 2021; Ilgın, 2022; Ilgın et al., 2022a; Ilgın and Karjalainen, 2022). In the initial phase of tall building construction, building designs were simple and most of the tall buildings had regular traditional configurations e.g., square, and rectangular prisms (Ilgın and Günel, 2007). However, recent tall and supertall buildings have had various unusual configurations including taper, setback, and twisted forms (Ilgın, 2021a) as in the examples of the 99-story and 541m high One World Trade Center with its tapered form (Figure 1) and the 87-story and 462m high Lakhta Center with its tapered/twisted form (Figure 2).

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Figure 1 One World Trade Center (Wikipedia)

Figure 2 Lakhta Center (Wikipedia)

There are two important issues to be resolved in the wind-related design of supertall towers. First, their aerodynamic performance, particularly the reduction of across-wind response caused by

excitations due to vortex shedding, and the reduction of along-wind response. Another issue is the pedestrian level wind characteristics around supertall buildings due to downstream effects and Venturi effects, causing human discomfort issues and difficulties (Wang and Ni, 2022).

Regarding the first issue above, for buildings over 40 stories, the structural design, in general, begins to be controlled by wind loads (Günel and Ilgın, 2014a). These buildings are subject to complicated loading conditions, particularly urban aerodynamics created by neighboring clusters of high-rise structures (Micheli et al., 2019). They are wind-prone structures due to their great flexibility and low natural frequency, and their response to wind loads is a critical parameter in their structural design (Hou and Jafari, 2020). Both the structural safety and the comfort of the use of tall buildings are seriously threatened by strong winds. Additionally, the dramatic increase of wind speed with building height, and combined increases in slenderness ratios make them more flexible and therefore more susceptible to wind loads (Micheli et al., 2020). The reduction of wind-induced loads and hence wind-induced responses has always been a challenge in the design of supertall towers (Holmes, 2015). In this sense, in supertall building design, to guarantee functional performance and occupancy comfort, structural system selection, aerodynamic modifications, and supplementary damping devices play an important role (Günel and Ilgin, 2014b).

As commonly used approaches to reduce wind loads on supertall towers, aerodynamic modifications can alter the wind pattern around structures by suppressing the uniformity of vortex shedding (Sharma et al., 2018), thereby effectively mitigating wind loads on buildings (Kareem, 2007). In addition, vortex shedding poses a significant danger to the serviceability issue, especially when it reaches the natural frequency of the structure (Xie, 2014). Aerodynamic design considerations can be divided into two groups: major and minor modifications (Ilgın and Günel, 2021). Major modifications, which play a critical role in mitigating the wind effect on supertall towers, include building orientation, aerodynamic form, plan variation, and the aerodynamic top that have a significant impact on the overall architectural design. On the other hand, minor modifications including corner modifications and air passes do not significantly change the overall architectural design (Ilgın, 2006; Arslan Seçluk and Ilgın, 2017). Among major modifications, reducing the plan area through building height i.e., the use of tapered and setback forms as plan variation is an efficient method to mitigate wind loads (Ilgın, 2018).

Moreover, although the interaction of tall buildings with wind is a subject that includes many variables and needs to be examined specifically for each building (Elshaer et al., 2017), rectangular building forms are considered more sensitive to wind-induced lateral loads than aerodynamic building forms such as triangular, elliptical, and cylindrical formed structures (Günel and Ilgin, 2014b). Similarly, among major aerodynamic modifications, tapering the building in height is one of the most effective ways to the windproof design of numerous supertall towers in the world such as the 115-story and 599m high Ping An Finance Center (Ilgın, 2021b). Many studies in the literature have shown that tapered buildings can efficiently mitigate wind loads. Among them, Cooper et al. (1997) measured the unsteady wind effect on a tapered supertall tower with beveled corners as functions of reduced velocity and motion amplitude. The results showed that the frequency of local vortex shedding in each layer of the model increased with the increase of the model height. Tanagi (1999) showed that tapered towers can efficiently mitigate the across-wind motion via aeroelastic tests. Nakayama et al. (2002) also reported that the tapering approach can effectively mitigate across-wind motion. Kim and You (2002) tested four types of tall buildings with different tapering ratios of 5%, 10%, and 15%, and a square-section basic building model, under two typical boundary layers representing a suburban and urban flow environment, considering the effect of wind direction. They found that tapered buildings can extend the vortex shedding range to a wider frequency range, thus mitigating the across-wind motion. Similarly, Kim et al. (2008) tested three aeroelastic, tapered tall towers with taper ratios of 5%, 10%, and 15%, and a square-section basic building model. It was found that the tapering effect appeared when wind speed was high, and the structural damping was between 2-4%. Kim and Kanda (2010) analyzed two models with 5% and 10% different taper ratios under two typical boundary layers representing (sub)urban flow

situations. They found that the tapering effect helps mitigate the drag and fluctuating lift forces. Li et al. (2010) reported that the tapering effect could extend the frequency of vortex shedding on the tower's across-wind surface. Xie et al. (2011) measured wind pressures in various building models with various tapering ratios of 2.2%, 4.4%, 6.6%, and a square-section basic building model under the simulated boundary layers representing a typhoon environment. Their findings showed that a tapering effect can mitigate the across-wind response under certain conditions. Tanaka et al. (2012, 2013) performed wind tunnel tests to identify the aerodynamic loads on tall towers of different configurations, including tapered forms. It was found that the tapered forms show better aerodynamic performance compared to the square section. Deng et al. (2015) performed wind tunnel tests on supertall buildings with tapering ratios of 2.2%, 4.4%, and 6.6%. Their results showed that the global strategy of tapered elevation resulted in reduced aerodynamic loads and responses to the wind. Lo et al. (2017) studied the interference effects of tapered and helical tapered shapes on interference forces and responses. Tapered with helical taper were the forms found to be more sensitive to overall reduced velocity and interference positions. Daemei et al. (2019) examined seven triangular buildings through computational fluid dynamics analysis, including the tapering effect as a major modification. Their results showed that tapering modification can result in significant mitigation in the building's drag coefficient. Jafari and Alipour (2021) mainly reviewed past work on the double-skinned facades from an aerodynamic point of view, and one of the highlights of the review was that tapered forms, together with the setback forms in the triangular case, perform best for aerodynamic performance. Li et al. (2022) performed a series of pressure measurements in a boundary layer wind tunnel for four rigid models with various tapering ratios of 5%, 10%, 15%, and 20%. They concluded that the aerodynamic efficiency of high-rise buildings with rectangular forms is enhanced by the increased tapering ratio.

Additionally, a limited number of studies have been done in the literature analyzing the tall building form, considering the main design parameters. Among prominent studies, Elnimeiri and Almusaraf (2010) scrutinized the interrelation between structural efficiency and tall building form to indicate that efficient buildings are sustainable, and that efficiency is at the center of the structural design together with the economic structure. Alaghmandan et al. (2014) explored the architectural and structural assessments of more than 70 supertall buildings to predict the future trend in form and load-bearing systems and to make new design proposals. While Szolomicki and Golasz-Szolomicka (2019) investigated structural and architectural solutions for selected high-rise towers over the last decade, considering building form, structural system, damping systems, and sustainability, Golasz-Szolomicka and Szolomicki (2019) studied the constructional and architectural features of the most prominent twisted tall buildings with different functions, considering advances in computer technologies, the building information modeling system, and contemporary architectural trends and sustainability to evaluate innovative material applications and construction techniques. Ilgın et al. (2021) examined the contemporary developments in main architectural and structural design concerns and a variety of related interrelations using 93 supertall towers to provide insight for architects and structural engineers. Ilgın and Günel (2021) analyzed aerodynamic design considerations as contemporary trends in supertall building form. Ilgın (2021b) scrutinized space efficiency in supertall office towers with the primary architectural and structural considerations using 44 cases, whereas Ilgın (2021c) focused on space efficiency in supertall residential towers with the same considerations using 27 contemporary cases. Ilgın (2022) explored the interrelationships of load-bearing systems and key design parameters in supertall towers using 140 contemporary cases.

Overall, there is no comprehensive study in the literature providing an understanding of the interrelationships between tapered building forms and main planning criteria, considering the aerodynamic design concerns of the tapering effect in supertall buildings. This critical topic was examined in detail in this paper using 41 supertall buildings, considering location, function, structural system, and structural material as well as the aerodynamic taper effect. It is believed that this study will be a basic guide for design and construction professionals such as architects, engineers, and contractors.

2. Research Methods

This article was conducted through a comprehensive literature survey including the database of the Council on Tall Buildings and Urban Habitat / CTBUH (CTBUH, 2022), peer-reviewed journals, MSc and Ph.D. dissertations, conference papers, architectural and structural magazines, and other internet sources.

Furthermore, the case study method was utilized to gather and consolidate data on supertall buildings to analyze the interrelations of tapered form and key design considerations. These towers were 41 cases from different locations [29 from Asia (26 from China), 2 from the Middle East, 7 from North America (USA), 1 from South America, 1 from Europe, and 1 from Russia]. Detailed information about these buildings was given in Table 1. In the 41 selected case studies (see Tables 1 and 2), exceptionally detailed information was provided and tapered supertall buildings with insufficient information on related design features were not included in the building list.

Table 1 Contemporary tapered supertall buildings

#	Building name	Location (country / city)	Height (m)	# of stories	Completion date	Function
1	Suzhou Zhongnan Center	China / Suzhou	729	137	NC	M(H/R/O)
2	Ping An Finance Center	China / Shenzhen	599	115	2017	O
3	Goldin Finance 117	China / Tianjin	596	128	OH	M(H/O)
4	Lotte World Tower	South Korea / Seoul	554	123	2017	M(H/R/O)
5	One World Trade Center	USA / New York	541	94	2014	O
6	Tianjin CTF Finance Centre	China / Tianjin	530	97	2019	M (H/O)
7	Greenland Jinmao International Financial Center	China / Nanjing	499	102	UC	M (H/O)
8	Shanghai World Financial Center	China / Shanghai	492	101	2008	M (H/O)
9	International Commerce Centre	China / Hong Kong	484	108	2010	M (H/O)
10	Wuhan Greenland Center	China / Wuhan	475	97	UC	M(H/R/O)
11	Chengdu Greenland Tower	China / Chengdu	468	101	UC	M (H/O)
12	The Exchange 106	Malaysia / Kuala Lumpur	446	95	2019	O
13	Guangzhou International Finance Center	China / Guangzhou	438	103	2010	M (H/O)
14	Multifunctional Highrise Complex - Akhmat Tower	Russia / Grozny	435	102	OH	M (R/O)
15	Chongqing Tall Tower	China / Chongqing	431	101	OH	M(H/R/O)
16	Haikou Tower 1	China / Haikou	428	94	OH	M(H/R/O)
17	One Vanderbilt	USA / New York	427	58	2020	O
18	Guangxi China Resources Tower	China / Nanning	402	86	2020	M (H/O)
19	China Resources Tower	China / Shenzhen	393	68	2018	O
20	30 Hudson Yards	USA / New York	387	73	2019	O
21	Guiyang World Trade Center Landmark Tower	China / Guiyang	380	92	UC	M (H/O)
22	Golden Eagle Tiandi Tower A	China / Nanjing	368	77	2019	M (H/O)
23	Hanking Center Tower	China / Shenzhen	359	65	2018	O
24	Raffles City Chongqing T4N	China / Chongqing	354	74	2019	M (H/O)
25	One Shenzhen Bay Tower 7	China / Shenzhen	341	78	2018	M(H/R/O)
26	Tianjin World Financial Center	China / Tianjin	337	75	2011	O
27	Wilshire Grand Center	USA / Los Angeles	335	62	2017	M (H/O)
28	DAMAC Heights	UAE / Dubai	335	88	2018	R
29	China World Tower	China / Beijing	330	74	2010	M (H/O)
30	Golden Eagle Tiandi Tower B	China / Nanjing	328	68	2019	O
31	Salesforce Tower	USA / San Francisco	326	61	2018	O
32	53 West 53	USA / New York	320	77	2019	R
33	CITIC Financial Center Tower 1	China / Shenzhen	312	-	UC	M (R/O)
34	Ocean Heights	UAE / Dubai	310	83	2010	R
35	Guangfa Securities Headquarters	China / Guangzhou	308	60	2018	O
36	The Shard	UK / London	306	73	2013	M(H/R/O)
37	Northeast Asia Trade Tower	South Korea / Incheon	305	68	2011	M(H/R/O)
38	One Manhattan West	USA / New York	303	67	2019	O
39	Torre Costanera	Chile / Santiago	300	62	2014	M (H/O)
40	Shimao Riverside Block D2b	China / Wuhan	300	53	UC	M (H/O)
41	Golden Eagle Tiandi Tower C	China / Nanjing	300	60	2019	O

Note on abbreviations: 'M' indicates mixed-use; 'H' indicates hotel use; 'R' indicates residential use; 'O' indicates office use; 'UAE' indicates the United Arab Emirates; 'UC' indicates under construction; 'NC' indicates never completed; 'OH' indicates on hold.

This paper analyzed the following considerations that play a significant role in the planning of tapered supertall towers: (1) location; (2) function; (3) structural system; (4) structural material and (5) aerodynamic modification (Table 2).

Table 2 Tapered supertall buildings by core type, structural system, structural material, and aerodynamic modification

#	Building name	Core type	Structural system	Structural material	Aerodynamic modification
1	Suzhou Zhongnan Center	Central	Outriggered frame	Composite	NA
2	Ping An Finance Center	Central	Outriggered frame	Composite	Tapering + tapered corner
3	Goldin Finance 117	Central	Trussed-tube	Composite	NA
4	Lotte World Tower	Central	Outriggered frame	Composite	NA
5	One World Trade Center	Central	Outriggered frame	Composite	Tapering +chamfered corner
6	Tianjin CTF Finance Centre	Central	Framed-tube	Composite	Tapering + rounded corner
7	Greenland Jinmao International Financial Center	Central	Outriggered frame	Composite	NA
8	Shanghai World Financial Center	Central	Outriggered frame	Composite	Tapering (with aerodynamic top)
9	International Commerce Centre	Central	Outriggered frame	Composite	Recessed/notched corner
10	Wuhan Greenland Center	Central	Buttressed core	Composite	Tapering + rounded corner
11	Chengdu Greenland Tower	Central	Outriggered frame	Composite	Tapering
12	The Exchange 106	Central	Outriggered frame	Composite	NA
13	Guangzhou International Finance Center	Central	Outriggered frame	Composite	Tapering + tapered and rounded corner
14	Multifunctional Highrise Complex - Akhmat Tower	Central	Framed-tube	Steel	Tapering
15	Chongqing Tall Tower	Central	Outriggered frame	Composite	NA
16	Haikou Tower 1	Central	Outriggered frame	Composite	Tapering + rounded corner
17	One Vanderbilt	Central	Outriggered frame	Composite	NA
18	Guangxi China Resources Tower	Central	Outriggered frame	Composite	NA
19	China Resources Tower	Central	Diagrid-framed-tube	Composite	Tapering
20	30 Hudson Yards	Central	Outriggered frame	Steel	NA
21	Guiyang World Trade Center Landmark Tower	Central	Framed-tube	Composite	Tapering + rounded corner
22	Golden Eagle Tiandi Tower A	Central	Outriggered frame	Composite	NA
23	Hanking Center Tower	External	Trussed-tube	Steel	NA
24	Raffles City Chongqing T4N	Central	Outriggered frame	Composite	NA
25	One Shenzhen Bay Tower 7	Central	Outriggered frame	Composite	NA
26	Tianjin World Financial Center	Central	Outriggered frame	Composite	NA
27	Wilshire Grand Center	Central	Outriggered frame	Composite	NA
28	DAMAC Heights	Central	Outriggered frame	RC	NA
29	China World Tower	Central	Outriggered frame	Composite	Tapering
30	Golden Eagle Tiandi Tower B	Central	Outriggered frame	Composite	NA
31	Salesforce Tower	Central	Shear walled frame	Composite	NA
32	53 West 53	Peripheral	Diagrid-framed-tube	RC	NA
33	CITIC Financial Center Tower 1	Central	Diagrid-framed-tube	Composite	Tapering
34	Ocean Heights	Central	Outriggered frame	RC	NA
35	Guangfa Securities Headquarters	Central	Outriggered frame	Composite	NA
36	The Shard	Central	Shear walled frame	Composite	NA
37	Northeast Asia Trade Tower	Central	Outriggered frame	Composite	Tapering
38	One Manhattan West	Central	Shear walled frame	Composite	NA
39	Torre Costanera	Central	Outriggered frame	RC	NA
40	Shimao Riverside Block D2b	Central	Outriggered frame	Composite	Tapering
41	Golden Eagle Tiandi Tower C	Central	Outriggered frame	Composite	NA

Note on abbreviation: 'RC' indicates reinforced concrete; 'NA' indicates not available

Although there is still no global consensus on the number of floors or heights of tall and supertall buildings, 'supertall building' and 'megatall' were considered buildings 300 m and higher and 600 m and higher, respectively (CTBUH, 2022). In this study, the following core arrangement classification of Ilgın and Karjalainen (2022) was used: (i) central core; (ii) atrium core, (iii) external core, and (iv) peripheral core. In addition, hotel, residential, and office uses were considered the basic functions in supertall buildings, while their combinations were considered mixed-use (Ilgın et al., 2021). In this article, considering existing literature (e.g., Taranath, 2016; Ali and Moon, 2018; Fu, 2018; Moon, 2018; Ali and Al-Kodmany, 2022), the following structural system categorization

of Ilgın et al. (2022b) and Ilgın (2022) were used: (i) shear-frame system (shear trussed frame and shear walled frame); (ii) mega core system; (iii) mega column; (iv) outriggered frame system; (v) tube system (framed-tube including diagrid-framed-tube, trussed-tube, and bundled-tube); and (vi) buttressed core system, while the following structural material classification was used: (i) steel, (ii) reinforced concrete and (iii) composite. Furthermore, the following classification of aerodynamic design considerations (Ilgın and Günel, 2021) was used: (i) major modifications - noticeably changing the overall architectural design - (building orientation, aerodynamic form, plan variation, and aerodynamic top); (ii) minor modifications - not considerably change the overall architectural design – (corner modifications and air pass).

The tapering effect can be defined as floor plans and surface areas that decrease along the building height, where the size of the floor plan decreases continuously as the building goes up. The pyramidal form can be considered the most essential type of tapered form, together with the ancient pyramids, the first example of which was in Egypt.

The 100-story and 344m high 875 North Michigan Avenue, formerly known as John Hancock Centre with tapering ratio of long side 9.1% and short side 5.5% (Figure 3), the 73-story and 297m high Landmark Tower (1993) with tapering ratio of 5.7% on both sides and the 48-story and 260m high Transamerica Pyramid Center (Figure 4) are prominent examples of tapering modifications in real-time (Sharma et al., 2018). Here, the tapering ratio is defined as (bottom width - top width) / height × 100.

Figure 3 875 North Michigan Avenue (Wikipedia)

Figure 4 Transamerica Pyramid Center (Wikipedia)

When a tower is tapered, its outer surface area, where the wind load is exposed, decreases at higher levels, and increases at lower levels. As wind pressure increases slowly upwards and decreases rapidly downwards, lateral shear forces and overturning moments decrease as the tapered angle increases.

For tall buildings, the lock-in phenomenon caused by vortex shedding is often the most important structural design condition. Tapered forms help prevent tall and supertall towers from shedding organized alternating vortices, due to the constantly changing plan dimensions across the

height of the building. Thus, tapered structures are less sensitive to across-wind direction vibrations than high-rise towers with square cross sections.

Tapered forms mitigate the drag force owing to their geometric properties. Due to the increased size in the downward direction, the downwash phenomenon slows down less rapidly, and the upward flow accelerates at a higher speed due to the smaller width. This results in a lower pressure coefficient near the bottom and a larger pressure coefficient at the upper level compared to the reference square form.

3. Findings

3.1. Interrelations of tapered form and main planning considerations

Interrelations of tapered form and key design parameters associated with it, location, function, structural system, structural material, and aerodynamic modifications were analyzed in this part. As the most common core arrangement (>95%) in the sample group was central core typology (Table 2), no studies were conducted on it.

3.1.1. Location

Figure 5 shows that Asia was where tapered towers are most preferred (>70%), with a wider margin in all regions, followed by North America with 17%. Lateral loads from earthquakes and typhoons pose a great risk in Asia, especially in densely populated coastal cities such as Hong Kong and Shanghai. It is therefore crucial that structures in these Asian cities are designed to withstand a major earthquake or wind-induced loads, especially supertall buildings whose structural designs are governed by lateral loads, mostly wind (Günel and Ilgin, 2014b). Therefore, the reason why the tapered form was mostly used in Asian cities may be its superior structural and aerodynamic efficiency against lateral loads.

Location	#	%
Asia	29	71%
Middle East	2	5%
North America	7	17%
Other	3	7%
TOTAL	**41**	**100%**

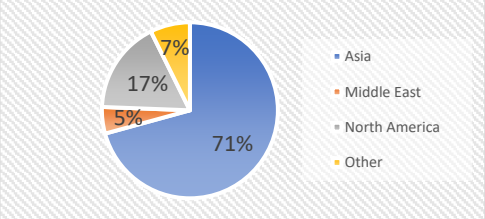

Figure 5 Tapered supertall buildings by location

3.1.2. Function

Figure 6 shows that among 41 tapered supertall buildings, mixed-use with a ratio of 61% is the most favored function, followed by office function with 32%. The reason for the high rate of mixed-use can be explained by the fact that the tapered form narrows as it rises, allowing different functional needs that demand various structural spans to be accommodated (Ilgın et al., 2021). On the other hand, from a financial point of view, the fact that it enables a wide customer portfolio with its 24-hour visitor potential and thus maximizes rentals may be the reason why mixed-use in tapered forms is most preferred (Ali and Al-Kodmany, 2012).

Function	#	%
Hotel	-	-
Residential	3	7%
Office	13	32%
Mixed-use	25	61%
TOTAL	**41**	**100%**

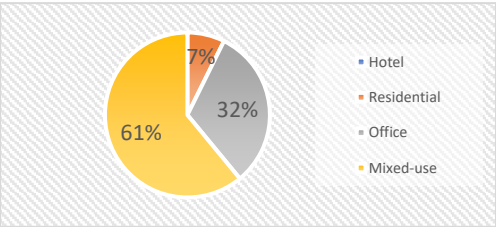

Figure 6 Tapered supertall buildings by function

3.1.3. Structural system

Figure 7 indicates that outriggered frame systems are mostly used (>70%) in supertall towers in the sample group, followed by tube systems with 20%. The predominance of outrigger frame system can be explained by the fact that this system allows the exterior columns to be widely spaced, thereby minimizing the obstruction created by closely spaced column arrangement, opening the exterior of the building so that architects can articulate the facade freely (Ali and Al-Kodmany, 2022).

Structural system	#	%
Outriggered frame	29	71%
Tube	8	20%
Shear walled frame	3	7%
Buttressed core	1	2%
TOTAL	**41**	**100%**

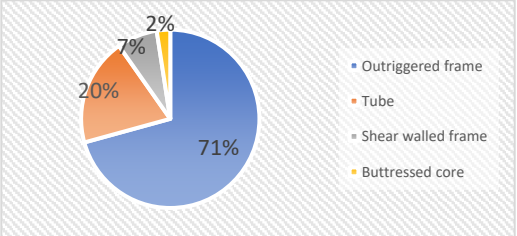

Figure 7 Tapered supertall buildings by structural system

3.1.4. Structural material

Figure 8 highlights that among 41 tapered supertall buildings, composite structures with 83%, with a wider margin, is the most common material, followed by reinforced concrete use with 10%. The use of composite structure can mainly be attributed to the benefits of both structural materials, namely the superiority of the (tensile) strength of steel and the fire resistance of concrete. Hence, it may come as no surprise that more than 80% of supertall cases were designed as composites.

Structural system	#	%
Steel	3	7
Reinforced concrete	4	10
Composite	34	83
TOTAL	**41**	**100%**

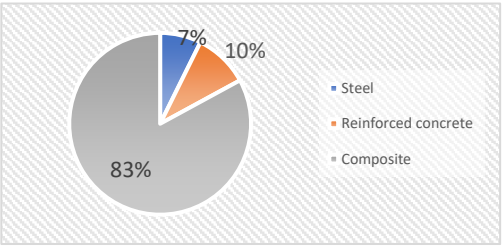

Figure 8 Tapered supertall buildings by structural material

3.2. Analysis of the use of tapering as an aerodynamic modification

There are 17 buildings in the sample group, which are known to use the tapering effect in their designs (see Table 2). In 7 cases, the tapering effect is accompanied by corner modifications, making the role of aerodynamic considerations in the design more evident. Among them, the 115-story and 599m high Ping An Finance Center utilized tapering and tapered corners, and according to Chinese regulation, these strategies provide a 32% and 35% reduction in the overturning moment and wind load, respectively (Malott, 2014) (Figure 9).

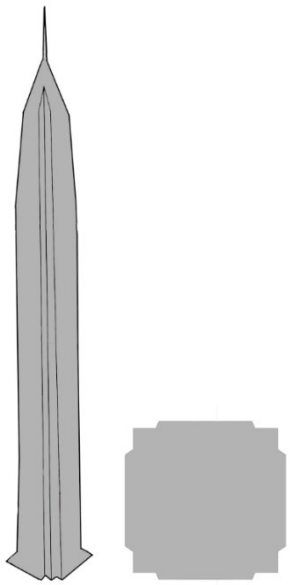

Figure 9 Tapering effects on Ping An Finance Center

Similarly, the 99-story and 541m high One World Trade Center, when combined with chamfered corners, tapers as it rises, creating an aerodynamically and structurally effective form (Lewis and Holt, 2011). In the 97-story and 530m high Tianjin CTF Finance Centre, tapering was combined with rounded corners. In this supertall structure, tapering contributed significantly to performing well in wind tunnel tests and minimizing the surface area exposed to wind, and due to rounded corners, not only can wind loads at the corners be mitigated but structural spans can also be reduced (Lee et al., 2020). Tapering form and an aerodynamic top played a critical role in the architectural design of the 101-story and 492m high Shanghai World Financial Center (Moon, 2015). The 97-story and 475m high Wuhan Greenland Center has a unique form that unites three key form concepts including a tapering effect through the building height, rounded corners, and a domed top to mitigate wind load and vortex shedding (Adrian Smith + Gordon Gill Architecture LLP, 2022). The 101-story and 468m high Chengdu Greenland Tower's tapering form together with a high-performance damper support system deflects the wind and contributes to the building's stability (Binder, 2015). The aerodynamic shaping of the 103-story and 438m high Guangzhou International Finance Center was designed as an efficient means of reducing the wind forces. Additionally, the corner tapering spreads vortex-shedding and thus helps the across-wind responses, the rounded building corners change the flow pattern around the building and mitigate wind-induced excitation (Kwok and Lee, 2016). The design of the final shape of the 102-story and 435m high Multifunctional Highrise Complex - Akhmat Tower was influenced by wind performance. The building, which was thought to have a square plan from the concept stage of the project, made the building elements more efficient thanks to its tapered form obtained by aerodynamic optimizations while providing significant tonnage and cost savings in steel, while at the same time reducing wind loads (Beardsley et al., 2018).

4. Discussion and conclusions

The findings obtained in this paper showed similarities and differences with other studies in the literature such as Ilgın et al. (2021). Among the 41 tapered supertall cases, central core planning was the most preferred arrangement, as reported in several studies in the literature (Ilgın et al., 2021; Ilgın, 2021b, c). In terms of location, it was observed that mostly tapered supertall structures were constructed in Asian cities. This finding can be attributed to Moon's (2015) finding that Asia was home to many tapering supertall buildings, such as the Lotte World Tower. It was expected to remain a dynamic supertall development area where building heights tend to increase. In this study,

supported by the finding of Ilgın et al. (2021), the most preferred function was mixed-use, followed closely by office use. In terms of the load-bearing system, the fact that outriggered frame system was predominantly utilized in selected supertall towers confirms the findings of other studies including Ilgın et al. (2021), Ilgın (2021b), and Ilgın (2021c). On the other hand, as in the findings of Ilgın et al. (2021) and Ilgın (2021b), the use of composite was much more common than reinforced concrete and steel construction.

Although the supertall building forms are primarily determined by site conditions, economic parameters, and architectural and engineering features, the design should be made by considering the aerodynamic properties of the building form. This is because even a small change in geometric shape can provide a significant advantage over wind-induced lateral loads. In this context, the tapered form is one of the most preferred building forms and enables the supertall tower to exhibit an effective behavior against wind loads. To provide this, the sample group included 17 cases that used the tapering effect with aerodynamic design concerns, some of which were accompanied by corner modifications.

In this study, using 41 supertall buildings, interrelationships between tapered building forms and main planning criteria, considering the aerodynamic design concerns of the tapering effect in contemporary supertall buildings were analyzed. In conclusion, it is believed that the findings obtained in this paper will be a basic guide for key professionals e.g., architects, engineers, and developers.

The empirical data given in this paper were limited to supertall towers (≥300 m). In addition, analysis of supertall cases using tapered forms in their aerodynamic designs was limited to the number of buildings (17) for which this information was available. However, given that the number of supertall buildings has increased significantly in recent years, it can be predicted that there will be a sufficient number of cases for analysis of aerodynamic issues in the near future. Moreover, buildings lower than 300 m might be included in the sample study group so that an adequate number of subclasses can be generated in future studies.

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Resume

Dr. Hüseyin Emre Ilgın received his Ph.D. (2018) in Building Sciences about tall building design in Architecture from METU. In his 15-year-professional-life, he worked in several architectural offices and companies in the building design and construction industry including design control and site supervision phases of numerous healthcare facility projects including over one million m^2 city hospitals. In academic life, he had taught in several universities as a part-time instructor for about 10 years. Since December 2019, he has been conducting post-doctoral research on wood construction at Tampere University. Now Dr. Ilgın works as a Marie Skłodowska-Curie postdoctoral research fellow on dovetailed massive wood board elements in the same university.

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An evaluation of smart windows in a reference office building in Kayseri

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Abstract

As a building element, the facade which interacts with external factors between two different environmental conditions is an important interface in energy consumption and the building life cycle. In recent years, smart materials have become a research topic in the field of sustainable architecture and facade technologies. The traditional material understanding which expects materials to not be affected by external environmental conditions by preserving their qualities throughout their lifespan has begun to leave its place to the understanding of materials that change quality and energy by reacting to external stimuli. Developing facade technologies and the energy-efficient design approach also achieve the development of new technologies in window systems. The most promising of these new window technologies, called smart windows, are electrochromic, thermochromic, and photochromic windows. Within the scope of this study, the energy performance of smart window systems has been evaluated comparatively with a traditional window system in a reference office building in Kayseri, Turkey. This study aims to evaluate the energy performances of smart windows and reveal their advantages and disadvantages over the available window system in this climate condition. In this context, smart window systems have been classified and explained their properties. In the simulation part, a reference office building has been modeled with each smart window system to evaluate their energy performances comparatively. Nevertheless, a reference office building with a traditional window system has also been modeled to reveal differences in energy performances with an available window system. Finally, the results have been evaluated with graphs and recommendations on the best-performed window system have been explained.

Keywords: energy efficient buildings, facade materials, smart materials, smart windows, sustainability

1. Introduction

Today, facades have a large amount of energy consumption in high-rise office buildings. The facade is a building element that separates the interior and exterior environment in buildings and is an interface that interacts with physical, chemical, and biological factors throughout the building life cycle. Due to being in interaction with the exterior conditions, most of the energy loss of a building occurs in the facade, especially in the window systems. Factors such as daylight, visual, and thermal comfort in high-rise office buildings affect the quality of the work, user comfort conditions, and energy consumption. High heating and cooling energy use in buildings cause depletion of energy resources and significant problems in the scope of sustainability. Therefore, the window system used in a high-rise office building has a significant impact on the importance of sustainable architecture and energy-efficient building targets in the field of architecture.

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Technological developments in material science and architecture allow the development of new facade materials and systems. In this context, innovative window systems have been developed to prevent and minimize energy gains and losses. Smart materials, which are used and intended to be used in many fields of architecture, also have a wide extent for facade technologies. The main varieties of smart windows are film-coated window systems consisting of electrochromic, thermochromic, or photochromic materials. In these innovative window systems, the window aims to balance heat losses and gains by changing its opacity level according to the solar radiation intensity, and temperature or with an actuator to provide thermal insulation and lighting control. In brief, smart windows aim to provide user comfort and reduce energy loses by balancing heating, cooling, and lighting loads.

1.1. Purpose of The Study

This study focuses on the performance of smart windows in high-rise office building facades in Kayseri, Turkey. The primary aim of the research is to provide brief information on the definition and characteristics of smart facade materials and to compare smart window systems with a standard window system in Kayseri climate conditions. Also, the impacts of opacity changes in smart windows for comfort conditions and energy consumption in high-rise office buildings are aimed.

1.2. Methodology

In this study, the properties of electrochromic, thermochromic, and photochromic window systems, together with a preferred window technology today, are explained. Afterwards, a simulation study is carried out on a case high-rise office building placed in Kayseri.

First, electrochromic, thermochromic, and photochromic smart facade materials, which are the components of smart window systems have been revealed. This part contains a brief literature review with recent case studies and examples of buildings that are designed with smart windows.

For the optimization round, the material properties to investigate are the U-value of building components suitable for the climate conditions specified. Optical and physical properties of the smart windows such as U-value, SHGC, and VT values, application system of the window, and dimensions are compiled. These properties have been found on manufacturers' websites, articles, and other open channels. For the simulation study, energy simulation software's have been evaluated considering their ease of use, accessibility, and capacity to generate the desired data.

After the research review, a high-rise office building is modeled as a prototype with a defined geometry and window application in the simulation process. The first model consists of the electrochromic window as an active smart window that changes its opacity with voltage. The second smart window model contains the thermochromic material as a passive property-changing smart material that changes its opacity according to temperature changes. The third model represents the photochromic window as a passive smart window that changes its opacity with light. Also, Low-E coated window system has been chosen as the fourth model to compare with other smart windows since it is suitable for the required window properties according to the standards and widely has been used in Turkey. Thus, the advantages and disadvantages of the standard window can be compared to smart windows. These models are analyzed and optimized through computer simulations. As a result of extensive research, Design Builder software has been chosen as the building simulation tool. The performances are evaluated through four window systems via simulation run-time. Finally, an evaluation is done for energy performance through energy consumption for heating and cooling.

2. Smart Materials

Until the 20th century, materials were expected not to change their properties due to environmental impacts during their use. Because thereupon, the material changes in properties have been expressed as decay, corrosion, collapse, mold, etc. (Okay, 2003). After the industrial

revolution at the end of the 19th century, the traditional material understanding, and facade systems have been changed through developments in technology and gained awareness for a better future (Orhon, 2012). With the new material understanding, the expected outcome from smart materials in the facade will help make quality changes against external influences besides the classic material understanding (Okay, 2003). The understanding of smart materials is based on responding to external stimuli, unlike the classical materials that struggle against external influences (Orhon, 2012).

2.1. Properties of Smart Materials

The principle of the definition and classification of the smart materials are according to the two approaches that are used as the main references, which are Addington & Schodek's and Ritter's approaches. Basically, there are five fundamental characteristics to distinguish between traditional and smart materials as follows: transiency, selectivity, immediacy, self-actuation, and directness. Also, the expected to be found in smart materials are (Addington and Schodek, 2005):

- Property change capability
- Energy exchange capability
- Discrete size/location
- Reversibility

The classification of smart materials is determined by the environmental factor affected, the way of responding to this effect, and the perceived change in the material by the human eye. All of these parameters are included in the classification system (Karakaya and Özgünler Acun, 2021). If the external input affects the internal energy of the material by altering either the material's molecular structure or microstructure and a property change occurs in the material, it is accepted that these types of materials are property-changing smart materials. If the external effect changes the energy state of the materials while material composition does not alter and only results in an exchange of energy from one form to another, these types of materials are energy-exchanging smart materials. In brief, in property-changing smart materials, the material absorbs the input energy and goes through a change, whereas in energy-exchanging smart materials, the material stays the same, but the energy undergoes a change. In addition, these changes are on the micro-scale (Addington and Schodek, 2005).

Today, many smart materials are still under research and have a wide area in the field of architecture, especially in facade technologies. Color and optically changing smart materials or in other words chromogenic smart materials are the most used smart materials in facades (Table 1). In this group, external input or inputs influence the material's molecular-atomic structure generally from its surface and a change occurs in the material's opacity. These inputs can be passive factors such as light, temperature, or active inputs via electric current, voltage, etc. The materials respond directly and reversibly by changing their opacity states due to these passive and active inputs (Addington and Schodek, 2005).

Table 1 Color and optically changing smart material types in relation to input and output stimuli (Addington and Schodek, 2005).

Type of Smart Material	Input	Output
Electrochromics	Electric potential difference	Color/Opacity Change
Thermochromics	Temperature difference	
Photochromics	Radiation (Light)	

Addington and Schodek have entitled this smart material group chromic or color-changing smart materials. However, the term color changing does not mean that the materials change their colors. The material changes its optical properties; hence this change is perceived as a color and/or opacity changing by the human eye. These color changes can be perceived in many colors depending on the optical features (crystalline or molecular structure) of materials and the light may be absorbed or converted to energy (Addington and Schodek, 2005).

2.2. Smart Window Systems

In order to meet the requirements, glazing materials and window systems have been developed by adding extra layers to the window in today's technology. Furthermore, new material types such as window layers have been applied to high-rise buildings with large facades to enhance building performance (Kızıltoprak, 2019). Result of extended surveys of color and optically changing smart materials in facade technologies, they are generally used in passive or active applications in facade systems, which are called smart windows. There are three main smart window systems that are manufactured with color and optically changing smart materials in the market, which are electrochromic, thermochromic, and photochromic smart windows (Orhon, 2012).

2.2.1.Electrochromic Smart Windows

Electrochromic smart windows reversibly change their optical properties by application of an electric current and/or potential via a small voltage through the user control. The reversible color change in the window is based on the movement of ions between the electrochromic layers by applying a small amount of voltage basically (Figure 1) (Lampert, 1998). Optical changing in the chemical structure of the material is perceived as color and/or opacity change (Figure 2) (Ritter, 2007).

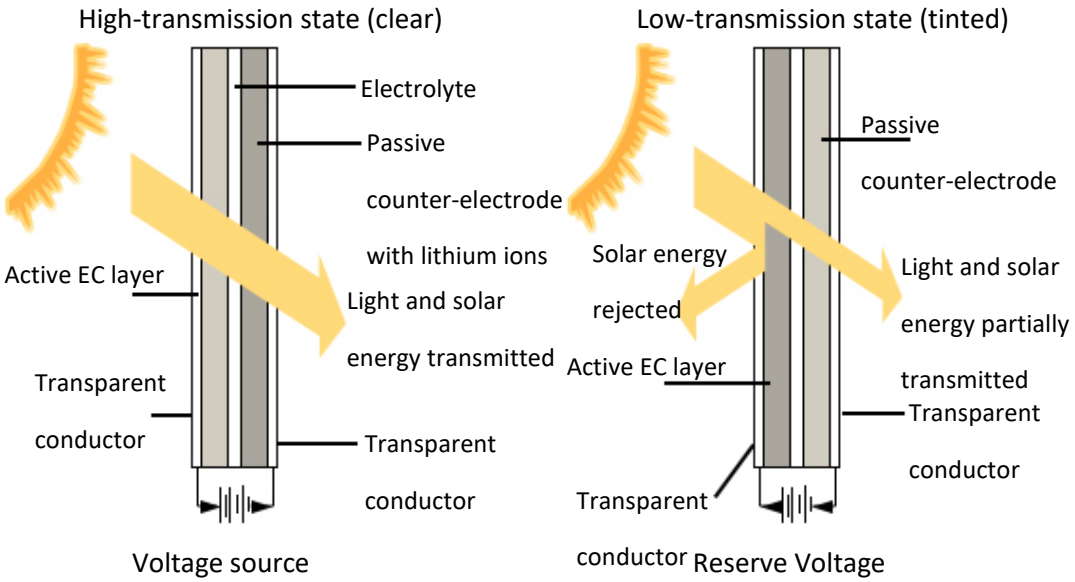

Figure 1 Diagram of the tungsten-okside covered electrochromic windows (URL-1).

Figure 2 Transparent and tinted states of electrochromic smart window in Dirty Habit DC facade (URL-2).

2.2.2.Thermochromic Smart Windows

Thermochromic smart windows reversibly change their visible optical properties in response to temperature changes in thermochromic thin films that are integrated into the window system through absorption of heat (Figure 3). This temperature change generates a chemical reaction or phase transformation in the structure of the material, hence the material opacity convert into the perception of color change (Ritter, 2007).

Figure 3 Trasparent and tinted states of thermochromic smart window in Masco Building facade (URL-3).

2.2.3.Photochromic Smart Windows

Photochromic smart windows reversibly change their optical properties due to the impact of light (visible light, UV light, IR light; electromagnetic radiation) with the perception of color change. This change can be achieved with a photochromic film applied to the window without needing any actuator (Ritter, 2007).

2.3. Advantageous and disadvantageous of smart windows

The smart behavior of the smart window system is advantageous to reduce heating and cooling loads (Lee and DiBartolomeo, 2002). However, the application of smart windows to high-rise office building facades can be disadvantageous depending on the climate conditions. In the study "An Evaluation of Chromic Glazing as Smart Material in High-Rise Office Building Facades Within The Scope of Sustainability" it has been observed that electrochromic windows increase the building energy efficiency compared to other smart window systems and Low-E coated windows in Istanbul for winter and summer periods, hence total energy use, and it has been determined that their use is advantageous in temperate climates. However, the Low-E coated window system shows the best performance in Antalya, which is in the hot climate, since smart windows increase lighting loads due to being in the tinted state cause of high solar radiation intensity in hot climate regions, therefore their use may be considered disadvantageous when considered the total energy uses for winter and summer periods (Karakaya, 2022). Other advantageous and disadvantageous of smart windows are as follows:

- Thermochromic and photochromic smart windows can change their opacity state to optimize energy losses and gains passively, yet, electrochromic smart windows work with an actuator to achieve the opacity change, hence called active systems. However, electrochromic smart windows need even less energy to maintain the desired color (Erdemli, 2018). Therefore, the application of a voltage can be a disadvantage in the scope of sustainability, however, the total energy uses should be considered (Addington and Schodek, 2005).
- The optical transmittance of smart window systems is continuous, and it has the ability to reflect and absorb between transparent and tinted surfaces (Yelkenci Sert and Güzel 2015). However, in opacity-changing smart window systems, generally, the switching time to darken takes a little longer than transparency (Erdemli, 2018).
- One of the most important advantages of smart windows is that they can be applied to various window systems with different numbers of layers and glass types, hence, the performance of the window system can have better quality (Lee and DiBartolomeo, 2002).
- They can operate between a wide range of glass surface temperatures (Yelkenci Sert and Güzel 2015).

- The switching time of the window has also a major impact on user comfort. In thermochromic smart windows, it takes 20-30 minutes to switch the color, thus electrochromic products have a remarkable difference within 3-5 minutes of switching time on visual comfort (Tällberg et al, 2019).
- Among passive smart windows, thermochromic smart windows have lower manufacturing costs despite photochromic materials (Yelkenci Sert and Güzel 2015).
- When taking into consideration users' requirements in office buildings, the smart window is a good solution to control brightness levels and glare in working zones. However, although they have advantages in energy balance and daylight control, which is significantly important for visual comfort, artificial light may be a necessity when the window got tinted (Lee and DiBartolomeo, 2002).

3. Case Study

Smart window systems can switch the state from clear to tinted without interrupting the visual connection due to solar radiation intensity. In recent years, simulation studies have been carried out to evaluate the energy performances of smart windows in different climate conditions. Smart windows have an important role in today's window technology with the optimization ability of heating and cooling loads. Recent studies show that smart windows contribute to the energy efficiency of the building and more positively affect the comfort conditions of the user in some climate conditions. In order to enlarge the knowledge of smart window performances in different climates, the energy performance evaluation of electrochromic, thermochromic, and photochromic windows is made comparatively with a reference window system in Kayseri. In this context, a case office building with 15 floors has been modeled in the DesignBuilder simulation tool (Figure 4).

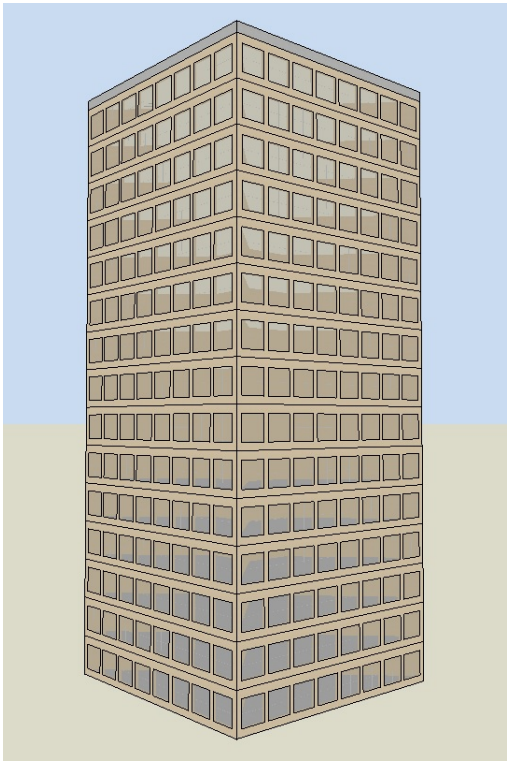

Figure 4 Rendered view of the case high-rise office building.

As the result of extended surveys of suitable building simulation tools, the EnergyPlus-based DesignBuilder Simulation Program has been found as the best software to simulate and comparative in high-rise office buildings facades designed with smart windows since the requirements of a higher-level work and expertise for other program tools are needed (Crawley et al, 2008, Loonen et al, 2013).

The case high-rise office building is designed with a square plan, four open facades, and 15 floors. The area of the building is 625 m² (25 m x 25 m), with a floor height of 4 m and a total building height of 80 m. The schematic plan of the model building is given in Figure 5. The working hours of the day are accepted between 08:00 and 18:00.

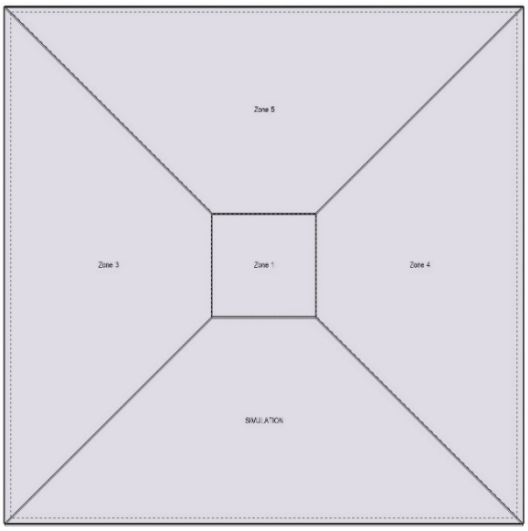

Figure 5 Schematic plan of the case building

3.1. 3.1 Location and Climate Characteristics

Information and assumptions about climate conditions, building structural features, spatial conditions, and user features are explained in detail below. In computer modeling, necessary parameters related to environment, building, and user are defined according to ASHRAE and TS-825 standards.

The building location has been selected as Kayseri which is a plot city of the 4th climate zone in Turkey. The climate and location characteristics of these region are given in Table 2. Each facade of the building consists of four facades of linear and equal dimensions. Modeling has been done by assuming that the surrounding buildings are far, hence shading factors from them have not been taken into account. In calculations, evaluations have been made on a module located. In evaluating the thermal performance of the building, climatic data accepted by ASHRAE is defined on the simulation program (ASHRAE, 2009, TS825, 2013).

Table 2 Location features of reference building for Kayseri.

Location:	Kayseri
Climate Type:	Continental Climate
Climate Zone (TS825):	4. Region

The reference U-Values determined for the climate zones in the TS 825 standard for the building materials used in the case buildings are given in Table 3. The required U-values of the external wall, floor, roof, and window components of each are highlighted (TS825, 2013).

Table 3 The required U-values (W/m²K) for the climate zones (TS825, 2013).

Climate Zone	Exterior Wall	Floor	Roof	Window
1.Region	0,66	0,43	0,66	1,80
2.Region	0,57	0,38	0,57	1,80
3.Region	0,48	0,28	0,43	1,80
4.Region	**0,38**	**0,23**	**0,38**	**1,80**
5.Region	0,36	0,21	0,36	1,80

According to the required U-values of building envelopes for TS 825, the case high-rise office building is modeled (Table 4).

Table 4 U-Values of reference building envelopes for Kayseri.

Exterior Wall	Floor	Roof
0,36 W/m²K	0,23 W/M²K	0,37 W/m²K

3.2. Heating system

The set temperature for heating period is considered to be 21°C. It is assumed that the heating system starts to operate when the indoor temperature is below 19°C.

3.3. Cooling system

During the cooling period, the indoor set point temperature is accepted as 26°C and it is assumed that the cooling system activates when the indoor temperature is above 28°C.

3.4. User heat gain and office equipment loads

The working hours of the day are accepted between 08:00 and 18:00. The office work area is designed as an open office with equal 4 zones, assuming that 15 people work in each zone. A value of 123 W/person has been chosen for light workers from the DesignBuilder activity list. It has been assumed that there are a total of 15 computers in a department, one for each employee. 230 W/computer value was selected for these computers in the DesignBuilder program. The heat loads of the other devices that continue to work on weekends and during office hours have not been taken into account in the calculation.

3.5. Properties of Window Systems

In the simulation process, electrochromic, thermochromic, photochromic, and Low-E coated windows are selected to operate.

- window height: 3 m
- window width: 2,5 m
- window parapet height: 0,2 m
- the total number of windows on the facade: 10.

Each window type is modeled as a double-glazing system with 6mm glass, 12 mm air gap, and 6 mm glass. Even though different gases have been used in different windows, the gas in the air gap is selected the same from the program library properly to ignore the effect of gas type. The frames for each window are fixed and the most suitable aluminum frame with a thermal barrier has been used in the systems since different types of frames would affect the evaluation. The U-value of the frame system has been considered while selecting. In all of the alternatives, the impermeability value (infiltration) is accepted as 0.5 ac/h according to ASHRAE standard 55 and BEP-TR data.

Optical properties such as SHGC, VT, and U-Values are significant properties that create the difference in the performance of each window. Moreover, these values differ for each tinted state of smart windows, for instance, VT and SHGC values reduce when the clear state turns tinted. The linear optical change can not be calculated with the simulation tool. In order to evaluate the performance of the smart windows, 4 opacity states during the day of the window with optical properties are selected from manufacturers' websites, case study data, and articles. In the calculation, smart window states are selected in accordance with the manufacturers' websites. Consequently, all graphs and tables for each state have been evaluated with daytime behavior outcomes.

In the daily evaluations, August 14 is chosen as the hottest day for the summer months and February 12 as the coldest day for winter months, representing the summer and winter months, and the changes in cooling and heating loads have been analyzed depending on the external

climatic changes on these days. The evaluation has been represented for the south facade office zone on the 5th floor of the building. The optical properties of the windows are represented (Table 5, Table 6, Table 7, Table 8).

Table 5 Optical properties of electrochromic windows per state.

Window States	U-Value	SHGC	VT
Clear State	0,29 W/m²K	0,33	0,45
Intermediate State 1	0,29 W/m²K	0,20	0,19
Intermediate State 2	0,29 W/m²K	0,12	0,06
Tinted State	0,29 W/m²K	0,10	0,01

Table 6 Optical properties of thermochromic windows per state.

Window States	U-Value	SHGC	VT
Clear State	1,36 W/m²K	0,25	0,30
Intermediate State 1	1,36 W/m²K	0,21	0,20
Intermediate State 2	1,36 W/m²K	0,17	0,10
Tinted State	1,36 W/m²K	0,13	0,05

Table 7 Optical properties of photochromic windows per state.

Window States	U-Value	SHGC	VT
Clear State	1,58 W/m²K	0,33	0,28
Intermediate State 1	1,58 W/m²K	0,30	0,26
Intermediate State 2	1,58 W/m²K	0,28	0,24
Tinted State	1,58 W/m²K	0,25	0,23

Before evaluating and comparing the energy performance of windows for heating, cooling, and lighting, it is important to clarify how the smart window system works during the day and how it responds to external influences. In the evaluation, 4 different opacity states of smart windows are calculated. In the literature review and the data collected from the manufacturers, it has been seen that the smart windows are colorless at 10 °C and the direct solar radiation intensity on the glass surface is 100 W/m². Likewise, it was determined that at 65 °C, the direct solar radiation intensity on the glass surface was 450 W/m², in which the glass became tinted (Tällberg et al, 2019). It has been explained in the previous sections that different types of windows change with the intensity of solar radiation coming to the glass surface, with the temperature change, and with the user control. Considering that these control strategies differences can not be controlled in the simulation program, the threshold temperature and solar radiation intensity are accepted that the windows change their levels at these threshold values. Accordingly, smart windows can be found in clear, intermediate-1, intermediate-2, and tinted states. It is assumed that when the direct solar radiation intensity on the glass surface is 0 W/m², the smart window is clear and the smart window is tinted when the solar radiation intensity is 450 W/m². Intermediate states are changed between 0-450 W/m².

Table 8 Optical properties of Low-E coated windows.

U-Value	SHGC	VT
1,80 W/m²K	0,59	0,77

In the simulation study, the cooling system is modeled to fix the indoor temperature to 26°C during the summer months. In the evaluation, it is assumed that the smart window changes the opacity level when the energy is consumed for the cooling load and the window level is fixed when the cooling energy is 0 W/m² again. It is also assumed that when the indoor temperature reduces below 26°C, the opacity level of the window increases and gets into a clear state linearly. In this

context, daily cooling loads have been compared in the south-facing zone of the high-rise office building.

3.6. Evaluation of Cooling Loads

For the calculation of the daily cooling loads, the hourly outdoor air temperature and direct solar radiation intensity graph of August 14 for Kayseri is given (Figure 6). The maximum value of outdoor temperature is 34,30°C at 14:00. The lowest value of solar radiation intensity is 323.71 W/m² at 08:00 and the highest value of solar radiation intensity is 842.64 W/m² at 16:00. Consequently, when the solar radiation intensity is in the range of 300-450 W/m² at 08:00, smart windows are at the intermediate-2 state in Kayseri. The solar radiation intensity is higher than 450 W/m² between hours 09:00 and 18:00. Therefore, the window is in the tinted state.

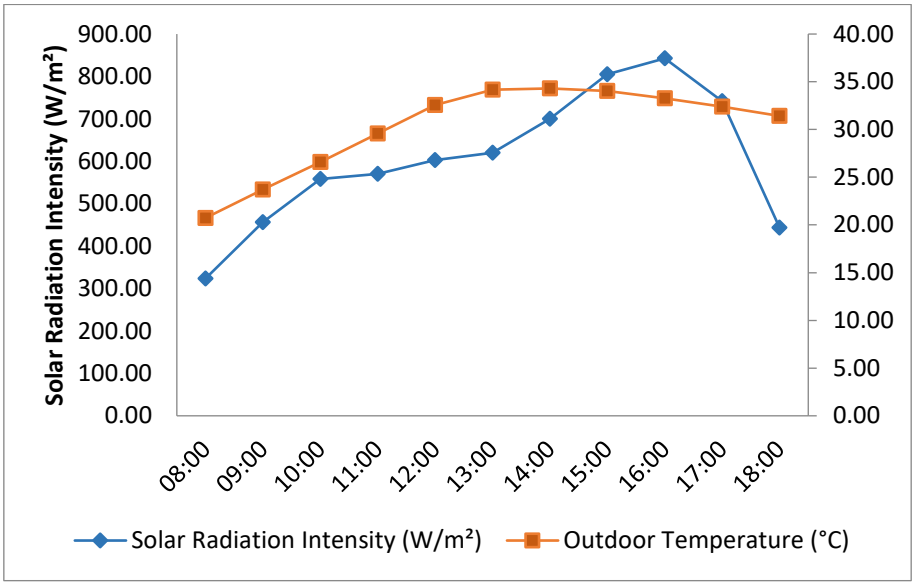

Figure 6 Solar radiation intensity and outdoor temperature for August 14 in Kayseri.

According to the solar radiation intensity levels, cooling loads of windows for August 14 graph is given in Figure 7.

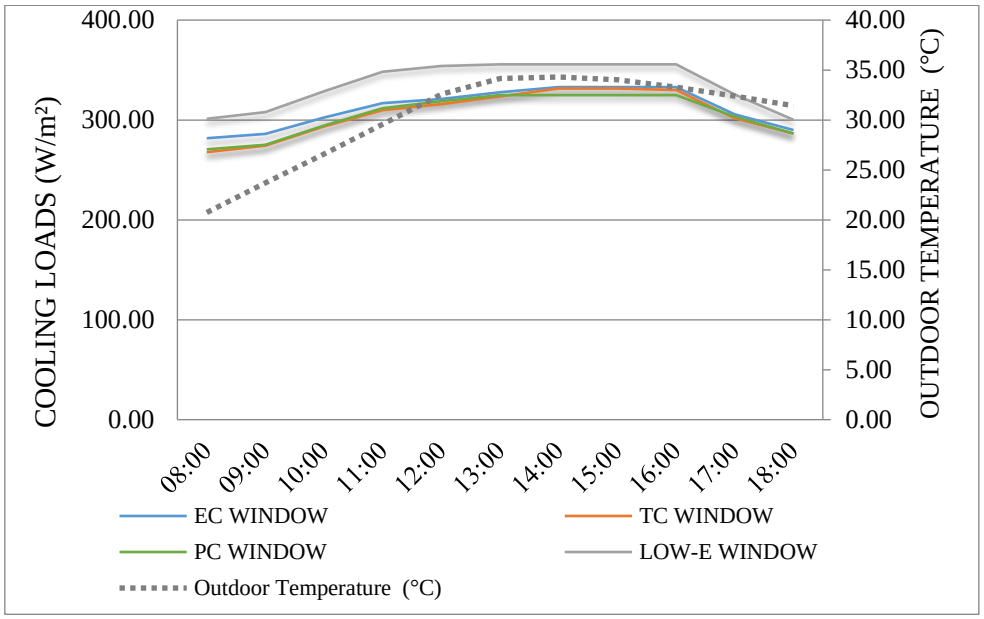

Figure 7 Cooling loads of windows for August 14 in Kayseri.

The smart windows are at the tinted state in this time interval, however, between 08:00 and 09:00 it has been in the intermediate-2 level when the solar radiation intensity on the window

surface is down the threshold value. All window types have reached the maximum value of cooling loads at 14:00. After reaching the maximum value at 14:00, a decrease in cooling loads has been observed in smart windows for rest of the day.

Cooling loads for each window option are at minimum values at 08:00 when the outdoor temperature is 20.73ºC. An increase has been observed in the cooling loads on all windows until 14:00. Accordingly, the lowest and the highest cooling loads are 281.70 and 332.90 W/m² for the electrochromic window, 267.78 and 331.49 W/m² for the thermochromic window, 270.58 and 324.88 W/m² for the photochromic window, and 300.18 and 355.66 W/m² for the low-E coated window in this hour range.

In the Low-E coated window, the maximum cooling loads have been calculated among all windows during the working hours. Similar to the photochromic window, an increase in cooling loads has been observed until 14:00, reached the maximum level at this time, and decreased after all. The maximum cooling load reached during the day is 323,97 W/m² and the lowest is 280,29 W/m² at 18:00.

For the electrochromic window, the minimum cooling loads have been calculated among all windows during the working hours. In the electrochromic window, cooling loads increase during the day. The maximum cooling load reached 275,98 W/m² at 17:00. The electrochromic window switched to the intermediate-2 state between 17:00 and 18:00 with the solar radiation intensity on the window surface exceeding the threshold value.

In the thermochromic window, cooling loads reduce until 09:00 in the tinted state. The thermochromic window has also shown similar behavior to other smart windows as is in the intermediate-2 until 18:00 and in the tinted state for the rest of the day. The maximum cooling load reached 301,96 W/m² during the day. After 14:00, the cooling loads relatively reduce until 17:00, and during this period the cooling loads are approximately equal to 300,15 W/m². Although the outdoor temperature has continued to increase until 18:00, the cooling load has not increased due to the glazing being in the tinted state, preventing overheating.

In summary, the highest cooling load at 08:00 was measured as 295,76 W/m² for the PC window. The highest cooling loads for each window type are between 14:00 and 17:00. In this hour range, the energy consumed for cooling increased up to 275,98 W/m² for the EC window, 301,96 W/m² for the TC window, 307,26 W/m² for the PC window, and 323,97 W/m² for the Low-E window. This can be explained in direct proportion to the air temperature graph because the outdoor air temperature reached the highest levels in this hour. The best-performing window system is the electrochromic smart window when the total cooling loads are compared.

The window option with the highest total cooling load is the Low-E coated window. The SHGC value of the Low-E window is 0.56, and therefore, since the SHGC value is high, a high rate of solar radiation coming to the glass surface causes heating by passing into the interior environment, thus causing an increase in the cooling energy. The SHGC values (from the clear state to the tinted state) of the electrochromic, thermochromic, and photochromic windows are 0.33-0.10, 0.25-0.13, and 0.33-0.25 respectively. The lower values in tinted states of electrochromic and thermochromic windows are important factors in lower cooling loads compared to photochromic windows.

Cooling loads tend to increase when the solar radiation intensity is the highest. Since the illuminance values could not exceed the determined value for office buildings (500 lux), a sufficient illuminance level was not provided in the indoor environment and the comfort condition could not be met. It has been observed that artificial lighting is needed to provide the necessary comfort condition (500 lux), and therefore an increase in lighting loads needed to occur.

When the total cooling loads of the south-oriented office unit are compared during the day, the photochromic window shows the best performance with the lowest cooling energy use of 3360.02 W/m² on February 12 in Kayseri (Figure 8).

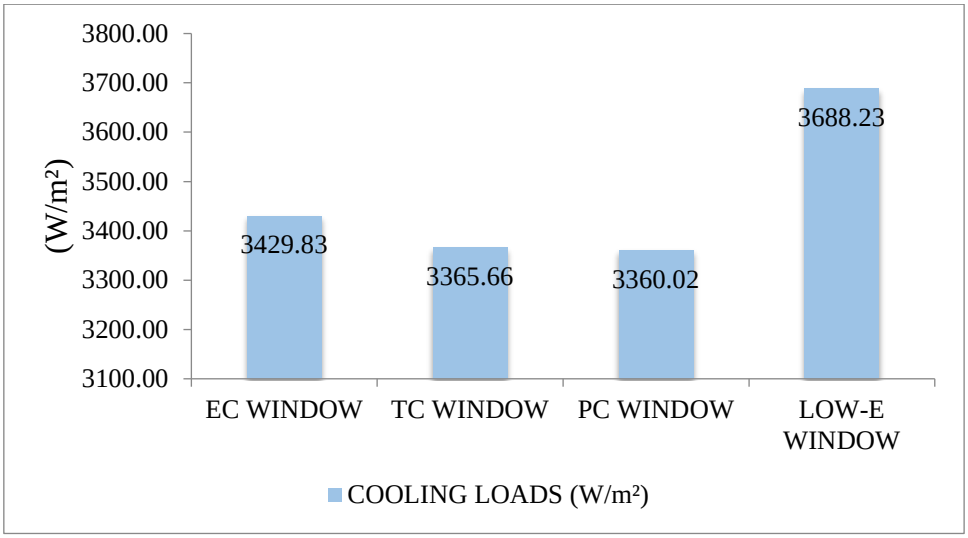

Figure 8 Total cooling loads of the windows for August 14 in Kayseri.

Total cooling loads on other smart windows are higher during the day to ensure indoor comfort conditions. The best performing window systems after the electrochromic window are the thermochromic window with a value of 3365.66 W/m² and the electrochromic window with a value of 3429.83 W/m², respectively. The worst-performing window system with the highest heating energy consumption is the Low-E coated window with a value of 3688.23 W/m².

3.7. Evaluation of Heating Loads

According to the graph, the outdoor temperature stays between -10°C and 4 °C without showing a sudden rise or fall during the day (Figure 9). The highest value of solar radiation intensity is 18.61 W/m² at 13:00. Therefore, smart windows remained in the clear state throughout the day due to the solar radiation intensity on the smart window surface being below the threshold value to reverse its level.

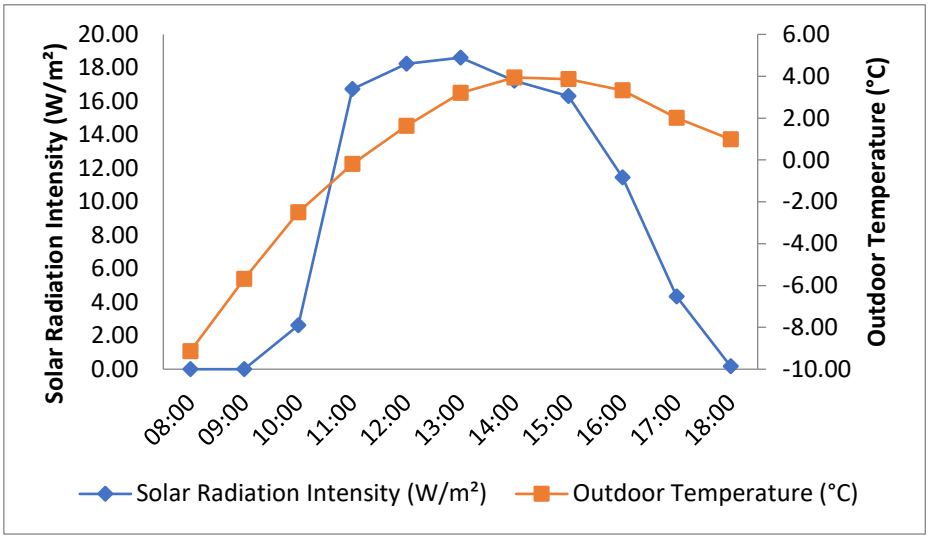

Figure 9 Solar radiation intensity and outdoor temperature for February 12 in Kayseri.

According to the solar radiation intensity levels on the window surfaces, heating loads have been evaluated for February 12. In the evaluation, the hours of 08:00-18:00, which are determined as the working hours of the day, have been taken into account (Figure 10).

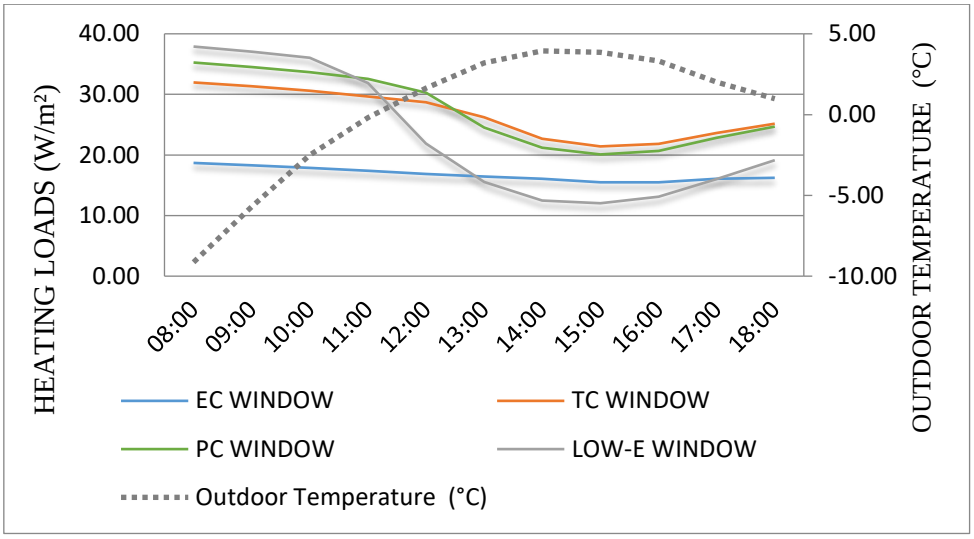

Figure 10 Heating loads of windows for February 12 in Kayseri.

Heating loads for each window option are at maximum values at 08:00 when the outdoor temperature is -9°C. A reduction has been observed in the heating loads on all windows until 15:00. Accordingly, the lowest and the highest heating loads are 15.49 and 18.69 W/m² for the electrochromic window, 21.41 and 31.97 W/m² for the thermochromic window, 20.09 and 35.26 W/m² for the photochromic window, and 12.03 and 37.90 W/m² for the low-E coated window in this hour range.

While there were no sudden fluctuations in the heating loads between hours 15:00-18:00, an increase has been observed in the heating loads on all windows. Accordingly, in this hour range, the heating loads reach the value of 16.24 W/m² for the electrochromic window, 25.16 W/m² for the thermochromic window, 24.69 W/m² for the photochromic window; and low-E coated window reached 19.15 W/m² at 18:00.

In the evaluation, the best-performing window type with the lowest heating load is the electrochromic window. The Low-E coated window has shown the best performance after the electrochromic window even though the beginning value of heating energy is the highest. Although the heating loads in thermochromic and photochromic windows are close by, the thermochromic window performed relatively superior to the photochromic window, hence photochromic window has shown the poorest performance.

When the total heating loads of the south-oriented office unit are compared during the day, the electrochromic window shows the best performance with the lowest heating energy use of 184.89 W/m² on February 12 in Kayseri (Figure 11).

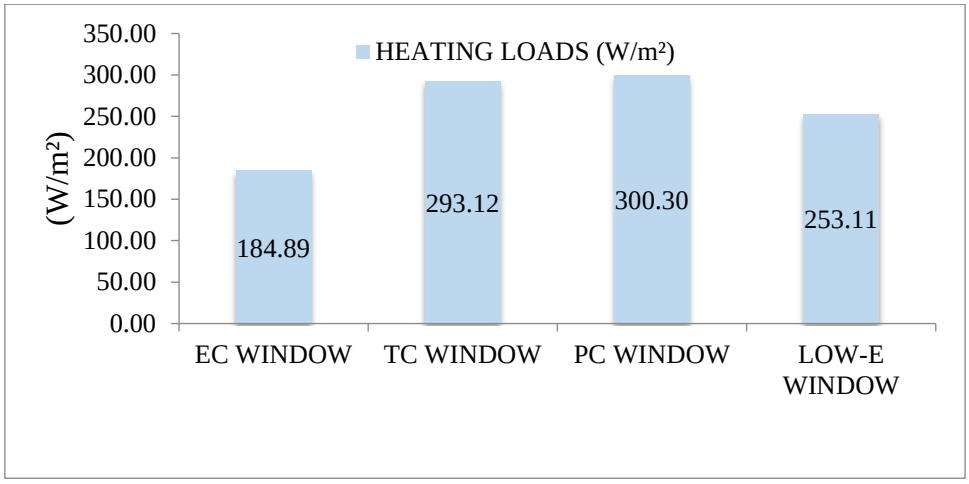

Figure 11 Total heating loads of the windows for February 12 in Kayseri.

Total heating loads on other smart windows are high during the day to ensure indoor comfort conditions. The best performing window systems after the electrochromic window are the Low-E coated window with a value of 253.11 W/m² and the thermochromic window with a value of 293.12 W/m², respectively. The worst-performing window system with the highest heating energy consumption is the photochromic window with a value of 300.30 W/m².

4. The Results of the study

Window systems in the high-rise office buildings are one of the most important components that make up the outer shell of the building, advanced in terms of functional and aesthetic aspects with the development of technology and offer better solutions to user needs. Windows are the facade elements with the highest heat loss and gain in the building envelope. Since they are transparent facade elements, they have a big role in terms of light and glare control in the interiors. Therefore, the windows used in the buildings are aimed at controlling the heat losses and gains while providing indoor comfort conditions for the user.

Within the scope of sustainability, it is expected that the building elements minimize energy loads such as heating, cooling, and lighting, that is for energy efficiency. Smart windows are innovative window systems developed and under research within the scope of this goal. The purpose of smart windows is to reduce heating and cooling loads and reduce energy expenditure by changing the opacity level of the window in response to solar radiation intensity. In recent studies, it is observed that smart windows can reduce heating and cooling loads in buildings. Within the scope of this study, the performances of smart windows and a traditional window system in Kayseri have been compared. In this comparison, the Low-E coated window system, which is a highly preferred window system, has also been added to the evaluation. The change in opacity of smart windows against solar radiation intensity in this climatic condition is given on an hourly basis for the dates of August 14 and February 12. The simulation study has been carried out with the Design Builder program. In this context, a case building has been modeled with four different window systems; daily performance of heating and cooling performances have been evaluated. Finally, total energy uses for electricity and primary energy in winter and summer time have been evaluated in Kayseri. Nevertheless, the differences in electricity are converted into primary energy with a conversion factor to prevent energy type differences in heating and cooling. According to the results, the total energy used for heating and cooling is given (Figure 12).

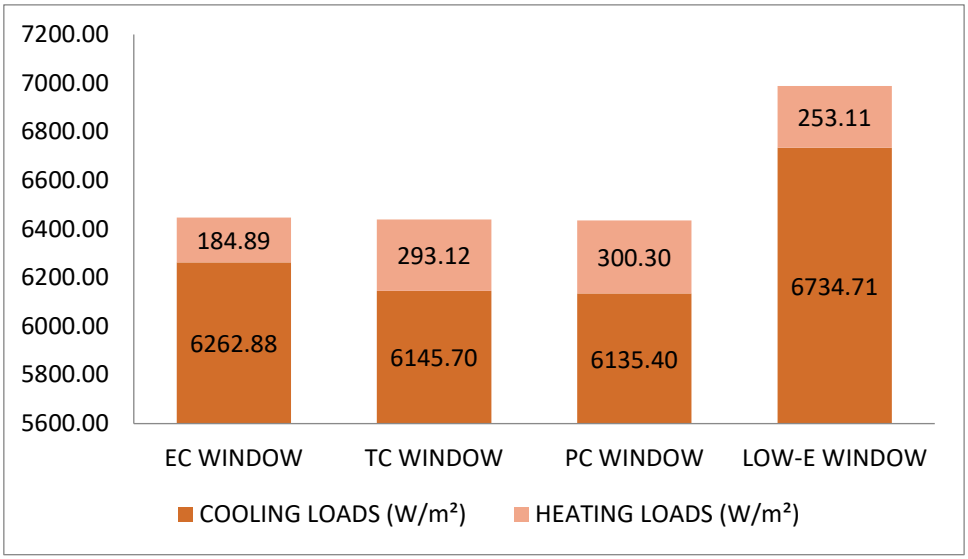

Figure 12 Total energy uses for heating and cooling for August 14 and February 12.

As the results of this study.

- Low-E window system has the least efficient cooling performance with the highest cooling loads of 6734,71 W/m².

- Although the cooling performances are close, the photochromic window system has a better performance than the thermochromic window system with the value of 6135,40 and 6145,70 W/m² respectively.
- In all smart window systems, the electrochromic window system shows the poorest performance on cooling loads with a value of 6262,88 W/m².
- Photochromic window system has the least efficient heating performance with the highest heating loads of 300,30 W/m².
- Although the heating performances are close, the thermochromic window system has a better performance than the photochromic window system in the winter period with a value of 293,12 W/m².
- In all window systems, the electrochromic window system shows the best performance on heating loads with a value of 184,89 W/m².
- Low-E coated window system shows the best performance on heating loads after electrochromic window systems with the value of 253,11 W/m².
- The photochromic window is the window system that showed the best performance with the lowest total energy use in Kayseri.
- In total energy uses, Low-E coated window system has the worst performance.

5. Conclusion

In conclusion, it has been observed that photochromic and thermochromic windows increase the building energy efficiency compared to other windows in Kayseri for winter and summer periods, hence total energy use, and it has been determined that their use is advantageous. In all smart window system types, electrochromic windows show the poorest performance, however, using electrochromic window have advantages in winter periods. When looking at the total values in Kayseri, the photochromic window shows the best performance. Therefore, photochromic windows are relatively preferable when compared to thermochromic and electrochromic windows in total energy use. Although Low-E coated window systems perform more positively in heating loads when compared to the photochromic and thermochromic window systems, Low-E coated window shows the poorest performance among all in total energy uses due to the higher cooling loads. This result can be explained by switching all smart windows to darker states due to the high solar radiation intensity, hence preventing overheating in the summer period in Kayseri. However, it has been observed that smart windows increase lighting loads due to being in the tinted state cause of high solar radiation intensity in recent studies, therefore their use may be considered disadvantageous for energy efficiency.

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Resume

Ayşenur Karakaya has completed the M.Sc in Environmental Control and Construction Technologies Programme from Istanbul Technical University, Turkey. She has a publication in smart materials named 'A Research About Smart Facade Materials Within the Context of Sustainable Architecture'. She is presently workings on more papers on smart materials and energy performances of smart windows and comparative studies on different cities. Her other areas of specialization include architectural design and construction drawings due to her career experiences.

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Geospatial technologies for physical planning: bridging the gap between earth science and planning

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Abstract

The application of geospatial information technologies have increased recently due to increase in data sources from the earth sciences. The systematic data collection, storage and processing together with data transformation require geospatial information technologies. Rapidly developing computer technology has become an effective tool in design and physical planning in international platforms. Especially, the availability of geospatial information technologies (remote sensing, GIS, spatial models and GPS) for diverse disciplines and the capability of these technologies in data conversion from two dimensions to the three dimension provide great efficiency. This study explores how digital technologies are reshaping physical planning and design. While the potential of digital technologies is well documented within physical planning and visualisation, its application within practice is far less understood. This paper highlights the role of the geospatial information technologies in encouraging a new planning and design logic that moves from the privileging of the visual to a focus on processes of formation, bridging the interface of the earth science and physical planning.

Keywords: remote sensing, GIS, spatial model, GPS.

1. Introduction

The universal understanding of physical planning and design is based on knowledge-based approaches. The principles of this concept are still same since Design with Nature by Ian L. McHarg (1969), however today the volume of accessible information and instruments have largely increased as a result of advancing technology and the increase in multi-disciplinary studies. Thus, the concept of “big data” has emerged. As Eric Schmidt, the former CEO of Google, stated that data produced by humanity until 2003 is recorded every two days today. Processing and converting data into information became a major concern.

After the first geographic data processing software (SYMAP) with vector-based punch card-operated two-dimensional analysis capability at Harvard in 1965, ESRI (Environmental Systems Research Institute) released the first commercial Geographic Information Systems (GIS) software in 1982, and GIS completed its dissemination process until 1990. With the acceleration in computer

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technology after 1990 and the rise of climate change studies after 2000, the increase in multidisciplinary collaborative studies in geosciences have improved the amount of data and processing techniques.

From physical planning point of view, there has been a chance to use approaches that go from data-constrained studies to data-intensive studies, from static snapshot detection to dynamic continuous monitoring processes, from coarse-scale generalizations to high-resolution details, from simple and general models to more detailed integrated complex models.

Planning, which is defined as the process of systematically designing future actions, has a multidisciplinary structure by nature and the spatial decision problems of interest are in the form of ill-structured problems (ISP) (Davidoff and Reiner 1962). It started as a sub-field under the discipline of architecture, limited to field research and physical planning, primarily in the form of determining the locations and sizes of different land uses in urban areas. Over time, working disciplines that are closer to art have been influenced by the quantitative evolution in social sciences that started in fields such as geography and sociology, and have gained a technical discipline identity (White, 1974; Ceuclelis, 1982, Taylor, 1998; Brail and Klostermann, 2001; Çubukçu, 2008).

Spatial planning activities are tried to find a solution to “How can we create livable environments” question in bases. In this context, time and space-related data sets are constantly encountered. It can be mentioned about the processes that change depending on the structure and dimensions of the space, which is defined as planning support systems (PSS) (Batty, 1995) and a part of the Spatial Decision Support Systems (SDSS).

As a result, the most important research question is, can we produce the right information with up-to-date spatial information technologies? Can we transfer the generated information to the planning and design process?

This study aims to evaluate the potential of remote sensing, GIS and spatial models for physical planning within the scope of spatial information technologies.

2. Spatial Planning and Geospatial Technologies

Geospatial sciences such as remote sensing (RS) and Geographical Information Systems (GIS) are provided essential tools in data preparation (digitalizing, extraction, definition, integration, registration etc.), and data analyzing (decision making, change detection, impact assessment, scenario development etc.) stages in the SDSS process associated with spatial planning.

Nowadays SDSS is used in many fields that is interested in geosciences because of multiple data assessment ability, multi criteria assessment techniques (MCA), and machine learning approaches are one of the most important parts of the geospatial science. Şatır (2013) was evaluated the studies related with MCA and GIS in planning, and decision assessment process. Land suitability (28.5%), plan and scenario assessment (15.4%), area selection (14.5%), resource analyses (11%), transportation (7.8%) and impact assessment (3.4%) were defined as the most studied areas of MCA and GIS.

RS provides easy, fast, accurate, low-cost and up-to-date opportunities in the process of obtaining the base data for planning. The benefits of RS tools in spatial planning are presented in Table 1.

Table 1 Benefits of RS tools in spatial planning (adopted from Şatır *et al*., 2022).

Information type	Material type	Method	Benefit
Land Use Cover Change and quantity.	Aerial photos and satellite dataset	Classification techniques, index-based approaches, change detection analyses	Mapping past and current Land use and covers.
Road networks, river streams and watershed boundaries	Ortho photos, radars and satellite images	Digitalization and automatic extraction techniques,	Accessibility analyses, stream network extraction, topographic situation.

		classification and 3D production methods	
Building stock and urban morphology	Aerial photos and satellite images	Extraction and digitalization techniques, classification techniques	Built up area detection, urban resilience definition, risk assessment.
Topography	Orthophoto production techniques (UAV etc.), radar datasets, sterio satellite images.	Point cloud production, ready to use data providing	Obtaining the Slope, aspect, elevation, land form, sun effect data.
Climate data	Thermal imaging, meteorological or atmospherically research satellites.	Thermal data processing techniques, radiative transfer models, ready to use data providing.	Surface temperature data, precipitation data, evapotranspiration data, humidity data.
Soil data	Hyperspectral satellites and aerial photos, broad band satellite and radar dataset (C and X bands).	Target based detection techniques, target-based indices, radar interpolation and processing techniques.	Soil humidity, soil salinity, soil organic carbon detection, some of the nutrient's detection in the soil, rough soil texture, structure and soil stoniness.
Vegetation data	Infrared satellite and aerial dataset.	Vegetation indices, classification techniques, object-oriented techniques.	Detection of green structure, vegetation type and plant species, change and Ecosystem service gain or loss.
Social data	Anthropogenic impacts on ecosystem such as (road, built up, industrial sites etc.)	Anthropogenic impact indices, environmental impact indices, landscape metrics.	Pressure on natural ecosystems and temporal changes.

The spatial planning tools have the capacity to integrate remotely sensed images, spatial plans, graphical information's or planning decisions inside the spatial modelling tools and can be incorporated into GIS environment effectively. The basic components of the spatial modelling were given in the Figure 1.

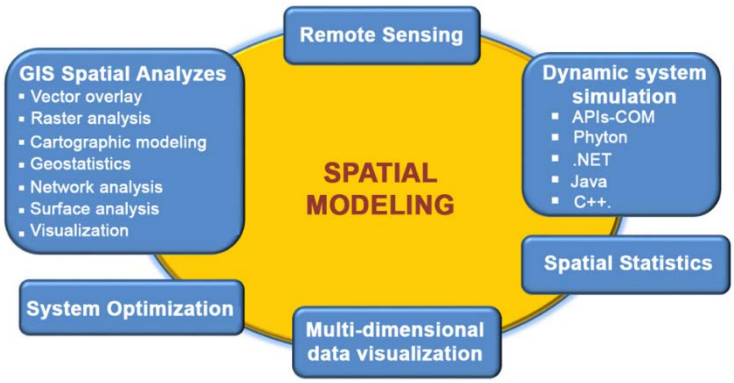

Figure 1 Spatial modelling context

The determination of suitability maps that meet certain criteria in geographic data to analyze information about location and condition is seen in the regional studies of Ian MacHarg, especially in the early period (1969-1980). As a result of the formation of regular data sets, the diversification of different data sources such as remotely sensed data (Landsat, SPOT) and their accessibility, the direction and trend of monitoring and change have begun to be examined since the 1980s. As a result of the intensive use of spatial statistics together with geographical data in the 1990s, it was ensured that the cause-effect relationship was understood together with the problem determination of the spatial distribution and pattern. Since the late 1990s, modeling studies have taken their place in geographic information technologies intensively. Increasing the software development skills of geoscientists and the transformation of climate change studies into an important research area have led to modeling studies. However, modeling studies, which allow simulating the results of plan decisions, have not yet entered the agenda of physical planners sufficiently.

Modelling is a simplified presentation of an occurrence for the purpose of planning, estimating, explaining, or describing. Terrestrial model types are grouped into four groups according to their purposes: Descriptive; Explanatory; Predictive; Normative models.

3. Environmental Modelling as a Spatial Planning Tool

Spatial models include regional economic development models, land and housing market models, facility location models, spatial diffusion models, migration models, travel and goods transport models, and urban land use models regarding all areas of human influence.

The use of these models makes important contributions to the production of quantitative data that will facilitate the plan decision making. Today, at the point of data evaluation, only the basic functions of GIS are used to support planning decisions, while spatial models have capability of processing further (Figure 2).

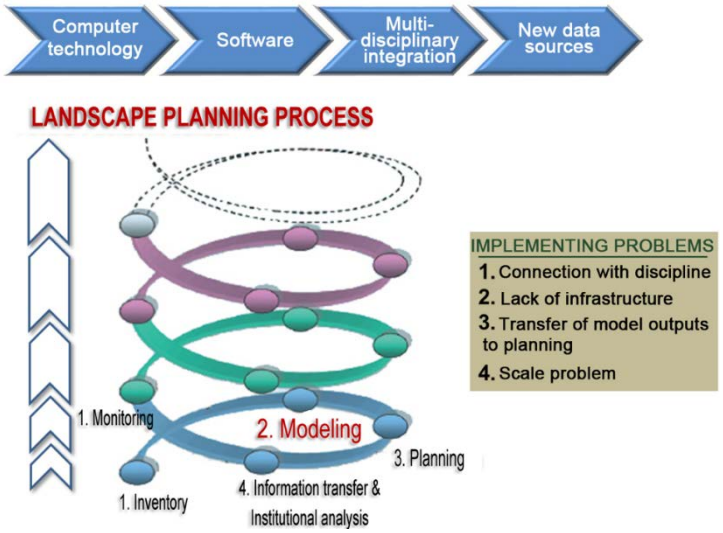

Figure 2 Spatial Modelling Development Process

Although the use of information technologies and modeling studies in recent years has brought great innovations in every field of physical planning, urban growth and 3D modelling techniques were presented.

Scenario-based urban modelling

Spatial modelling tools incorporated with scenario layer such as spatial plans are the key factor for the sensitive analysis and realistic planning for the future. The concept of scenario planning was developed for military purposes in the 1950s at RAND Corporation (Pillkahn, 2008; Heijden, 1996; Bradfielda et al., 2005). During the 1960s, scenario methodology was extensively used for social forecasting, public policy analysis and decision making. In the early 1970s scenarios were improved and use of scenario planning has significantly increased during the last decade. Scenarios reveals visions or possible alternatives and are used to evaluate the implications of decisions and policies (Chakraborty and McMillan 2015). Besides, increasing population, nonrenewable natural sources and environment, and the global climate change necessitates the integration of quantitative techniques into the planning process. Recently, remote sensing data with different spectral, spatial and temporal resolutions, and GIS have been successful in modelling the dynamic LULC change and scenario layers can be effectively evaluated into the modelling process. The advantages of modelling and scenario planning are reflected in the reduction of uncertainty by creating and identifying possible alternatives paths of the future developments.

Comprehensive studies are performed in order to understand complex relationships among the urban drivers with the spatial modelling. Urban system models are theoretically grounded, sophisticated, and data-intensive spatial models. They are based on theories and mathematical relationships to simulate a set of interactions between transportation, prices, land use, policies, demographic and economic systems across different scales (Klosterman 1997). Thus, in order to acquire ecologically sensible and environmentally sustainable urban plans, planning process should be based on quantitative modelling approaches.

Until today many quantitative techniques considers planning decisions or scenario layers have been developed (Dietzel and Clarke, 2007; Jantz et al., 2010; Berberoglu et al., 2016; Thapa and Murayama, 2012; Lord et al., 2015; Jaoude et al., 2022).

Today, many urban growth modelling approaches have been developed including, LUCAS, Markov chain, SLEUTH, Smart Growth Index, UPLAN and UrbanSim. Cellular self-processing (Cellular Automata (CA)) attracts the attention of researchers in simulating and predicting urban development. Although CA models seem simple in scope, they have the potential to simulate complex areas such as cities and successfully predict the process of the spatial structure of the city over time. The advantages of CA models include: (i) being interactive (results can be interpreted and quantified visually), (ii) easily correlated in a GIS environment, (iii) available from spatially-based cellular data, eg remotely sensed images (iv) easily correlated with environmental models (Tanriover, 2011).

To model urban process dynamics, s and Hoppen (1997) developed a revised cellular automation method: SLEUTH (Slope, Land use, Exclusion, Urban, Transportation and Hillshade). Five basic input maps are needed in SLEUTH: urbanization, transportation, 'inference' areas where urbanization should not exist, slope and slope views. Urbanization is the most important layer in the model and spatial scatter images of the city from at least four different years are needed for statistical calibration (Silva and Clarke, 2005) (Figure 3).

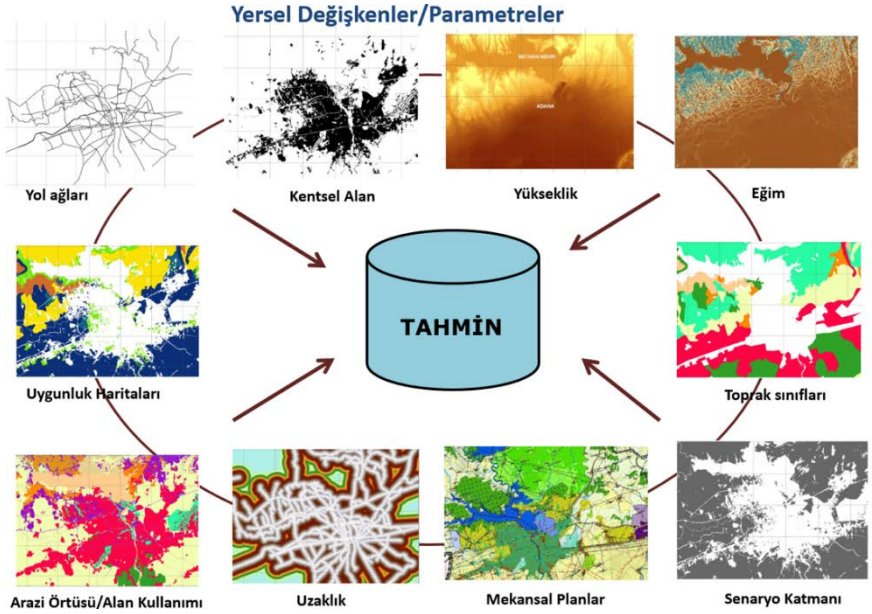

Figure 3 Urban growth modelling inputs for Adana.

Akın et al., (2014) investigated the effects of scenario layers on the future urban development including unmanaged growth with no restriction on growth (S-1); the growth by considering environmental protection and assumes managed growth with strict protection (S2), and managed growth with moderate protection (S3) derived from the 2023 spatial plans. Between 1967 and 2007, urban change was determined for Adana province in ten-year periods and urban growth probability images were created for 2023 using SLEUTH (Figure 4) (Berberoglu 2011; Akın et al., 2014).

Eventually, the simulation of the current urban spatial pattern should help planners and decision makers to evaluate the past implementation of urban planning, and scenarios simulation can provide effective support for future urban planning by evaluating the consequences.

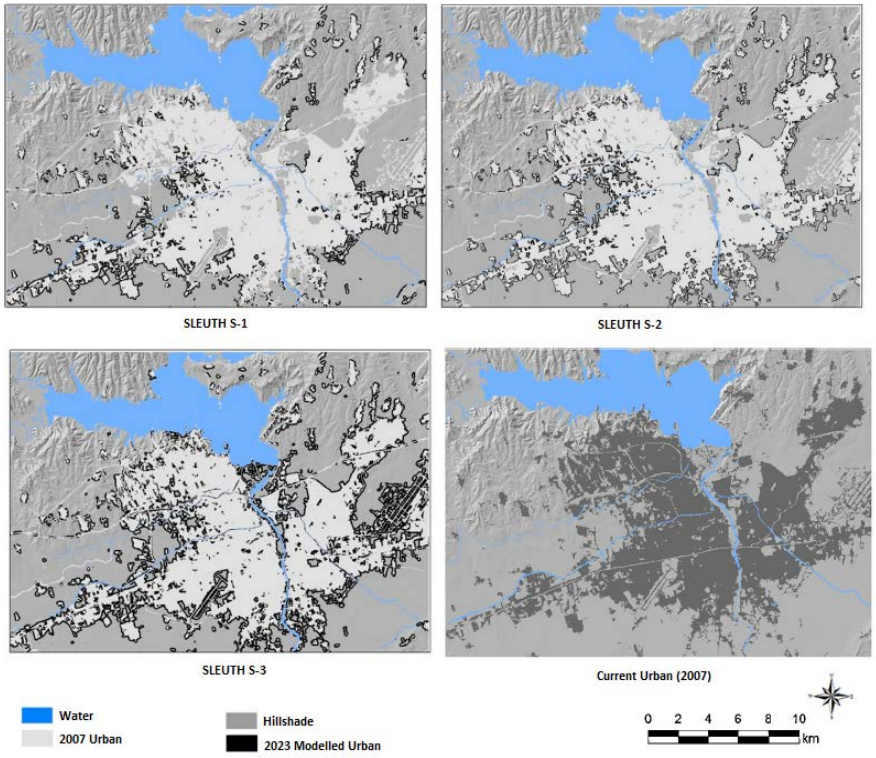

Figure 4 Comparison of potential urban growth for 2023 modelled with different scenario layers (Berberoglu 2011; Akın et al., 2014).

3.1. Three-dimensional data generation

Stereo Images

Digital tools are gradually developed from the two-dimensional level to the three-dimensional level and even the fourth dimension to support the decision-making process and to share ideas quickly and effectively so that they are easily accessible to users. Today, data produced by remote sensing and photogrammetry techniques are used in many areas. Unmanned Aerial Vehicle (UAV) photogrammetry may partially replace data collection from traditional platforms, but it also opens up new possibilities for many fields, both in research and in practice (Remondino et al. 2012, Colomina and Molina 2014, González-Jorge et al. 2017). UAVs provide users with great flexibility in terms of available sensor equipment, time and flight planning. UAV Systems can include video, thermal, multispectral, hyperspectral cameras or lidar sensors according to different carrying capacities. In addition, the GNSS/INS (Global Navigation Satellite System/Inertial Navigation System) system in UAVs provides high precision positioning of the data received from the sensors.

The use of affordable UAVs as versatile flying platforms for various sensors and photogrammetric software enables physical planners to create geo-referenced 3D models at a much lower cost and faster than traditional topographical survey methods. Data collected by UAVs is not limited to topography, but can also be used to assess flood risk, vegetation, or to base landscape design studies.

Conversion from overlapping images to point clouds, surface models or orthophoto images can be done at low cost and high speed (Figure 5).

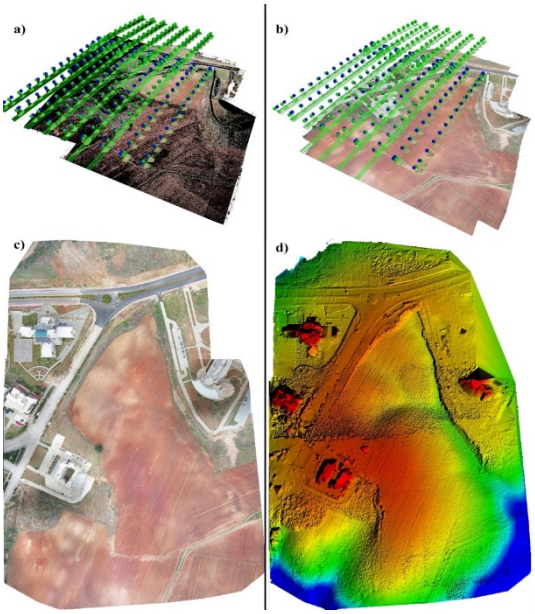

Figure 5 Generation of point cloud (a), surface modeling (b), orthophoto (c) and digital elevation model (d) images for merging photogrammetric images (Cukurova University Campus).

Images taken from UAVs with a 70% overlap are combined as a result of photogrammetric processes, and orthophotos are produced and used as a base in planning studies. As an example, the HEPP plant was used quite effectively in the rehabilitation project as a result of the deterioration in the topography during the construction. Topographic data is produced for the areas where restoration is required. The images were acquired over the areas using UAV and orthophoto maps were derived using photogrammetric processes with a sensitivity of 5 cm. (Figure 6).

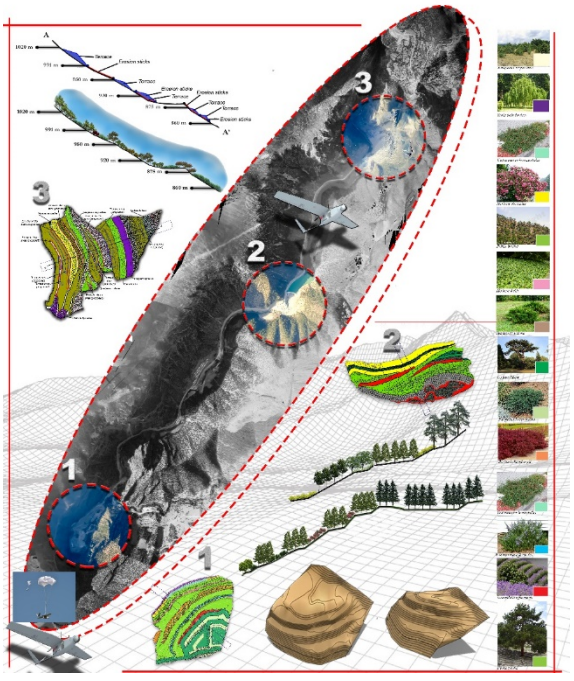

Figure 6 3D models created using UAV images and their use in landscape restoration projects (Adana, Saimbeyli - Yamanli HEP site)

Generating 3D with Lidar Images

Lidar (Light Detection and Ranging) technology plays an important role in digital imaging of objects, 3D scanning and modeling, and remote sensing and terrestrial photogrammetric methods in creating landscape topography. Lidar locates the distance of an object or a surface using laser pulses by determining how long it takes for the signal it sends to return. These positionings are

created by sending millions of laser pulses per second, transforming them into a cloud of laser dots with millions of coordinates representing the scanned object with GPS / GNSS receivers. From the point cloud obtained from the LIDAR data; Basic measurement data, 2 or 3D drawings, 3D animation, solid surface models or 3D models with realistic surface textures can be obtained.

In recent years, laser scanning systems have been widely used in urban planning and design studies to produce 3D models with high accuracy (about 5 cm precision) (Figure 7).

Figure 7 Lidar sensors on unmanned aerial vehicles

Generating 3D with Radar Data

Remote sensing systems/sensors are basically divided into two as active and passive sensors. Active sensors use their own energy source to observe objects, while passive sensors need an energy source such as the sun. Active sensors detect the object by providing radiation in a certain waveband range without the need for a different energy source. Most active sensors operate in the microwave portion of the electromagnetic spectrum. Detection takes place when the energy sent by the active sensor reaches the object and some of the energy is reflected back to the sensor. While the energy reaches the object and returns to the sensor, the sensor creates a two-dimensional image of the surface by recording the range and magnitude of the energy reflected to the targets.

Synthetic Interferometric SAR (InSAR) data can be used to directly estimate Digital Elevation Model (DEM) generation using SAR data can be performed by various techniques. The main ones are radargrammetry and Interferometric SAR (InSAR). InSAR uses the intersection differences of at least two complex value SAR images acquired at different orbital positions and/or different times. The InSAR method is known to represent a unique method for detecting and mapping surface displacements with precision in the centimeter and even millimeter range. InSAR method is widely used in studies such as surface changes in urban areas.

4. Discussion

Spatial information technologies including remote sensing, spatial modelling, and GIS have been successful in dynamic environmental change such as urban growth. A realistic spatial planning should include realistic driving factors of environmental patterns and quantitative modelling techniques. These driving forces should include socio-economic, ecologic and multi-temporal data sets to achieve sustainable environmental management related with the effective spatial planning. Thus, given the recent developments in geospatial technologies and the increase in modelling methods and tools, have the many forms in which that spatial data is required. Besides, environmental models are among the objective geospatial methods for determining the priorities for planning process and designed to assess the ecological impact of variate spatial data associated with demographic, economic, policy, and environmental scenarios.

These well-established modelling tools have enabled a better understanding of the complex interactions of environmental processes. For example, GIS-based models of property and demographics traditionally associated with urban planning policy are being coupled with models of energy consumption traditionally associated with urban management (Saunders et al., 2020). Similarly, models associated with transportation and planning are being coupled with 3D models associated with urban design and development (Dawwas, 2018; Easa et al., 2002).

Spatial modelling with geospatial technologies can develop as a more effective discipline that promotes greater understanding and better decision making in the planning, design and management of cities and urban regions. Cities and urban regions can then be better prepared to mitigate environmental impacts through more sustainable practices (OECD, 2011).

Considering the education programs, academic studies are limited to classical data sets and techniques, so spatial information technologies (remote sensing, GIS, spatial models and GPS) within the field of physical planning, have significant advantages for planners. In this context, the main problem is transferring the information into planning and design through spatial information technologies. Our education programs, especially postgraduate studies, should support these areas, by bringing the model results into a format that can be transferrable to planning process, and there is a need to form the results into appropriate scales using downscaling techniques. Thus, it is important to train well-equipped physical planners who can understand and use spatial information technologies. The main goal is sustainable planning and design in harmony with nature, and the way to achieve this goal by using the right information in planning and design.

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Resume

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Assessing the performance of machine learning algorithms in Google Earth Engine for land use and land cover analysis: A case study of Muğla province, Türkiye

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Abstract

Regions with high tourism density are very sensitive to human activities. Ensuring sustainability by preserving the cultural characteristics and natural structure of these regions is of critical importance in order to transfer these assets to the future world heritage. Detecting and mapping changes in land use and land cover (LULC) using innovative methods within short time intervals are of great importance for both monitoring the regional change and making administrative planning by taking necessary measures in a timely manner. In this context, this study focuses on the creation of a 4-class LULC map of Muğla province over the Google Earth Engine (GEE) platform by utilizing three different machine learning algorithms, namely, Support Vector Machines (SVM), Random Forest (RF), and Classification and Regression Tree (CART), and on comparison of their accuracy assessments. For improved classification accuracy, as well with the Sentinel-2 and Landsat-8 satellite images, the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) are also derived and used in classification of the major land use classes, which are 'built-up area & barren land', 'dense vegetation', 'water surface', and 'shrub, grassland & sparse vegetation'. Experimental results show that the most relevant algorithm is RF with 0.97 overall accuracy and 0.96 Kappa value, followed by SVM and CART algorithms, respectively. These results indicate that the RF classifier outperforms both SVM and CART classifiers in terms of accuracy. Moreover, based on the results of the RF classifier, 19% (2,429 km^2) of the study region is classified as built-up area & barren land, 48% (6,135 km^2) as dense vegetation, 2% (301 km^2) as water surface and 30% (3,832 km^2) as shrub, grassland & sparse vegetation class.

Keywords: Google Earth Engine (GEE), land use/land cover (LULC) maps, machine learning, remote sensing.

1. Introduction

Due to globalization and rapid population growth, while the world's resources are rapidly depleting, an ever-increasing energy need has emerged. Analysis and evaluation of land use are crucial now more than ever to fulfill the needs of developing cities and growing populations (Avtar, Tripathi, Aggarwal, & Kumar, 2019; Long, Qu, Tu, Zhang, & Jiang, 2020). One of the main parameters

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in protecting natural resources by ensuring sustainable development and combating climate change is the creation of regional and global land use and land cover (LULC) maps (Borrelli et al., 2017; Rajbongshi, Das, & Adhikari, 2018; Feizizadeh, Omarzadeh, Kazemi Garajeh, Lakes, & Blaschke, 2021). LULC maps, which can be produced with high-resolution satellite images and remote sensing (RS) techniques (Dou, Shen, Li, & Guan, 2021; Fonseca et al., 2021), play a critical role in the determination and effective management of land use (Harper et al., 2018; Shirmohammadi et al., 2020). For instance, the planning of actions such as monitoring and guiding urbanization, agricultural activities, and conservation of natural resources by decision-makers, taking into consideration the economic benefit, is directly related to the efficient production of LULC maps (Y. Qu & Long, 2018; Stehfest et al., 2019). For this reason, improving classification accuracy in RS applications has long drawn the interest of researchers. (Richards, Landgrebe, & Swain, 1982; Khatami, Mountrakis, & Stehman, 2016; Phiri & Morgenroth, 2017).

With its strong capacities to access, handle, and analyze huge volumes of multi-source, multi-temporal, and multi-scale earth observation data through a cloud platform, Google Earth Engine (GEE) has been recognized as a significant geospatial analysis platform for RS applications (Sazib, Mladenova, & Bolten, 2018). GEE provides more than 40 years' worth of remotely-sensed data from satellites like Landsat, MODIS, Sentinel 1, 2, 3, and 5-P, National Oceanographic and Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA AVHRR), and Advanced Land Observing Satellite (ALOS), as well as demographic, geophysical, climate, and weather datasets (GEE, 2022). In this regard, GEE offers fascinating possibilities for a wide range of studies, such as those involving climate change, urban mapping, crop mapping, forest mapping, water surface investigations, soil moisture, and soil carbon sequestration (Tamiminia et al., 2020; GEE, 2022). Moreover, GEE is considered to be a promising tool for the production of LULC maps with the abilities of evaluating changes in forest and water areas, land and agricultural areas (Huang et al., 2017; Sidhu, Pebesma, & Câmara, 2018; Carrasco, O'Neil, Morton, & Rowland, 2019; Qiu, Schmitt, Geiß, Chen, & Zhu, 2020). However, it is often challenging to scale-up these findings globally because most of the existing studies in the literature concentrate on the production of LULC maps for certain regions (Loukika, Keesara, & Sridhar, 2021). A more wide-ranging application area would be provided if further studies are conducted on improving the accuracy of the machine learning algorithms used to generate these maps. For example, Li, Qiu, Ma, Schmitt, and Zhu (2020) proposed a framework for African land cover mapping at 10 m resolution, and the effectiveness of GEE for large-scale areas was evaluated. In a study conducted by Aghlmand, Kalkan, Onur, Öztürk, and Ulutak (2021), the feasibility of creating land use maps over GEE with RS methods in Eskişehir/Türkiye was investigated. Farda (2017), in the study conducted in Segara Anakan lake/Indonesia, aimed to determine the accuracy level for multi-time land use mapping of coastal wetlands with ten different machine learning algorithms in GEE. The obtained results showed that machine learning in GEE is very useful for multi-temporal land use mapping, where CART being the most successful method with an overall accuracy of 96.98% among the others. The oil palm distribution in Malaysia was mapped by Shaharum et al. (2020) with a variety of machine learning techniques using RS and GEE. The results investigated that the SVM algorithm with an accuracy of 93.16% was the most effective one. L. a. Qu, Chen, Li, Zhi, and Wang (2021) examined the effect of six ancillary features in GEE on accuracy improvements in the classification of LULC maps in the Yangtze River Delta/China region.

Understanding machine learning techniques and how they work in popular cloud-based systems like GEE is crucial given the rising need for trustworthy LULC maps derived from satellite images. The aim of this study is to produce LULC maps of Muğla province in Türkiye using machine learning algorithms in the GEE platform and to compare the performance of the algorithms for LULC classification task. In this context, three different machine learning methods - namely, Support Vector Machines (SVM), Random Forest (RF), and Classification and Regression Tree (CART), are utilized in the classification of four major land use classes which are 'built-up area & barren land', 'dense vegetation', 'water surface', and 'shrub, grassland & sparse vegetation'. Multispectral satellite images from Landsat-8 and Sentinel-2, as well with two indexes (Normalized Difference

Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI)) are used in producing the LULC maps. The selected study area, Muğla, is significant in terms of its natural resources and tourism potential, but also has high fire activity rates continuously increasing due to climate change (Sari, 2021). The original aspect of this study is the production of the 4-class LULC map of the Muğla province, with Sentinel-2 and Landsat-8 image collections and two supplementary indexes over the GEE platform. Another aspect of the study is the accuracy assessment of these machine learning algorithms with standard metrics and comparison with each other in LULC classification task. The study contributes to the literature in producing the LULC maps of the Muğla province at the regional level and in improving the classification accuracy.

2. Materials and Methods

The study area and the material and methodology utilized in the study are described in this section.

2.1. Study area

The study area is Muğla province, located between 37.928 N - 35.93 N and 27.045 E - 29.87 E in southwestern Türkiye, with a surface land area of 13,338 km^2 (Muğla Valiliği, 2022). The province, which consists of 13 districts and 14 municipalities, has a population of 1,021,141 according to 2021 records (Muğla Valiliği, 2022). In terms of climate, it has a rather humid Mediterranean climate, where summers are hot and dry, and winters are warm and rainy (Atmaca et al., 2022). Located at the intersection of the Aegean and the Mediterranean, the province has the longest coastline in Türkiye, with a total of 1124 km. It is one of Türkiye's leading provinces in the tourism sector, world-famous gulfs and bays, forested areas covering 67% of its land area, and a wealth of cultural treasures. (Bahar, 2008). At the same time, significant economic activities are carried out in the province in agriculture, animal husbandry, and industry sectors (T.C. KTB, 2022).

After İstanbul and Antalya, Muğla is the third-most-visited city in Türkiye. Due to the city's tourism-driven growth and the activities experienced in the coastal regions, both the continuation of conservation efforts and the preservation of the city's cultural traits must be handled with care (Yücel & Ertin, 2019). In this context, the Muğla Governorship Provincial Culture and Tourism Directorate (Bingöl, 2022), Muğla Metropolitan Municipality (Muğla Büyükşehir Belediyesi, 2022b), Department of Reconstruction and Urbanization (Muğla Büyükşehir Belediyesi, 2022a), and related institutions conduct various studies and legislative arrangements. The province of Muğla is selected as the study region to support this legislative structure and assure the adoption of innovative methodologies in the construction of a LULC map that can be utilized by decision makers. The location of the study area is illustrated in Figure 1.

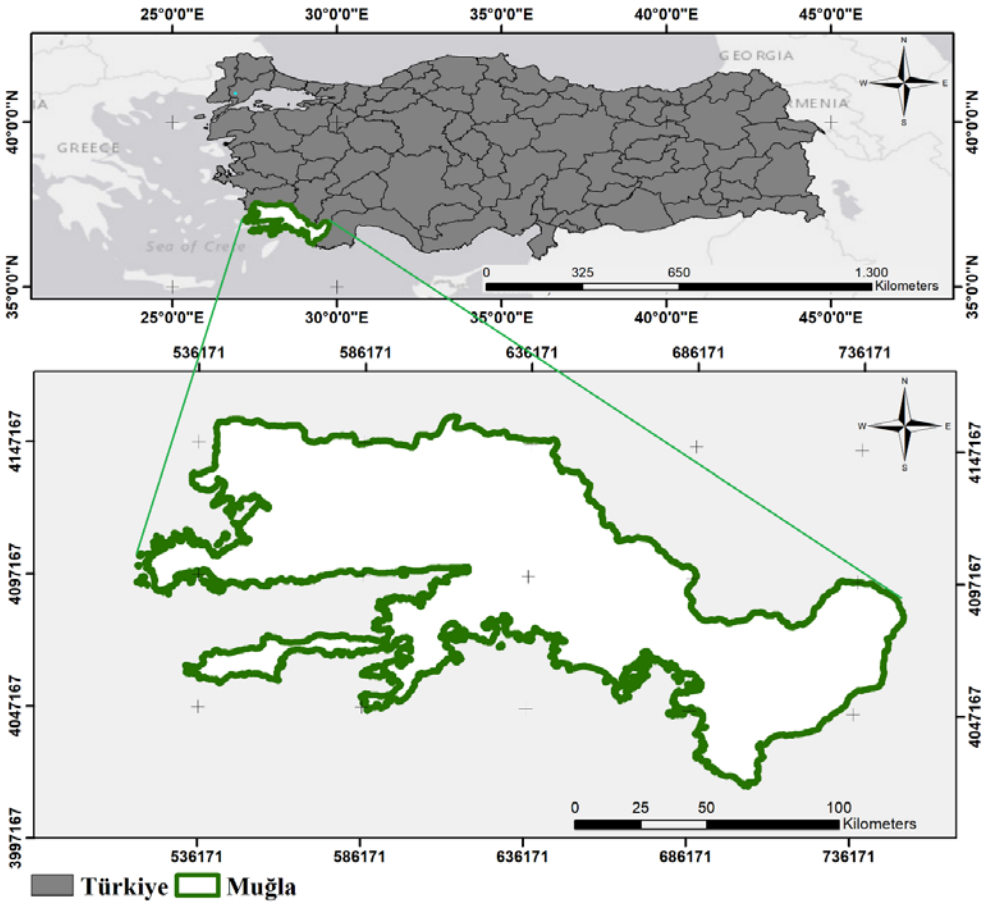

Figure 1 Location of the study area: Muğla Türkiye

2.2. Material and Method

The main material of the study is the satellite imageries. Two different spatial resolution satellite data, Landsat-8 satellite images at 30 m resolution and Sentinel-2 satellite images at 10 m resolution, are utilized that are retrieved through GEE searches. The search results are filtered with "5% cloudiness" for the period "2020-05-01 to 2020-08-11" and image collections are compiled between these dates. By adding a cloud cover percentage filter on the images, it is aimed to minimize the noise sources. Then the median values of the obtained images are calculated. For this study, Bands 2, 3, 4, 5, 6, 7 of Landsat-8 satellite images, and Bands 2, 3, 4, 5, 6, 7, 8 of Sentinel-2 satellite images of Muğla province are used in the classification stage, as well with the auxiliary data (NDVI and NDWI) generated from these bands. The resulting maps are visualized with the ArcGIS-ArcMap 10.7.1 program.

The method of this study is to perform four-class supervised classification process in Muğla province by utilizing three different machine learning algorithms over GEE and to compare the performance of the algorithms using standard metrics. In this context, SVM, RF, and CART machine learning algorithms are trained with the band features, as well with NDVI and NDWI indexes.

In the first stage of the study, the auxiliary data that have the ability to extract certain information more effectively, are generated, which are used together with the band features as input in the classification. Within the scope of the study, as auxiliary data NDVI and NDWI are produced both to provide input to machine learning algorithms in supervised classification task and improve the accuracy of classification analyses. This way, a more comprehensive determination of the vegetation and water surfaces in the study area is aimed.

NDVI is one of the most preferred data for monitoring vegetation (Julien & Sobrino, 2009; Ozyavuz, Bilgili, & Salici, 2015; Mutti, Lúcio, Dubreuil, & Bezerra, 2020). NDVI analysis, which is performed using various bands of satellite imagery, is often used in many studies such as monitoring

drought, determining the health of plants, the productivity of agricultural lands, and the effects of forest fires (Ozenen Kavlak, Cabuk, & Cetin, 2021; Dikici, 2022). On the other hand, NDWI developed by McFeeters (1996) and Gao (1996) is relevant in identifying water components from satellite images. Water components can be determined by sieving soil and above-ground vegetation using near-infrared (NIR) and visible green (Green) bands. The values obtained as a result of NDVI and NDWI analysis are between -1 and 1. For higher chlorophyll density, the NDVI value is expected to be 1 or close to 1, and for higher water density, the NDWI value is expected to be positive (Bhandari, Kumar, & Singh, 2015). The formulas used in the calculation of these indices are given in Table 1.

Table 1 The formulas of NDVI and NDWI (Hayati, Hestrio, Cendiana, & Kustiyo, 2021)

Name of the index	Index	Formula
Normalized Difference Vegetation Index	NDVI	$\frac{NIR - Red}{NIR + Red}$
Normalized Difference Water Index	NDWI	$\frac{Green - NIR}{Green + NIR}$

The second stage of the study is to reveal the LULC map of the Muğla province including four different land use classes as

- built up area & barren land,
- dense vegetation,
- water surface, and
- shrub, grassland & sparse vegetation,

using RS and different machine learning methods over GEE. It also includes the comparison of the advantages and weaknesses of different machine learning methods in LULC map production. The GEE platform contains various classification methods provides users with fast analysis and results (Tamiminia et al., 2020). Algorithms used in this study are CART, SVM, and RF.

CART is a supervised machine learning method that generates a binary decision tree (Rokach & Maimon, 2005). A homogeneous tree structure is obtained by creating two child nodes from the parent node. The decision tree begins with a root node generated from any variable in the feature space and minimizes an impurity measure for the two sibling nodes. Then, the decision tree expands through consecutive subdivisions until it reaches a point where further subdivision does not result in a meaningful reduction in impurity (Shaharum et al. 2020). It works for both numerical and nominal values (Olfaz, Tirink, & Önder, 2019).

SVM is another supervised machine learning technique that is effective both in classification and regression. It performs the classification process by optimally separating the classes using a hyperplane (Mantero, Moser, & Serpico, 2005). Even though there are numerous ways to divide the data points, the primary goal of SVM is to locate the hyperplane with the greatest margin of separation (Shaharum et al. 2020). The LibSVM library is used in this study (Chang & Lin, 2011).

RF is an alternative supervised learning approach that generates a forest consisting of random decision trees. In order to obtain more precise and reliable predictions, RF builds numerous decision trees and ensembles them. It is applicable to both classification and regression problems (Breiman, 2001).

To evaluate the accuracy of the machine learning algorithms used in LULC map development as an image classification task, for each land use classes 300 points, thus a total of 1200 points are randomly selected from the study area. 70% of all developed samples (840 points) are used to train the algorithms, while the remaining 30% (360 points) are utilized to validate and evaluate the accuracy of the algorithms. Classification and assessment are performed in GEE, and accuracy

metrics are obtained through the standard confusion matrix approach (Cohen, 1960; Parida & Mandal, 2020) based on the validation data.

Accuracy assessment is the process of checking whether pixels are assigned to the correct classes to which they belong. As a result of the classification, a pixel can be assigned to a class actually it does not belongs. This is known as classification error, and it is preferred to be small since accuracy increases as classification error decreases (Canters, 1997, Sunar, Özkan, & Osmanoğlu, 2016). In evaluating the performance of different classifiers, various accuracy assessment metrics can be derived based on the confusion matrix, producer accuracy and user accuracy metrics for class-level comparison, overall accuracy for general comparison, and kappa coefficient are widely used in LULC mapping (Lu & Weng, 2007). Overall accuracy is the ratio of the total number of correctly labeled pixels to the total number of control pixels. A success rate of 80% is considered sufficient for overall accuracy (Sunar et al., 2016). The overall accuracy is computed using Equation 1, where $P_{correct}$ is the number of pixels classified correctly by the classifier, and P_{total} is the total number of pixels (Lu & Weng, 2007; Loukika et al., 2021).

$$Overall\ Accuracy = \left(\frac{P_{correct}}{P_{total}}\right) x\ 100 \quad \textbf{(1)}$$

Kappa is used as an indicator of the overall agreement between the classifier results and ground truth. Kappa test is a statistical method that measures the reliability of agreement between two or more observers and shows whether findings are statistically better than random (Congalton & Green, 2019).

Kappa is used as an indicator of the overall agreement between the classifier results and the ground truth. It is a statistical method that measures the reliability of the agreement between two or more raters and shows whether findings are statistically better than random (Congalton & Green, 2019) (2). The value of Kappa ranges between -1 and +1. If the raters completely agree, then Kappa value is 1. Kappa is 0, if there is no agreement amongst raters beyond what would be expected by chance. It is possible for the statistic to be negative, if the evaluations of the two raters are completely opposite to each other. Kappa is calculated using Equation 2, where Po is the relative observed agreement among raters, and Pc is the probability of chance agreement (Kiliç, 2015).

$$K = (Po - Pc) / (1 - Pc) \quad \textbf{(2)}$$

3. Results

This study is examined the performance of three different machine learning algorithms on LULC classification of Muğla province using Landsat-8 and Sentinel-2 images on the GEE platform performed using the methodology outlined in the materials and methods section. Two widely utilized indices, NDWI and NDVI, which are representative of water bodies and vegetation characteristics, respectively, are utilized in the study as auxiliary classification inputs for LULC.

Figure 2 depicts the experimental results of the NDVI analysis for the province of Muğla, while Table 2 depicts the distribution of NDVI findings by study area.

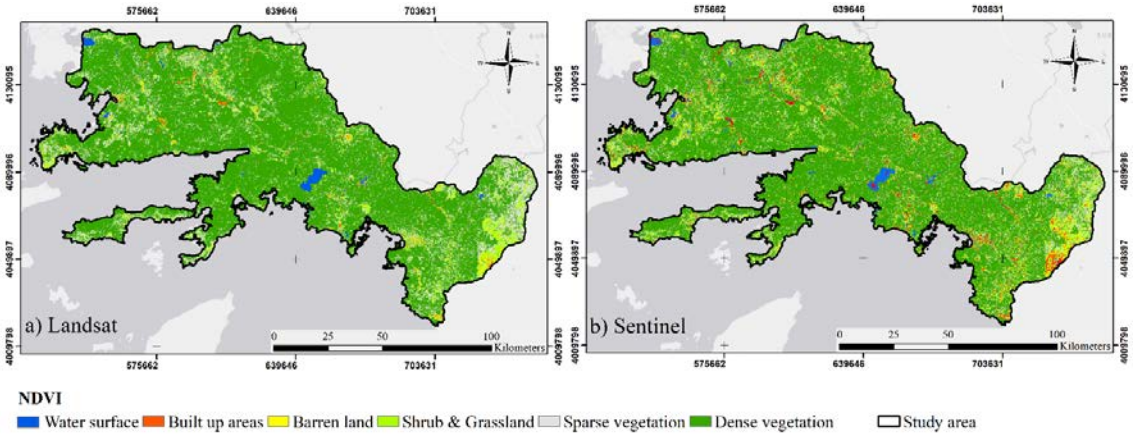

Figure 2 The results of NDVI analysis for Muğla province on (a) Landsat-8 and (b) Sentinel-2 images

As can be seen from Table 2, the results of the NDVI analysis performed with both Landsat-8 and Sentinel-2 satellite images contain similar features, and it is noteworthy that more than 70% of the study area has dense vegetation. Water surface, built-up areas, and barren land areas occupy 4% more area in total in the NDVI analysis results obtained from Sentinel-2 data.

Table 2 Distribution of NDVI results for Landsat-8 and Sentinel-2

NDVI	Landsat-8		Sentinel-2	
	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
Water surface	174	1	193	2
Built up areas	128	1	373	3
Barren land	127	1	328	2
Shrub & Grassland	881	7	1,150	9
Sparse vegetation	1,929	15	1,508	12
Dense vegetation	9,444	75	9,130	72
Total	12,682	100	12,682	100

The experimental results of the NDWI analysis for Muğla province is shown in Figure 3. Table 3, summarizes the distribution of NDWI results in the study area with Landsat-8 and Sentinel-2 satellite images. Accordingly, while 1% of the study area is covered with water surfaces, approximately 1% of it consists of shallow wetlands.

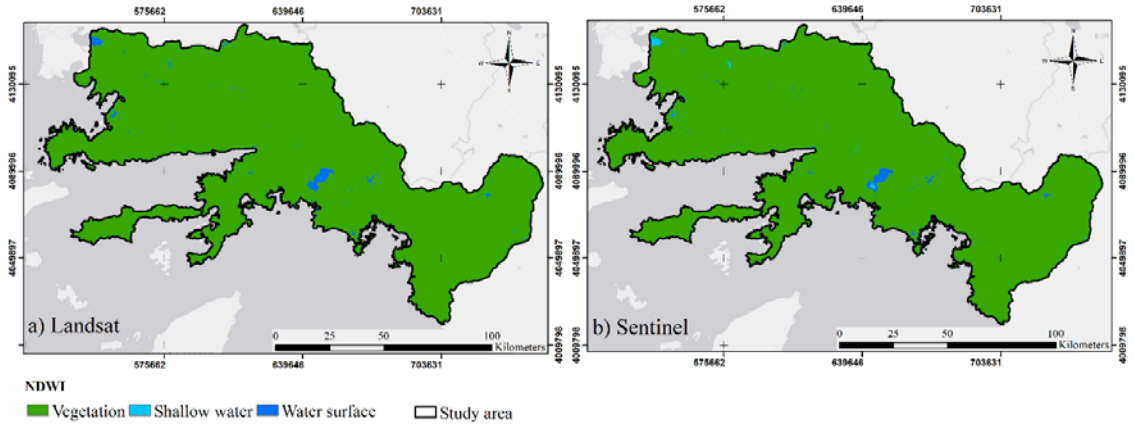

Figure 3 The results of NDWI analysis for Muğla province on (a) Landsat-8 and (b) Sentinel-2 images

Table 3 Distribution of NDWI results for Landsat-8 and Sentinel-2

NDWI	Landsat-8		Sentinel-2	
	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
Vegetation	12,493	99	12,494	98
Shallow water	28	0	82	1
Water surface	161	1	106	1
Total	12,682	100	12,682	100

In the second part, SVM, RF, and CART algorithms are utilized in the classification of four major land use classes ('built-up area & barren land', 'dense vegetation', 'water surface', and 'shrub, grassland & sparse vegetation') and the LULC maps of the Muğla province is generated.

The LULC map of Muğla province produced by the CART algorithm is given in Figure 4. According to the classification results, 17% (2,109 km^2) of the study area is classified as built-up area & barren land, 39% (4,999 km^2) as dense vegetation, 6% (801 km^2) as water surface, and 38% (4,788 km^2) as shrub, grassland & sparse vegetation class.

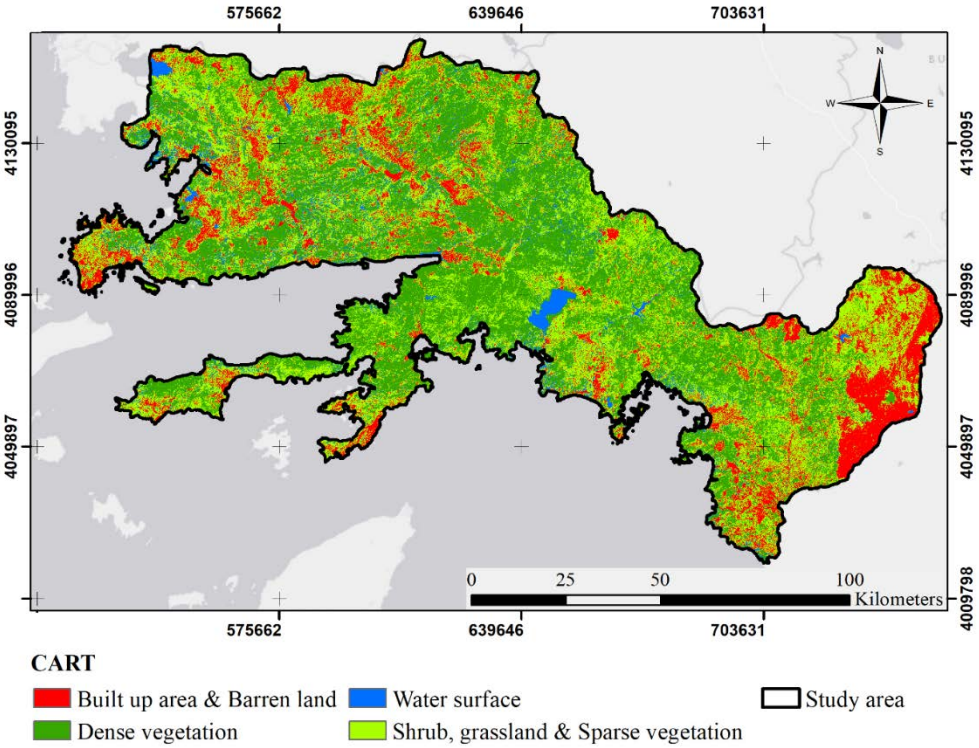

Figure 4 The LULC map of Muğla province generated using the CART algorithm in GEE

The results of the SVM algorithm in LULC map generation of Muğla province is given in Figure 5. According to the results, 9% (1,167 km^2) of the study area is classified as built-up area & barren land, 51% (6,530 km^2) as dense vegetation, 4% (446 km^2) as water surface, and 36% (4,554 km^2) is classified as shrub, grassland & sparse vegetation class.

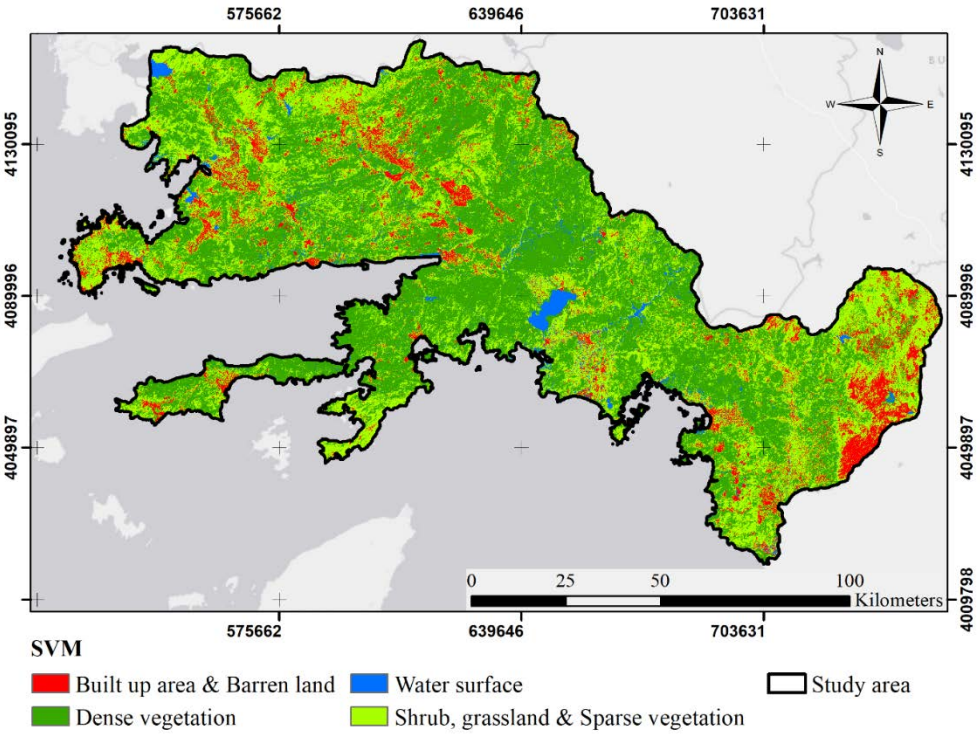

Figure 5 The LULC map of Muğla province generated using the SVM algorithm in GEE

The LULC map of Muğla province produced by the RF algorithm is given in Figure 6. Based on the results of the RF classifier, 19% (2,429 km^2) of the study region is classified as built-up area & barren land, 48% (6,135 km^2) as dense vegetation, 2% (301 km^2) as water surface and 30% (3,832 km^2) as shrub, grassland & sparse vegetation class.

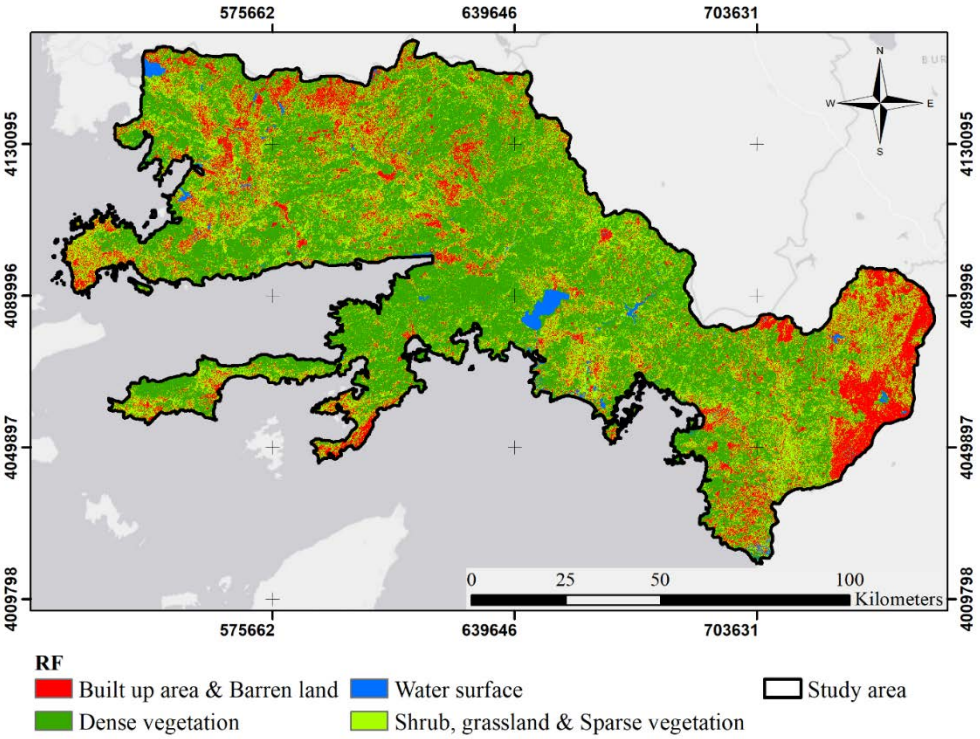

Figure 6 The LULC map of Muğla province generated using the RF algorithm in GEE

In order to evaluate the obtained results of the CART, SVM, and RF algorithms in LULC map production task, the overall accuracy, and the kappa are calculated for all classifiers. The assessment of the classifiers based on overall accuracy and Kappa are presented in Table 4.

Table 4 Overall accuracy and Kappa of the classifiers

	Overall Accuracy (%)	Kappa
CART	80	0.74
SVM	88	0.84
RF	97	0.96

Table 4 indicates that the RF algorithm is highly accurate in LULC mapping with 97% overall accuracy and 0,96 Kappa value among all three classifiers, followed by SVM with 88% overall accuracy and 0,84 Kappa value, and CART with 80% overall accuracy and 0,74 Kappa value, respectively.

4. Conclusion

High-tourism-density regions are extremely vulnerable to human activities. It is crucial to ensure sustainability by preserving the cultural aspects and ecological diversity of these areas. Muğla province is Türkiye's third-most visited city. However, especially during the summer season, forest fire danger is fairly significant. In the decade spanning the years 2012-2021, 3,312 forest fires have burned 57,242 hectares of forests (Muğla OBM, 2021). In this context, it is of the utmost importance to continuously monitor and analyze land cover by generating LULC maps in all provinces, especially high risky areas as Muğla.

Recent advancements in remote sensing and earth observation technologies, as well as the growing availability of various satellite images, have evolved remote sensing into a big data methodology requiring automated, cost-effective, and efficient approaches. GEE is a cloud-based platform that provides access to a vast collection of satellite images from across the world, as well as image processing and classification capabilities utilizing modern techniques such as machine learning and deep learning.

The aim of this study is the comparison of the performance of machine learning methods for LULC map production on the GEE platform. SVM, RF, and CART, are the three machine learning algorithms applied in the study. Landsat-8 and Sentinel-2 satellite images of Muğla province are used, as well with two supplementary indexes, in LULC classification of four land use classes - 'built-up area & barren land', 'dense vegetation', 'water surface', and 'shrub, grassland & sparse vegetation' -. Accuracy assessment is done by using the overall accuracy and Kappa value. According to the experimental results, RF showed out to be the most efficient and effective data classifier in the GEE platform with 97% overall accuracy and 0,96 Kappa value, followed by SVM, and CART, respectively.

It is commonly recognized that LULC maps can be evaluated for numerous applications such as land use planning and monitoring, as well as sustainable development assessment. This study contributes to monitoring programs of LULC changes over broad areas by applying machine learning methods. From an environmental standpoint, the results are crucial for decision-makers and authorities for understanding LULC changes and establishing relevant polices.

In future, the performance of the deep learning-based algorithms can be incorporated in the assessment. Moreover, the results can be enhanced to track more complicated earth properties, and further studies can be undertaken including hyperspectral satellite data coupled with more features like topographical data for the enhancement in LULC map production.

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Resume

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An experimental study on production opportunities of biocomposite by using fungal mycelium

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Abstract

Due to the adaptability, durability, and affordability of synthetic polymers, their usage has been increasing in the global industry. These petroleum-based polymers remain intact in nature for many years after they expire and cannot be included in the natural recycling network in any way. Producing polymers using fossil resources increasingly day by day threatens existing resources and affects the circular economy negatively. Considering the various negative effects of polymers on the environment, biopolymers could be seen as a strong alternative; which is a polymer group formed by living organisms such as plants, animals, and microorganisms. Ecological, low-emission, and recyclable biopolymers open up new and a broad range of topics in the field. Composite materials created with these biopolymer materials that act as natural adhesives; have different developing areas of applications such as packaging industry, textile, furniture, and industrial design sectors, architectural designs, and structural insulation materials. Fungal mycelium, a biopolymer, consists of fibrous filaments called hyphae, which can be defined as elongated cells, mainly composed of chitin, glucan, and proteins. The ability of fungal mycelium to digest and grow through organic matter makes it possible to produce biocomposites from mycelium. Mycelium-based composites are mixed with fungal mycelium, forming an interpenetrating three-dimensional filamentous network that binds the raw material to the material, and after completing the growth period, the mycelium growth is stopped by heat, thus offering an alternating fabrication paradigm based on the growth of materials. In this study, firstly, it was tried to find the most efficient ratio among different mixing ratios by using the mycelium of the genus Pleurotus Ostreatus and the same raw materials. Afterward, it was aimed to investigate the mechanical and physical properties through experimental studies, especially the production process, of mycelium-based composites formed by mixing different raw materials in determining proportions.

Keywords: bio-composite building material, biopolymer, mycelium, mycelium composite, sustainable materials.

1. Introduction

With the increasing population and urbanization in the world, the annual waste production and the consumption of available resources are gradually increasing. The waste generated mainly originates from trade centers, the construction sector, houses, agriculture, and various industries. Inappropriate recycling of the wastes produced causes pollution of water bodies, air, landfills, and fertile soils, causing serious damage to the environment. In addition, the rapid and unconscious consumption of natural resources necessitates the search for renewable and recyclable materials

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and the search for alternative ways to use existing resources (Abdel-Shafy & Mansour, 2018; Alemu et al., 2022; Joshi et al., 2020).

As a result of the current linear economy "produce, use and dispose of" model; It is seen that the construction sector has a significant share in global greenhouse gas emissions, depredation of natural habitats and industrial waste production. The increasing use of non-renewable materials such as concrete and steel in the sector creates environmental pressure on limited natural resources and is thought to lead to permanent depletion of resources in the near future. As a result of resource scarcity and public awareness of the building industry's increasing consumption of materials and energy, there has been a growing interest and demand for bio-based building materials and components. In this context, the emergence of biopolymers is considered promising for the future. Biopolymers are a powerful alternative to synthetic polymers. The production of biopolymers is based on living organisms such as plants, animals, and microorganisms. The increasing demand for biopolymer raw materials in industrial use leads to competition with existing stocks for food supply and complex socio-economic troubles. Therefore, the discovery of new alternative materials that are not only naturally grown and harvested, but also produced through developable processes that can be reused in waste streams and have reusability and recyclability at the end of the life cycle becomes important. (Bitting et al.,2022; Heisel & Rau-Oberhuber, 2020).

With its favorable material properties and rapid growth, fungal mycelium has become a popular research topic in recent years. Recent advances in mycelium-based renewable composites show significant potential in converting industrial waste streams into a suitable source to produce more sustainable and cyclical materials. Mycelium is the vegetative part of the fungus, which comprises of a dense network of microfilaments and is called hyphae. Myceliums are chitin-based biopolymers that can bind food, agricultural and industrial wastes with little or no commercial value and transform them into high-value composite materials with a wide variety of applications. (Bitting et al.,2022).

The quality of the composite formed with fungal mycelium as a natural adhesive material based on both the type of fungus and the type of raw material to compound. It also has unique properties low cost, low emission, and recyclable. In addition to using low amounts of energy during production and having a high biodegradability profile, mycelium-based materials are considered excessively customizable throughout the cultivation and manufacturing processes. This makes it possible to produce mycelium-based materials with several properties that can provide varying criteria from different disciplines and they are suitable for several applications. Structural applications of low-carbon materials such as mycelium in the construction industry have the potential to dramatically improve a building's environmental performance. When the structural applications of mycelium-based composites are examined, their application as a carrier structural element is restricted due to their low mechanical properties. However, with its insulating properties and moderate durability, this composite material is seen as an ideal bio-based substitute for conventional insulation elements. Today, the inadequacy of mycelium composites in large-scale architectural applications is due to the monopoly of mycelium-related patents on the market. This situation hampers the distribution of information for the mass production of mycelium composites. In addition, publications on new research and applications of mycelium-based materials prone to store data on the types of fungi used, incubation parameters, feedstock compositions, and detailed production procedures. The scarcity of generalized knowledge; makes it difficult for users to be aware of the existence of these materials and to trust large-scale applications (Attias et al., 2020; Bitting et al.,2022; Jones et al., 2020).

Within the scope of this study, mycelium-based composite material samples were produced based on the production methods and rates in the existing literature and physical and mechanical property tests of the samples produced and the results were evaluated. It is thought that this study will contribute to the development of environmentally friendly, sustainable alternative materials.

2. The Production Processes, Usage Areas and Current Studies of Mycelium Based Composites

This section describes the structure and production processes of the mycelium material. Afterward, an overview of the usage areas and the existing examples are presented.

2.1. Mycelium

Mycelium is a complex network of interlocked, microscopic, tubular fibrous cell chains, containing the vegetative part or roots of saprophytic fungi. It represents the structure that provides the necessary nutrition for the growth and development of fungi. Mycelium consists of fibrous filaments called hyphae, which are mainly composed of chitin, glucan, and proteins, which can be described as elongated cells. (Attias et al., 2020; Etinosa, 2019; Haneef et al., 2017). Schematic picture of mushroom mycelium is shown in Figure 1.

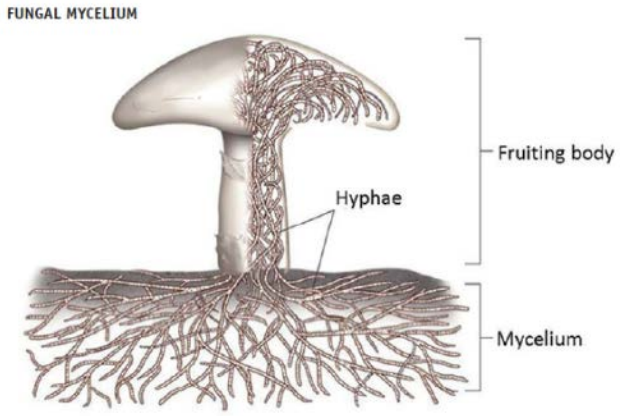

Figure 1 Fungal Composition Divided into Underground Mycelium and Fruiting Body (Url-1).

The ability of fungal mycelium to digest and grow through organic substances allows composites to be produced from mycelium. In short, mycelium acts as a natural binder that holds organic fibers or particles together, making it possible to create a natural, lightweight biocomposite. (Attias et al., 2020; Etinosa, 2019; Haneef et al., 2017). In Figure 2, mycelium morphology, hypha structure and cell wall are schematized.

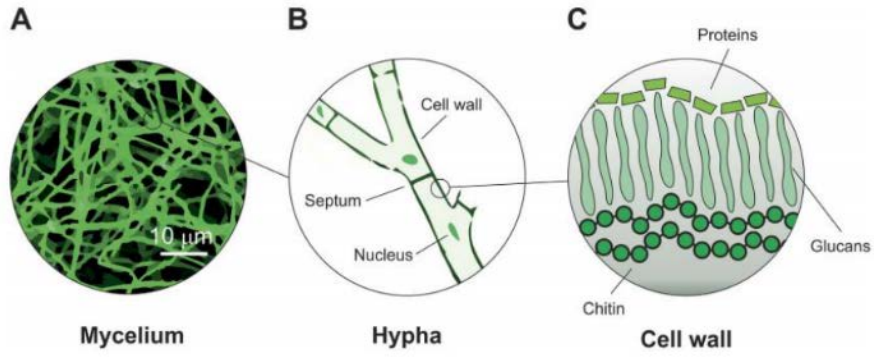

Figure 2 (A) Optical Morphology of Mycelium Fiber (B) Schematic Representation of Hyphae (C) Schematic Representation of The Cell Wall (Haneef Et Al., 2017).

2.2. General Overview of Production and Growth Methods of Mycelium Composites

The fungal myceliums represents the structure that provides the necessary nutrition for the growth and development of fungi. The ability of the fungal mycelium to be digested and grown through organic substances makes it possible to produce composites from mycelium. (Attias et al., 2020; Etinosa, 2019; Haneef et al., 2017).

The production processes of mycelium-based composite materials consist of several steps. First, the mycelium needs to be mixed with the nutritious feedstock to grow. The fact that these nutrients consist of materials with cellulose-rich content (straw, sawdust, hemp, cotton, etc.) is substantial for the growth of the fungus. Because fungi, unlike other organisms, have the ability to break down cellulose and convert it into glucose. Its means that fungi can grow swiftly in cellulose-rich environments. It is necessary to purify the selected feedstocks from other organisms that may infect the fungus before mixing it with mycelium, to prevent the formation of mold. For this reason, first of all, the feedstocks must be sterilized in the autoclave device. The raw materials that have been sterilized should be kept to cool before mixing with the mycelium, then mixed with the selected mycelium type using tools such as pre-sterilized containers. Then the molded mixture is left to grow. (Elsacker et al., 2020; Etinosa, 2019; Lelivelt, 2015).

It is substantial that the environment is dark during the growth phase. Because some species of mushrooms try to produce fruit in the presence of light, thinking that it has reached a free surface. In addition to darkness, the growth environment should contain high humidity (~80-90%), suitable temperature (~25-30°C) and oxygen. It is known that in optimized conditions, fungal growth lasts about 14-16 days. After the growth stage reaches the desired level, the drying process should be done. Otherwise, the mushroom micelles will begin to produce fruit after consuming all the feedstock. High temperature drying is required to terminate this growth. (Elsacker et al., 2020; Etinosa, 2019; Lelivelt, 2015).

Production variables are influential in the yield of fungal growth. In addition, it can be said that the fertile varies according to the structural properties of the components that make up the composite. Table.1 shows the factors affecting fungal growth.

Table 1 Factors Affecting Fungus Growth (adopted. Elsacker et al., 2020).

FACTORS AFFECTING FUNGUS GROWTH	
STRUCTURAL FACTORS	**PRODUCTION VARIABLES**
• FUNGUS TYPE SELECTION	• SUBSTRATE STERILIZATION METHOD
Phylogenetic diversity Hyphal growth, branching and fusion Cell wall composition Lifestyle and capacity to degrade lignocellulose	• INOCULATION METHOD • PACKING METHOD • GROWTH CONDITIONS
• SELECTION OF RAW MATERIAL TYPE	• GROWTH TIME
Nature of lignocellulosic feedstock Direct impact of the feedstock type on the material properties Impact of feedstock on fungal biology	• DRYING METHOD • POST-PROCESSING

As it is known, since mycelium-based materials are naturally degradable, they can dissolve and rejoin the life cycle when they reach the end-user when they reach the end of their useful life. The diagram in Figure 3 shows the production stages of mycelium-based materials (Etinosa, 2019; Elsacker et al., 2020; Lelivelt, 2015).

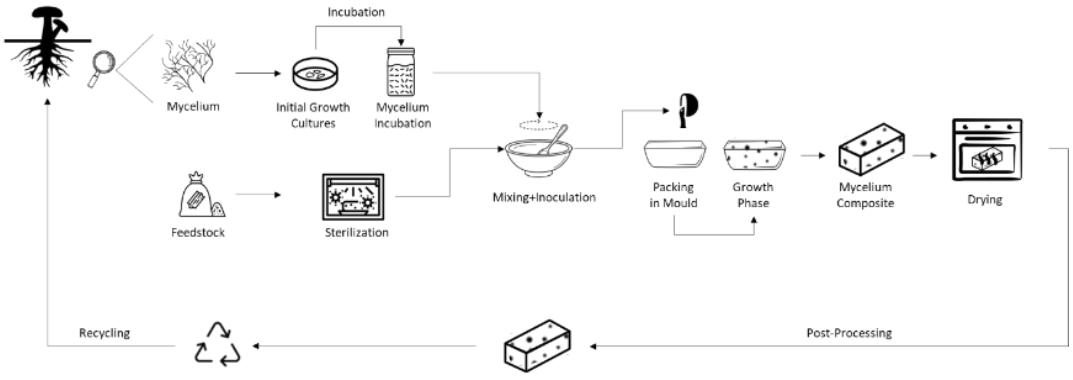

Figure 3 Diagram Showing the Production Stages of Mycelium-Based Materials (adopted Dias et al., 2021; Elsacker et al., 2020; Girometta et al., 2019; Lelivelt, 2015; Rafiee et al., 2021; Udayanga, D., & Miriyagalla, 2021).

There is no set standard for the production of mycelium-based materials. Although there are many studies as a result of the literature review, it is seen that information about mycelium composite production is deficient. It can be said that publications on new research and applications of mycelium-based materials prone to hide information and data on the types of fungi used, incubation parameters, feedstock compositions, or detailed production procedures. As the huge majority of authors are affiliated with commercial companies. Some data related to experimental studies on the production of mycelium-based materials, in which data on mycelium production stages are shared in the literature, are compiled in Table 2 below.

Table 2 Production Protocols Sorted by Years, Developed by Different Researchers (adopted. Elsacker et al., 2020).

Fungal Species	Feedstock	Sterilization Method	Growing Conditions	Growth Time	Drying Method	Application Field	Year	References
Coriolus Versicolor Pleurotus Ostreatus	Hemp hurd, wood chips, hemp mat, hemp fibres, non-woven mats	Pasteurization	25 °C 90-100% RH	30 Days	125 °C 120 min	Foam	2015	Lelivelt et al.
Ganoderma Lucidum	Sawdust	Not Specified	25-30 ℃	14 Days	70°C	-	2016	Travaglini et al.
Pleurotus Djamor	Sawdust	Not Specified	20–25°C, 80% RH	5-25 Days	55°C 20 min	Foam	2016	Ahmadi
Ganoderma Lucidum Pleurotus Ostreatus	Cellulous Cellulous-PDB	120°C 15 min Autoclaving	25–30°C , 70–80% RH	20 Days	60°C 120 min	Fibrous Film	2017	Haneef et al.
Irpex Lacteus	Macerated Sawdust Millet Grain Natural Fibre Calcium Sulfate Wheat Bran	Pasteurization	Not Specified	14-42 Days	60°C 24 h	Foam	2017	Yang et al.
Pleurotus Pulmonarius	Sawdust	121°C 60 min Autoclaving	25°C	28-35 Days	105°C 48 h	Building Material	2017	Attias et al.
Ecovative Design	Biotex Jute, Biotex Flax, BioMid cellulous plain weave	Sterilized by 10% hydrogen peroxide solution	24°C	5 Days	82°C 12 h 93°C 8 h	The core of sandwich structures.	2017	Jiang et al.
Pleurotus Ostreatus Fomes Fomentarius	Beech European oak pear wood chips sand gravel aggregates	Autoclaving	25°C–28°C	14-28 Days	95 °C	Building Material	2017	Moser et al.
Trametes Ochracea Pleurotus Ostreatus	Beech Sawdust Straw Cotton-fibre	Not Specified	25°C 55-70% RH	24 Days	150°C 20 min	Foam	2018	Appels et al.
Pleurotus Ostreatus Pleurotus Citrinopileatus Pleurotus Eryngii Ganoderma Lucidum	Jute Cotton Starch	80-90 °C sterilized by heating in the oven	25 °C	7 Days	90 °C 120 min	Textile Material	2018	Silverman
Trametes Virsicolor	Pirinç Kabuğu, Cam Kırıkları, Buğday Taneleri	121 °C 40 min Autoclaving	25°C 50% RH	12 Day	50 °C 48 h	Building Material	2018	Jones et al.
Trametes Versicolor	Flax, flax dust,flax longtreated fibres,flax longuntreated fibres, flaxwaste, wheatstraw dust,wheat straw,hemp fibresand pinesoftwood shavings	121°C 20 min Autoclaving	28°C	8+8 Days	70 °C 5-10 h	Thermal Insulation	2019	Elsacker et al.
Pleurotus Ostreatus	Sawdust Coir Pith	121°C 15-20 min Autoclaving	27°C 80% RH	14 Days	140°C 20 min	Building Material	2021	Sivaprasad et al.
Trametes Versicolor Ganoderma Resinaceum	Hemp Hurd Beechwood Sawdust	121°C 20 min Autoclaving	26°C 60% RH	9-11 Days	125°C 10 h	Building Material	2021	Elsacker et al.
Pleurotus Ostreatus	Hemp, Rice Straw, Lacquer Wood Chips, And Oak Wood Chips	121°C 90 min Autoclaving	25°C 65% RH	21-25 Days	65°C 24 h	Building Material	2021	Lee and Choi
Pleurotus Ostreatus Trametes Hirsuta	Oat Bran Coarse Wheat Flour	121°C 30 min Autoclaving	27°C	27 Days	120°C 3 h	Building Material	2022	Kuribayashi et al.
Ganoderma Lucidum	Cellulose Fibre RPS	121°C 40 min Autoclaving	30°C 58% RH	7+14 Days	Not Specified	Building Material	2022	Gauvin et al.
Ganoderma Lucidum	Sawdust	60 min sterilized by heating in the oven	23-25 °C	7+7 Days	100 °C 45 min	Industrial Object	?	Url-2

The studies examined show that the production conditions are generally similar to each other. In some cases, it can be said that differences are also observed according to the type of mushroom and feedstock chosen.

Usage Areas of Mycelium Composites and Current Studies

Today, there is a growing interest in mycelium-based materials. In the studies on this promising new material, it is known that the companies are in partnership with the academy. Therefore, most academic studies do not include information about materials and data due to commercial concerns. (Attias et al., 2020).

One of the leading companies in the mycelium sector is Ecovative Design LLC. The company focuses on developing mycelium in the areas of protective packaging products and the production of insulating material to replace conventional polystyrene-based materials. Grown.bio is a company focused on creating ecologically based alternatives to fossil fuel-based plastics such as polystyrene (EPS) and expanded polypropene (EPP) in the packaging industry, industrial products, and construction industry using mycelium technology pioneered by Ecovative Design LLC. Mogu, another company conducting mycelium composite studies, aims to develop sustainable alternatives in interior and product design applications. It produces acoustic insulation and floor tiles made of mycelium. Another company that is active in the industrial potential of mycelium-based composites is MycoWorks Inc. The company, which started its activities with studies on mycelium bricks, focuses on mycelium-based leather production today. (Url-3, Url-4, Url-5, Url-6).

The application scale of mycelium-based materials; is divided into two categories: the basis of the product described as small and the basis of the architectural project described as large. Some examples of applications at the product scale include interior architectural furniture, industrial design products, and consumer products such as clothing, insulation materials, and building materials. At the architectural scale, it includes large assembly applications with the gathered individual modules. (Bitting et al., 2022).

Product Scale Application Areas of Mycelium Composites

In this section, examples of Product Scale Application Areas of Mycelium Composites are discussed.

Furniture Area

The chairs designed by Eric Klarenbeek, who developed products produced by three-dimensional printing where the materials used were bioplastics and mycelium instead of fossil-based materials, constitute unique examples of the use of mycelium in the furniture sector. Products produce oxygen throughout life by using mycelium material. In addition to minimum energy use in the production process, the products are also considered very substantial in terms of being fully recyclable after completing their useful life (Attias et al., 2020; Bitting et al. 2022; Elbasdı, 2016). The picture of the example is shown in Figure 4.

Figure 3 Eric Klarenbeek's Mycelium Studies (Url-7).

Packaging Area

The first examples of the use of mycelium in the packaging industry are produced by Ecovative Design LLC. with a mixture of hemp husk and mycelium. Packages that have completed their useful life can be separated naturally and reintegrated into the life cycle without any additional processing. (Url-3). The picture of the examples are shown in Figure 5.

Figure 4 Ecovative Design LLC. Packaging Products (Url-3).

Textile Area

It is seen that the use of mycelium material is directed toward productions that can be an alternative to leather, especially in the field of textiles. MycoWorks Inc., one of the leading companies in mycelium production, focuses its work on the production of mycelium-based leather. In addition, as a result of designer Aniela Hoitink's work by combining mycelium with textile elements, a flexible composite product called MycoTex was developed. Again, as a result of the fashion world's search for alternatives to plastic and leather, the MYCL company offered a series of products made of mycelium for sale. (Elbasdi, 2016; Url-6; Url-8; Url-9). The picture of the examples are shown in Figure 6.

Figure 5 a) Mycelium Leather (Url-6) b) Mycelium Dress (Url-8) c) Mycelium Shoes (Url-9).

Electronic Area

As an alternative to the plastic parts used in the electronics sector, mycelium blocks are used, which are enlarged in molds and then shaped with a laser for the necessary equipment. The properties of mycelium such as deficiency of electrical conductivity and high fire resistance provide advantages in such applications (Bitting, 2022; Vasquez& Vega; 2019). The picture of the example is shown in Figure 7.

Figure 6 Applications of Mycelium Material in Electronics Industry (Url-10).

Building Materials Area

When compared to other conventional composites Mycelium-based composites have many advantages, such as lower energy consumption, low carbon footprint, recyclability, low density, and cost. Mycelium composites are composed entirely of a combination of organic materials. Thanks to this, fully compostable materials support the transition to the cyclical economy as they preserve their economic value and prevent waste generation. Although mycelium composites, which are advantageous in many respects, produce advanced solutions in various fields such as conventional plastic films, and synthetic foams, they constitute a new research area developing for the building industry (Javadian et al., 2020).

The thermal and fire resistance properties of mycelium composite materials pave the way for their use as a layable material in structural applications. The company Biohm produces mycelium insulation materials with a thermal conductivity coefficient of 0.024 W/m.K. These materials are capable of competing with conventional materials in terms of both performance characteristics and production costs. (Url-11).

Another feature of mycelium composites is that they are suitable for acoustic panels. In addition to its insulating performance, there are also areas of use such as floor coverings and tiles produced by Mogu company. (Bitting et al. 2022; Url-5). The picture of the examples are shown in Figure 8.

Figure 7 a) Mycelium Thermal Insulation Panel (Url- 11) b) Mycelium Acoustic Panel (Url-5) c) Mycelium Floor Tiles (Url-5).

Despite the ecological advantages of mycelium materials, they have several limitations for their use in structural applications. These limitations are due to the low water resistance capacity compared to synthetic alternatives due to the low strength properties of the material and its organic origin. However, studies show that these limitations can be improved by production methods, the type of mycelium, and the feedstock used. (Appels et al. 2019; Javadian et al. 2020).

Architectural Scale Applications of Mycelium Composites

In this section, examples of architectural scale applications of mycelium composites are discussed.

Mycotecture

Designed by artist Philip Ross, this work represents the shape of an arch created by combining materials in a prefabricated manner. All of the bricks used in the project were grown from mycelium. (Url-12). The picture of the examples are shown in Figure 9.

Figure 8 Mycotecture-2009 (Url-12).

Hi-Fi Tower

The Hi-Fi Tower project, designed by Living, is a tower of 10,000 bricks made from fibrous mushrooms connected to agricultural waste. After the structure was on display for three months, it was fully composted and distributed to local gardens, returning it to its life cycle. (Url-13; Url; 14). The picture of the examples are shown in Figure 10.

Figure 9 Hi-Fi Tower-2014 (Url-13).

Shell Mycelium Pavilion

It is a study that aims to introduce mycelium as an alternative material suitable for constructing temporary structures owing to the environmentally friendly properties of mycelium, which consists of the root network of fungi. (Url-15). The picture of the example is shown in Figure 11.

Figure 10 Shell Mycelium Pavilion-2016 (Url-15).

MycoTree

The MycoTree project uses improved mycelium composites to create a load-bearing structure. The strength and rigidity of the structure is derived from its geometry rather than its material (Heisel et al., 2017). The picture of the example is shown in Figure 12.

Figure 11 MycoTree-2017 (Heisel et al., 2017).

Monolithic Mycelium Experiments

The monolithic mycelium experiments, led by Jonathan Dessi-Olive, consist of a series of studies to adapt mycelium. While the belt created in the studies can carry a person's weight, it shows both the significance of geometry and the possibility of growing in place in an unsterile conditions (Url-16). The picture of the example is shown in Figure 13.

Figure 12 Mycelium Experiments of Jonathan Dessi-Olive-2017 (Url-16).

The Circular Garden

Scope of the project, the myceliums were grown over two months to create a series of arches. This project brought a new approach to mycelium composites by combining monolithic mycelium structures with prefabrication technique (Url-17). The picture of the example is shown in Figure 14.

Figure 13 The Circular Garden-2019 (Url-17).

The Growing Pavilion

The pavilion displays a combination of 88 façade panels made of mycelium, combining various bio-based materials such as wood, hemp, mycelium, long tail, and cotton. (Url-18). The picture of the example is shown in Figure 15.

Figure 14 The Growing Pavilion-2019 (Url-18).

MY-CO-X

The project is a prototype for temporary housing and is used as a sleeping and learning station, as well as an exhibition room. Its morphology is based on an uninterrupted functional diagram. The species Fomes Fomentarius was grown on pieces of hemp with mycelium (Url-19; Url-20). The picture of the example is shown in Figure 16.

Figure 15 MY-CO-X-2021 (Url-19).

MycoCreate 2.0

MycoCreate 2.0, offers a computational form-finding strategy for compression-only, component-based spatial structures produced with mycelium-based composites (Url-21). The picture of the example is shown in Figure 17.

Figure 16 MycoCreate 2.0.-2022 (Url-21).

La Parete Fungina

La Parete Fungina is a wall inspired by historic spiral brick walls on UVA's campus but created with fully biodegradable mycelium bricks (Url-22). The picture of the example is shown in Figure 18.

Figure 17 La Parete Fungina-2022 (Url-22).

Talinn Architecture Biennale

The project prints the wooden structure according to a generative algorithm using an industrial robot, demonstrating the potential of combining new technologies with natural organisms using mycelium. (Url-23). The picture of the example is shown in Figure 19.

Figure 18 Talinn Architecture Biennale-2022 (Url-23).

Many of the project applications of mycelium demonstrate tendency to use mycelium-based composites grown in molds. In most cases, the structure is divided into smaller components that will be prefabricated and assembled in place in a controlled environment. In these projects, the mycelium-based composite is used, then components that require an exoskeleton or an auxiliary structure to ensure the main stability. Due to the low mechanical properties of the mycelium-based composite, the height of the structure appears to be an substantial limiting factor. In projects where mycelium is grown on-site, the size of the projects is quite small due to logistical difficulties and the long time conjunction with the growth of mycelium. In addition, inadequate material strength is not able to adapt to the increased self-weight as the size of the structure increases. As a result, it is seen that the most successful mycelium-based material applications in reaching the construction sector are heat or acoustic insulation panels (Bitting et al. 2022).

3. Material and Method

The production of mycelium-based composite material is a new research topic. There is no determined standard for its production. In this study, first of all, samples were created with the mixture ratios of the two referenced studies in order to determine the yield according to the mixture ratios of the produced composites. Then, based on the determined ratio, samples were created in which different raw materials were mixed and studies were carried out to determine the mixture rate to be referenced and the raw material to be used. In addition, in order to compare samples at different incubation periods, each mixture was kept in a light- and the airtight environment under standard room conditions for up to 28 days with 7-day periods.

3.1. Materials

In this study, fungal myceliums of the genus 'Pleurotus Ostreatus' pre-grafted with oat bran and stored in the freezer were used. Myceliums, which contain a large number of hyphae, vegetative tissues, and spores, were purchased from a specialized company. In this preliminary study, the feedstocks required for the nutrition of myceliums were selected as hay, rice shell, beech shavings, walnut shell, and rice shell powder in line with the studies in the literature and the fastest supply conditions. (Gauvin et al., 2022; Jones et al., 2018; Url-2; Url-24).

The materials used as raw materials differ in terms of dimensions and the cellulose, hemicellulose, and lignin ratios they contain. In Figure 20, the images of the raw material types and the graph of the composition ratios are given.

Material	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Reference
Rice Husk	35-45	19-25	20	(Faruk et al., 2012)
Wheat Straw	38-45	15-31	12-20	(Faruk et al., 2012)
Rice Husk Powder	35-45	19-25	20	(Faruk et al., 2012)
Wood Shaving	35-50	20-30	25-30	(Jahirul et al. 2012)
Wallnut Shell	23.3	20.4	53.5	(de Caprariis et al., 2017)

Figure 19 Compositions of Feedstocks Used

To create a mycelium composite, fungal mycelium of the genus Pleurotus Ostreatus and straw were mixed with the mixing ratios of two different studies, and production was made based on the production stages shown in Figure 3. Information on reference mixing ratios is shown in Table 3.

Table 3 Mycelium Composite Mixing Ratios of Reference Studies

Mycelium	Feedstocks	Reference
50 g	200 g	(Url-2)
100 g	200 g	(Gauvin et al., 2022)

According to the mixture ratios in the reference studies, the samples produced were evaluated and a mixture ratio was determined. To observe the effect of feedstocks using the determined ratio, 5 different mixtures with rice shell, straw, rice shell powder, sawdust, and walnut shell were produced based on the stages in Figure 3.

The mixing ratios of the experimental studies are given in Table 4.

Table 4 Mycelium Composite Mixing Ratios of Experimental Studies

Experiment No	Ingredients	Mixing Ratio
1	Mycelium+Rice Husk	1:2
2	Mycelium+Wheat Straw	1:2
3	Mycelium+Rice Husk Powder	1:2
4	Mycelium+Wood Shaving	1:2
5	Mycelium+Wallnut Shell	1:2

3.2. Mixture Preparation and Growing Conditions

In this study, the solid grafting method was preferred instead of a liquid method with ovulation. While the mycelium is growing, each surface to be used to prevent bacteria-induced mold is sterilized with 70% ethanol. The myceliums, previously inoculated with oat bran, were cut into pieces by hand in a container and mixed with sterilized feedstocks. The materials mixed until homogeneous are left to grow in bags for 7 days to create a more comfortable growth environment

before molding. The incubation medium created for mycelium composite samples; is completely dark, with a relative humidity of ~75-80% and set at 24°C. Steps of the preparation of the mixture are shown in Figure 21.

Figure 20 a) Preparing the Mixture According to The Proportions b) Mixing The Mixture c) Samples Kept In The Bag For 7 Days d) Molded Samples And The Prepared Sterile Mold e) Drilling Holes In The Samples After Molding

At the end of the first period of 7 days, the mixture in the bag was poured into the sterile container, crushed and mixed until the whiteness dissipated. Then the mixture is sterilized and allowed to grow in cling film-coated molds with dimensions of 4x4x16cm. After the molding process, the top of the mold is covered with stretch film and holes are drilled on it for the sample to breathe. The samples left to grow in the mold were removed from the molds at the end of 7 days to ensure equal growth on each surface. The specimens, which were planned to have a growth period of 7 days, were dried at 100°C for 45 minutes to stop the growth of mycelium. The remaining samples were taken from the growth medium according to the planned periods of 14, 21, and 28 days and dried at 100°C for 45 minutes. Visuals of the post-growth stages of composite samples are shown in Figure 22.

Figure 21 a) Sample for The Samples That Have Completed the Growth Period b) The State of The Different Samples Before Drying c) The Drying of The Samples In The Oven d) The State of The Samples After Drying e) The Sample Sample After The Drying Process

3.3. The Experimental Studies

Experimental studies are described in this section.

Determination of Physical Properties

Experiments were carried out to determine the dry density, moisture content and water absorption rates of the composite material.

Dry density was calculated by the ratio of oven-dry mass to volume based on ISO 9427:2003.

$$\rho = \frac{m}{b_1 b_2 t} \times 10^6$$

m: is the mass of the test piece, in grams (g),

b_1 and b_2: are the width and the length of the test piece, in millimetres (mm), (b1 = b2),

t: is the thickness of the test piece, in millimetres (mm).

Moisture content Calculated based on ISO 16979:2003.

$$H = \frac{m_0 - m_1}{m_1} \times 100$$

m_0: is the initial mass of the test piece, in grams (g),

m_1: is the mass of the test piece after drying, in grams (g).

Based on BS EN 1097-6:2022 for water absorption rate measurements by weight.

$$WA_{24} = \frac{M_1 - M_4}{M_4} \times 100$$

M_1 is the mass of the saturated and surface-dried aggregate in the air, in grams (g),

M_4 is the mass of the oven-dried test portion in air, in grams (g).

In the test of water absorption rate by weight, a mechanism was created for the samples floating in water. The mechanism are shown in Figure 23.

Figure 22 Mechanism Formed for Water Absorption Measurement

Determination of Mechanical Properties

The compressive and bending loads of the samples were determined using the Instron load bench. It should be taken into account that the samples are not full-sized (4x4x16cm) due to mycelium growth and have rough surfaces. In addition, mycelium composites, which are ductile materials, were not divided into two separate parts after bending tests. In line with these reasons, the samples were divided into 3x4 pieces with a utility knife and compressive tests were performed. The test was stopped at the point where surface cracks began to form in the test samples. The visuals of the mechanical experiments are shown in Figure 24.

Figure 23 Mechanical Measurements

Flexural strength measurement is based on BS EN 196-1:2016.

$$R_f = \frac{1{,}5 \times F_f \times l}{b^3}$$

R_f is the flexural strength, in megapascals,

b is the side of the square section of the prism, in millimetres,

F_f is the load applied to the middle of the prism at fracture, in newtons,

l is the distance between the supports, in millimetres.

Compressive strength measurement is based on BS EN 196-1:2016.

$$R_c = \frac{F_c}{1600}$$

R_c is the compressive strength, in megapascals,

F_c is the maximum load at fracture, in newtons,

1600 is the area of the platens or auxiliary plates (40 mm × 40 mm), in square millimetres.

4. Results and Discussion

This section presents the results of the experimental study.

4.1. Sample Description and Growth Examination

In the production of mycelium composites, two different mixing ratios used in the referenced studies were tested by mixing mycelium and straw. According to the results of this production, mycelium growth was not observed for 28 days in the mixture with a mycelium-feedstock ratio of 1:4, while a gradually developing growth was observed in each of the 7-day periods in the mixture with a mycelium-feedstock ratio of 1:2. Growth observations according to the competition ratios are shown in Table 5.

Table 5 Growth Observation of Samples of Different Mixing Ratios

Ratio	14 Day	21 Day	28 Day
1I4			
1I2			

Since no growth was observed in samples with a mycelium feedstock mixing ratio of 1:4, the ratio of 1:2 was taken as the basis for later experiments. Since the complete coating of the composite surface with mycelium was completed within 28 days, the samples were left to grow for 28 days in the next stage.

In the second stage, in order not to observe the effect of feedstocks on growth and the properties of the formed composite; Samples were formed by mixing five different feedstocks as rice husk, straw, rice husk powder, sawdust, and walnut shell separately with mycelium. Details of the samples produced are given in Table 6.

Table 6 Test Samples

Experiment No	Feedstock	Sample	Detail
1	Rice Husk		
2	Wheat Straw		
3	Rice Husk Powder		
4	Wood Shaving		
5	Wallnut Shell		

Mold growth occurred in the composites formed as a result of tests 1, 3, and 5 within a 28-day period. Mycelium growth has not reached a level that completely covers the surface. Fragmentation was observed because the binding of samples with low, mycelium growth was weak. In the composites formed as a result of experiments 2 and 4, mycelium growth surrounded the surface, and the materials adhered to each other. No mold was observed during the 28-day growth period. To analyze the internal growth of the samples, the non-dispersed samples were split in half from their midpoint. Although a homogeneous mixture is formed during composite mixture preparation, weak growth is observed inside the samples. It is thought that a possible explanation for the weak growth in the sample may be that the materials selected as feedstocks are large in size or that they cannot be easily digested by the mycelium due to growth conditions. As a result of this situation, it is seen that while the outer surface grows, the inner growth does not continue. The cross-section of the samples is shown in Figure 25.

Figure 24 Cross-Sections of Samples from Experiments 2 and 4

The volume calculation was made taking into account the irregularity in the shape of the samples due to mycelium growth. The volume, starting weight, dry weight, dry density, and moisture content of the samples are given in Table 7. The measurements could not be made because the samples of experiment no 3 were scattered.

Table 6 Data of Obtained from Mycelium Composites

Experiment No	Volume (cm^3)	Weight Before Dry(g)	Weight After Dry (g)	Dry Density (g/mm)	Moisture Content %
1	234,68	50,77	34,76	148,13	46,18
2	217,8	61,47	28,29	131,19	117,03
3	Not Measured.				
4	287,4	114,81	71,95	383,57	59,71
5	212,15	134,66	104,32	495,15	30,69

4.2. The Results of Water Absorption Tests

The water absorption rate is an important factor in the application of mycelium composite as an indoor particle board or insulating element, as it will specified the durability of the material over time. Since composite components are organic products, high water absorption rates are expected. However, if we compare the composites with each other, it is seen that the samples consisting of mycelium + sawdust mixture absorb relatively less water than other mixtures. Data of the water absorption rate are shown in Table 8.

Table 7 Water Absorption Rate

Experiment No	Weight of Saturated Surface-Dried Sample(g)	Weight of Oven-Dried Sample (g)	Water Absorption %
1	103,55	50,77	206,81
2	139,49	61,47	411,13
3	Not Measured.		
4	125,23	114,81	74,51
5	242,33	134,66	135,22

4.3. The Results of Mechanical Property Tests

Since there is no standard test procedure for mycelium-based composites, it is settled when cracks begin to form in the sample for flexural strength. In compressive strength, the test was stopped when the compression value of 43% was reached based on the literature (Gauvin et al., 2022). The retention rates of the mixture components are very low because sufficient mycelium growth is not seen in samples containing rice husk, rice husk powder, and walnut shell. Therefore, the samples were scattered and mechanical tests could not be performed. The values are partially in line with previous growth observations. Sawdust-containing samples with dense white mycelium biomass resulted in higher values than those containing straw. In the reference study, samples containing rapeseed straw showed a compressive strength of 0.452 MPa, and samples containing cellulose fiber showed a compressive strength of 0.145 MPa (Gauvin et al., 2022). The findings obtained in our study were similar to the previous study. With the study where different feedstocks significant effect on the composite material. Data on the mechanical property tests are shown in Table 9.

Table 9 The Results of Mechanical Property Tests

Experiment No	Flexural Strenght (MPa)	Compressive Strenght (MPa)
1	Not Measured.	
2	0,37	0,21
3	Not Measured.	
4	0,39	0,32
5	Not Measured.	

5. Conclusion and Suggestions

The findings of this research contribute to the field of biological materials as they provide an overview of the production processes of mycelium-based composites, particularly mechanical and physical experiments. This study investigates the possibilities of manufacturing mycelium-based composites by combining Pleurotus Ostreatus type mycelium with different types of lignocellulosic supplements under the leadership of studies in the literature. The fundamental purpose of the study is to create the appropriate environment and conditions for the production of mycelium composites under existing laboratory conditions by conducting preliminary experiments and the dry density, moisture content, water absorption rate, bending, and compressive strength of the mycelium-based composites created were calculated.

This research is important in terms of eliminating the lack of information due to information not shared due to various concerns in the current literature by determining the mixing ratios to be used in creating mycelium composites. When the growth periods of the experimental mixtures prepared with the mixture ratios of the two referenced studies were observed, it was seen that the growth was at a minimum level in the mixture with a mycelium + feedstocks ratio of 1:4, while the expected yield was obtained from the mixture with a mycelium + feedstocks ratio of 1:2. Samples created with five different feedstocks at the determined mixing ratios then showed that mycelium composite production and mechanical properties depended on fiber types. The growth of samples containing wheat straw and sawdust resulted in more efficient results than samples containing rice husk, rice husk powder, and walnut shell. A possible explanation for these results is that there is a growth difference due to the difference in the ratio of cellulose, hemicellulose, and lignin contained in the feedstocks.

Although the mechanical properties are not yet optimal, this research shows that mycelium composites have the potential to replace fossil-based composites. However, the water absorption rate of the composite, which consists entirely of organic materials, must be reduced for structural applications. The study shows that the manufacturing process affects the desired properties of the composite. In addition, other properties related to insulation materials such as thermal

conductivity, fire resistance, aging, acoustics, and water vapor diffusion should be tested in further research.

The methodology used to assess the suitability and selection of organic waste streams, in general, has proven effective for mycelium-material manufacturing applications. The wide range of options for creating and growing mycelium composites complicates comparing the results with the available literature, as each parameter change affects the growth and mechanical behavior of the composite. More work needs to be done to improve growing conditions, optimize mechanical properties, and establish a standardized manufacturing protocol. Since it is thought that such studies will contribute to the solution of environmental and sustainability problems on a global basis, it is believed that they will shed light on other studies that can be done in this field.

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Resume

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To develop a model for design protocol in the research-based design process in architecture education

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Abstract

Despite a great deal of effort has been made to present systematic models of design process, in practice, a lot of designs still proceed through unsystematic methods. It seems that the reason for this is too much emphasizing on describing the final design (product) and little attention to the design process; such that, there is no clear method so as to research-based design. This led to illustrate a distinct pattern from configuration of "design protocol" in terms of research-based design process. The aim of this study is to develop a model that can be used in the architecture educational system. So at first step, the readers of this research are architecture students, and designers can also benefit from it in the next steps. So that all the readers of this research using this model, in a logical process, can recognize the right information for design and ultimately achieve an optimal architectural design. In this research, our preferred context is architecture, and the focus is on research-oriented design; therefore, any given example would be in the field of architecture. In this paper, the proposed process is the result of experience gained from five years teaching architectural design (2) in master's degree that includes three milestones as follows: 1) Statement of problem 2) The scheme and 3) Design protocol. "Statement of design problem" is obtained from people's concerns about "design subject" integrated in its "bed". The scheme, itself, constitutes the expectations, goals and mission representing two sets of information (cognitive and distinction) about design that finally leads to establish a "spatial-body program" of the project. As proceeding from the onset of diagram into the end, we passed from "analyze" into "synthesize" phase. In fact, in «analyze» phase, designer decides to collect and analyze information; however, as the process goes forward, he/she combines the information from the previous phase in order to achieve novel findings. Finally, we hope that by taking advantage of the proposed process, designers can find the best way to accomplish their design projects within a defined framework.

Keywords: research-based design process, design protocol, design problem, scheme, spatial-physical program, architecture.

1. Introduction

The design process along with what designers see and think about (Liu & Group, 1996) is one of the most sophisticated human activities (Hybs & Gero, 1992). In architectural research studies, the design phase has been known as process to solve the problem of the study (Cardoso et al., 2016). This process is composed of factors which are utilized by designer consciously or unconsciously, to solving the problem of the design. Although, the design process is considered of great importance than the final product, the design process is always ignored with the attention being focused on the final product (Hybs & Gero, 1992). Nowadays, the design process is known as complex mental activity, and many independent factors and elements are influencing the architectural design, due

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to fast growth of technology and expands of needs; therefore, struggling to make a comprehensive perception of the design process is necessary.

A review of literature demonstrates that, the majority of research studies were conducted on the design process in late 1950s and early 1960s when, some conferences had hold on the design method. The first generation of the design methodology was launched in 1960s, when it was studied as an academic discipline for the first time. In the 1970s, a great deal of effort was carried out by people such as Christopher Alexander and Jones in this field. In the 1980s, several conferences were held and books were published such as "How designers think", by Brian Lawson. During the 1990s up to now, increasing efforts on the development of design studies have been done through holding conferences, scientific journals and books. In line with the previous studies, this study aims to develop a model for the formation of a "design protocol" that can be used in the architecture educational system, so that a systematic research-based method for designing an architecture is introduced in which students and architect designers, in a logical process, can summarize a perceptual and rational process in an acceptable model, while considering all the topics and concepts associated with the subject and ultimately, achieve an optimal architectural design. In general, a "research-based design" is a design performed at the basis of a specific concept. In fact, a research-based design is to give an identity to a concept in terms of architecture. Thus, this research assumes to design an architecture subject that has been figured based on a specific concept. Accordingly, the design process starts with determining the "design subject". Afterward, next design stages will be demonstrated step by step and the related diagram will be also displayed. Finally, subjects will be presented in terms of a final diagram of a "research-based design process".

2. Design Subject

Architectural design process often begins with determination of a "design subject". So, determining the design subject is the first step in architectural design process. Design subject is a representative aspect of a "design problem" as well as a transformer of design product features. In this study, a design subject, only includes design title, nominal aspect and its function. It is assumed that despite the designer has no imagination of the subject, he/she has to achieve sufficient knowledge of design subject. For this purpose, it is necessary for designer to initially deal with and analyze a design problem.

3. Design problem statement

In this section, the "problem statement" for design has been discussed. In general, the term problem statement is a concise and clear description of a subject that should be addressed in problem solving process. The characteristics of the problem statement comprise clarity and accuracy, identifying key concepts and terms, not using unnecessary terminology, expressing boundaries and parameters of the study, etc (Hernon & Schwartz, 2007). In fact, naming a subject does not mean to define that problem. This is also true in the architectural design process and a process can start with a design subject. It seems unlikely that all aspects of design problem have been clearly stated in the early stage of the process; so, the primary task of a designer is to identify the problem. Cross (1995) believes that one of the most important and effective steps in architectural design process is to analyze and understand the design problem (Cross & Cross, 1995). Architectural design problem is complex and ambiguous, so in order to reduce this complexity and ambiguity, designers need to configure the design problem. The reasons making design problem should be initially addressed to configure the design problem. The origin of design problem can be examined within its "context".

3.1. Context

Since there is no problem without a context and problems always have at least one context, in order to define the problem, its background as well as causes must be also well recognized (Cherry, 1999). Context is defined as external elements that affect an object. These elements are physical

and non-physical. Roads, buildings and visible land are examples of physical elements, while non-physical elements consist of weather, local culture, as well as political and economic restrictions (Firrdhaus & Sahabuddin, 2011). It could be argued that problems are inseparable components arising from their contexts. So, the nature of problems should be analyzed and recognized in their beds. On the other hand, framing the design problem is a cognitive process of overall objectives and problem characteristics (Pinch et al., 2010). Palmer, (1981) divides design subjects into three categories in order to organize raw design information to provide a framework: human factors, body factors and external factors (Palmer 1981, cited by Duerk, 1993). According to Lawson (2006), four groups comprising legislators, clients, users and designers impose constraints- albeit with different degrees of flexibility- on design solution (Lawson, 2006). In this paper, based on Palmer and Lawson categories, design problem constraints originate from two sources: a series of constraints arising from bed's sociocultural values and the other comes from human factors (people who are related to the architectural design).

3.2. Socio-cultural values

This section describes the relationship between culture and architectural design. So, first, it is necessary to define the word "culture". A lot of work has been done to define this word. However, it seems there are still many thinkers and experts facing many difficulties about concept, evidence and problems of the culture.

Tyler (1870) considers culture as "a complex set of knowledge, belief, art, ethics, customs, and any ability and habit that man acquires as a member of a society" (Tyler British anthropologist 1870: 1; cited by Avruch, 1998). The definition shows one of the factors that makes up the culture, beliefs and values of the society that is considered by the authors in this study. Hofstede et al (2010) also believe that culture makes a distinction between groups (Hofstede et al., 2010). It is understood from this definition that culture is the symbol and identity of a place that distinguishes it from other places and nations. Matsumoto & Juang (2016) and Dykstra (2009) consider culture as "a set of attitudes, values, beliefs, norms and behaviors shared by a group of people that is passed down from generation to generation which is effective on behavior of each member " (Matsumoto & Juang, 2016 & Dykstra, 2009). This definition also includes predefined and more complete definitions. Therefore, culture is a set of values and beliefs of a society that is the symbol and identity of a community that is transmitted from generation to generation. In his research, Firrdhaus & Sahabuddin (2011) describe culture as a way of living in a place and the best way to accept the constraints of a place that is followed by generation to generation. Culture sometimes becomes the symbol and identity of a place. Adaptive architecture is the most popular way of showing the identity of a place (Firrdhaus & Sahabuddin, 2011). In this study, we choose the definition of Firrdhaus & Sahabuddin as the basic definition, because it is close to our goal, i.e. the existence of a relationship between the architecture and the culture of a nation. Finally, our definition of culture is: "Culture includes beliefs, values, and faiths and in general the way of life shared in a place which is passed down from one generation another affecting the behavior of individuals. Culture is sometimes the symbol and identity of a place. Adaptive architecture is the most popular way of showing the identity of a place in this regard".

Therefore, it can be argued that architecture is one of the most obvious manifestations of the culture of any nation, and it shows the human living space. In fact, the same buildings and memorials of a nation are known as culture due to being rooted in beliefs and values, and in fact they are the connection between the culture and the architecture of a society. Architecture is a knowledge that establishes a close relationship with culture and originates as a social phenomenon from culture and affects it, while meeting the human need for shelter and built environment.

3.3. Human factors

Legislator: Legislator is the most inflexible factor which influences the design process (Lawson, 2006). Although the legislator is not often involved in design itself, he/she imposes some limits within the framework of which, designers should work (Lawson, 2006). Regulations set by

municipalities for any urban constructions are common examples of legislative influences on architecture.

Client: The second factor influencing the design process is the client of the project. Client is an obvious example of design limitation source (Lawson, 2006). According to Le Corbusier, architects must consider client design requirements and demands; they should establish a good mutual relationship while combining spaces and forms with artistic ideas (Parsaee et al., 2015). As Pena (2012) said, high quality buildings are not accidently constructed. These buildings are scheduled to perform well, and implemented when qualified architects and clients are joined together in thoughtful and collaborative efforts (Pena & Parshall, 2012). However, nowadays, many designs are ordered by the clients who themselves, do not use those designs. For example, public buildings such as hospitals and schools are usually designed by architects who have little relationship with users (Lawson, 2006). When clients themselves do not plan to use their designs in the future, the issue is even more ambiguous than it seems. The growing gap between designers and those the designs have been performed for, increases the need to study about user's demands (Lawson, 2006).

Users: The third group influencing the design process are design users. Users are experts in building usage (Pena & Parshall, 2012) and in fact the most important groups associated with the building. They work, present, play, inhabit, and live there. In most projects, there are many different types of users. Each of these groups has various views about the project. Understanding of all those views is very important to achieve a successful building (Cherry, 1999). On the other hand, successful construction projects have been designed, built and equipped to meet the users' needs. Either about the function of an entire building or designing a single space, users possess a unique knowledge which should be integrated in design to ensure a successful construction project (Christiansson et al., 2011). So, users should be pervasively involved in planning a process for building design.

3.4. Sociocultural

As mentioned, it is concluded that analysis of the design problem must be started from the context and bed. In this process, factors such as human factors (legislator, client, and user) as well as sociocultural values impose some restrictions on the design problem in which the common point between context and aforementioned factors is design subject. In fact, design subject connects these two sets of communicational factors. Thus, statement of design problem is obtained from merging worries, concerns and negative beliefs which originate from different views, including legislators, clients, users, operators and sociocultural values about design subject within its bed and expressing them through a unique term. In summary, an analytical diagram is provided as below (Figure 1):

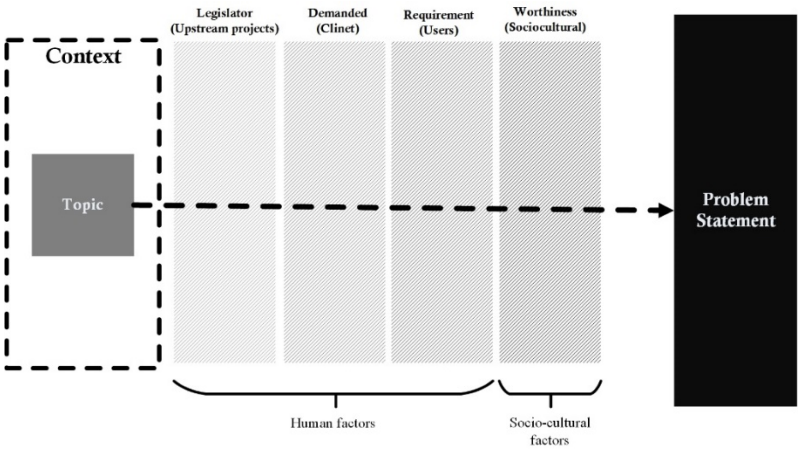

Figure 1 Formulation of design problem statement

In this paper, a practical example has been put at the end of each section for the sake of clarity. This selected example is a student project that was conducted by the third author of the article in the second plan of master's degree Program (during 2015 academic term at Hakim Sabzevari University) under the supervision of the first author. Here, example of problem statement to be shown (Table 1):

Table 1 Example of problem statement

topic		**Context**	
architectural faculty design		Site of Homa Hotel in Mashhad (bi-cornered site - area of 70,000 m^2) 	
Sub-phases	**specific explanation for project**	**Sub-problems**	**suggestion**
legislator	1. Height constraint up to floors 2. Using local materials 3.No increase in traffic load	1. Due to higher surrounding buildings, visual problems arise. 2. Surrounding buildings have not used local materials; a coordination problem with adjacent buildings exists. 3.1. Adjacent to two busy streets namely Ahmadabad and Kolahdouz 3.2 Design site is located at the intersection (causes congestion). 3.3. Adjacent to bus station from Kolahdouz Street	1. Design of different parts of a building at various heights (pilot parts are higher). 2. Designing friendly-environmental buildings (through utilizing renewable materials) 3. Define multiple entries for driveways (avoid making traffic at one point)
client	1. Research rehabilitation in architecture. 2. Designing faculty of architecture where the research is to be supported. 3. Designing faculty of architecture close to the professional community.	1. There is no value for research in existing architecture faculties, at all. 2. The priority is currently given to education instead of research. 3. A gap has happened between education and research. 4. Students have not been trained as researchers.	Research spaces should be provided in faculty; the appropriate strategies should be also adopted to attract students to research activities.
user	1. Research achieves a suitable place in the architecture course. 2. Providing spaces specially for research in faculty 3. Architectural design studio is designed such that in which, research activities will be carried out. 4. Providing spaces for conferences and meetings to convey information 5. Providing spaces for invited speakers 6. Providing a space where architecture connection is established with other areas of science and art.	1. There is no space assigned to research activities in the faculties of spatial architecture 2. The research is neglected in architectural design courses. 3. Design studio has been organized based on this view that design content should be directed toward practical purposes.	1. Designing faculty spaces considering research as a main priority 2. Designing studio space such that the students pass architectural design courses based on research. 3. Utilizing the site to provide outdoor spaces for meetings 4. Providing spaces especially for other scientific areas related to architecture
Cultural values	Designing architecture faculty so as to help develop and enhance the area	1. Low awareness of regional people 2. Lack of global updated knowledge 3. Failure to generate novel knowledge	Considering spaces which attract people; and increase their awareness, such as exhibiting spaces, outdoor lecture spaces to hold conferences with participation of community.
Problem Statement: "A gap between research and architecture": It seems that the major problem in project given is neglecting the research along with a gap between education and research educational system of architecture leading to weak students in field of research. When graduated students enter the professional labors, they more often design based on normative theories relying on individual perception; this leads to separation of academic and professional spaces in architecture.			

4. Scheme

In this section, "scheme" is explained which is considered as the third step in design process. In fact, the designer initially configures design problem to be able to understand it; then, he/she

presents scheme through it. Regarded to the word scheme, different meanings and definitions have been presented in various references. First, a number of these definitions are described.

According to Ruan (2010), scheme is a way through which human communications are organized with spatial arrangement (Ruan, 2010). Therefore, scheme can be considered as a regularizing factor. In part of the Webster Dictionary Definition (2017) of the scheme, the phrase "plan or action plan and a systematic or organized configuration (design)" has been given. In Oxford Dictionary (2017), "a large-scale systematic plan or arrangement to achieve a specific purpose" is the definition of scheme. According to the three definitions mentioned above, the scheme can be called the overall system of the structure.

On the other hand, Murphy (2002) sees the scheme as a model that integrates all our mental needs and helps us to identify and classify objects (Murphy, 2002). Therefore, the scheme should affect all the elements and components of the architectural design. Taura & Nagai (2013) call the scheme something that may be created by observing the properties of an object such as (appearance, attributes, functions, etc.) in the human mind or in the real world (Taura & Nagai, 2013). Therefore, it is argued that the scheme can be understood from the scale of the general design of the building to its more detailed parts. Darke (1979) interpreted the scheme as the "primary generator" (Darke, 1979). Therefore, it can be said that scheme can act as the initial spark of the scheme and follow up with subsequent ideas.

By summing up what mentioned above, we can call scheme the general system of structure that affects all elements and components of the architectural design and is understandable from the scale of the general design of the building to its most detailed parts. In fact, the scheme is the architectural response to the design issue; therefore, like a central core, it brings together all the components of the plan, including physical needs, environmental conditions, etc. followed by the following ideas. In his book, "Architectural Planning", Duerk (1993) also uses the term "purpose statement" that is intended to be close to our goal of scheme, that is; an appropriate purpose statement expresses the expected quality that the ideal solution or the final result must achieve. It also takes into account the wishes of the employer and the needs of the users. This statement of purpose should be short and focus on the quality of the environment that has set the "objectives" of the project. (Duerk, 1993). According to Duerk (1993), scheme consists of three sub-sections: goals, expectations, and missions.

4.1. Goals

"Goals", in fact, expresses the desires and intentions that a person tries to achieve. Goals are statements that will help us make design-related decisions. Among different types of goals affecting the project outcome, project goals are only related to the predicted results of project which are formed based on the client's requirements, user's needs and desired values (Duerk, 1993).

4.2. Expectations

This section is adapted from studies carried out by Gero (1992), Maher (1996, 1997) et al. Based on researches have been conducted by Hybs & Gero (1992), Maher & Poon (1996),Poon & Maher (1997), Maher & Tang (2003) and etc. we have found that according to the functional requirements and demands expressed in design problem space, the corresponding behavior of those requirements are taken into consideration which is called "expected behavior".Gero (2004) has also utilized the term "expected world" in a study with a representative model of the design process based on function - behavior - structure; the expected world is a world that will produce designer' supposed measures where the activities' effects are anticipated based on existing objectives and interpretations of the current state of the world (designer's problem space). In fact, when designers configure the design problem, some questions may reasonably arise that they have apparently a set of expectations about the answers to these questions (Dorst & Cross, 2001). Therefore, it can be recognized that a scheme must represent an accurate and appropriate expression of the

expected qualities within the project objectives to solve a design subject. In addition, the expectations are more abstract than goals which are more operational.

4.3. Mission

As defined by Duerk (1993), a mission is more related to the design subject. In a design project, "mission statement" is in fact a "major goal" which represents the main objective of the project dealing with the reason of implementing the project. For example, if it is decided to design a faculty of architecture, this question arises that what is the mission of an architecture faculty, and which characteristics and features must an architecture faculty have and what roles should it also plays. In general, mission, is a statement of the main objective of the project that must be successfully accomplished; it also includes a series of valued principles that assists to implement the project. This section is summarized in analytical diagram as below (Figure 2):

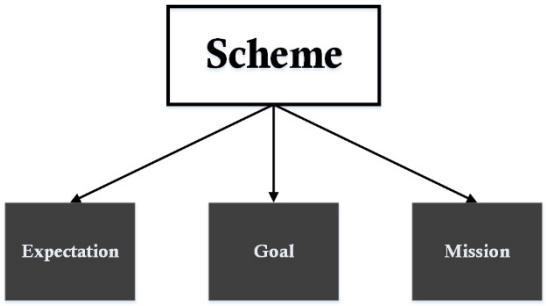

Figure 2 Formulation of "scheme"

Here, example of scheme to be shown (Table 2):

Table 2 Example of scheme

Scheme		
Sub-phases	**specific explanation for project**	
expectations	-	1. Extending the fields of research in architecture 2. Connectivity among citizens and faculty members increases citizens' awareness.
Goals	-	1. Rehabilitation of research in the faculty of architecture and making connections between the academic space and professional community in architecture: 1.1. Designing faculty spaces considering research as a main priority 1.2. Attracting architecture students to research activities 1.3. Establishing a connection between architecture and other scientific areas 1.4. Organizing architectural design studios based on research 1.5. Make Links between education and research (education coupled with research) in the faculty of architecture
Mission	-	architectural Faculty with its features and components
Scheme: Designing faculty of architecture in order to establish a link between research and architecture		

Generally, in research-based design, designer is concerned with two categories of information. First, the "general principles" or "cognitive studies" which are linked into the project mission. The other set of information entitled as "special principles" or "distinction studies" are related to the goals and expectations of the project.

5. Cognitive studies

In this section, cognitive studies of design project will be discussed. The term "cognitive" in the Webster Dictionary (2017) has been defined as conscious mental activity like thinking and reasoning, and activity based on actual experimental knowledge. Also, Oxford Dictionary (2017) has considered it as mental activity or the process of acquiring knowledge through thinking, experience and senses. In the Cambridge Dictionary (2017), it is an attribute associated with conscious thinking or mental processes and it is related to the process of knowing, understanding, and learning in the Longman Dictionary (2017). The raised meanings of the term cognitive generally overlap and are in line with each other. Therefore, it can be considered as a mental activity that is consciously carried

out and leads to knowing, understanding and learning something. According to this definition, the purpose of the writers of the "cognitive studies" is to carry out conscious activity that leads to the designer's knowledge of the subject of design. In fact, information and data are provided at the stage of cognitive studies according to the type of building uses and include a checklist of the names of the spaces and their dimensions. This checklist of spaces is provided, taking into account the criteria and standards as well as the specified per capita, which are reviewed below.

5.1. Regulations and standards

Design and development of the built environment are affected by the social-political and organizational (formal) complexities involving the application of rules and regulations related to the form and function of buildings; such that, since the first periods of architecture and construction, the architects' actions have been conditioned through a series of rules, regulations, standards, and monitoring practices including socio-cultural instructions, etc. (Imrie & Street, 2011) This control and monitoring is conducted in order to provide comfort, convenience, enjoy of the inhabitants, and also preserving the value of the properties. In fact, design's rules and standards have been considered as the most common method to control and monitor architecture. According to Imrie & Street (2011), the foundation of architectural rules and regulation is a part of a broad context of social- organizational and political intervention in design and development process which is used to determine the limits and definitions of the activities by architects. In general, regulations and standards in architectural design are considered as instructions set by the relevant governmental agencies such as the municipalities, housing and urban constructing department etc. These instructions are about the whole architectural generality of a building which affects architects' actions.

5.2. Per capita

"Per capita" refers to an index or measure calculated for each person of a community. In architectural design, spatial per capita is specifically calculated for that space's users.

5.3. Subspaces

Subspaces are places that exist in public parts of a building regarded to the usage issue. For example, if the design subject is a faculty of architecture, a list of the spaces which are common in the whole architectural faculties should be provided.

Based on the above, in cognitive studies step, considering regulations and standards, the designer provides a checklist of spaces' names, dimensions and qualitative characteristics regarded to spatial per capita. This checklist is actually a type of physical program for design subject called general program. 'Generality' is because that this list of spaces can be commonly used in all buildings with similar design subject. In brief, an analytical diagram is presented below (Figure 3):

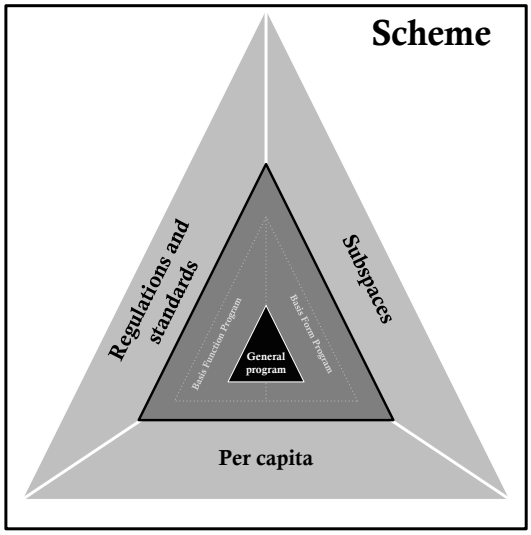

Figure 3 Cognitive studies (formulation of general program)

Here, example of general program to be shown (Table 3):

Table 3 Example of general program

Cognitive studies		
Sub-phases	**specific explanation for project**	
Regulations and standards	-	**General program:** A List of spaces within architecture faculty such as theoretical classes, practical classes, auditorium, administrative and service sectors as well as the number and dimension
Per capita	-	
Subspaces	-	

6. Distinction studies

In this section, "distinction studies" will be introduced. The term “distinction” in the Oxford Dictionary (2017) has been defined as the difference between the same acts, or individuals or groups, and the superiority that separates a person or something from others. Moreover, in Cambridge Dictionary (2017), this term means the difference between two similar things, and in the Longman Dictionary (v. 6, 2017), it is difference, superiority or exclusivity have been brought. These meanings generally overlap and confirm each other. Given the meanings, here the purpose of the writers of the term distinction is also the difference and distinction. The authors' purpose of distinction studies is a certain response to the design problem. It could be argued that each design is distinguished from another due to distinction studies. Because of having qualitative nature, design problems may include multiple responses; so, considering his/her creativity, design knowledge and experience, any designer differently responses to the design problem and adopts a specific "approach". Therefore, in the following, these three designer's abilities (creativity, knowledge and experience) will be discussed.

6.1. Creativity

Takala (1993) believes that creativity is perceived as the ability of a person to produce new and unexpected things (Takala, 1993). Csikszentmihalyi (1996) considers creativity as something resulting from the interaction of a system consisting of three elements, one of which is the person who brings something new (Csikszentmihalyi, 1996). In his definition of creativity, Ogot & Okudan (2007) uses the phrase "the ability to find new methods using existing knowledge for the production of new products" (Ogot & Okudan, 2007). Therefore, creativity can be defined as the ability to find new methods using existing knowledge in order to produce new things or solutions. Akin (1994) also considered creativity as developing new descriptions of the design problem in order to provide new solutions (Akin, 1994). Casakin (2008) considers the creative process to be able to define a problem from unusual view points and to seek out new solutions that are different from existing ones(H. Casakin, 2008). In these two definitions, as in the previous ones, we refer to the "production of new solutions", but from a different aspect, which is "a different look at the design issue". In this regard, (Kowaltowski et al., (2010) also defines creativity as a process of sensitization to a question in the field of knowledge. Therefore, it seems that a prerequisite for creativity is to look at design issue with a different perspective. On the other hand, Bergström (2000) also considers creativity as a natural activity of the brain and the human body, as well as a basic quality of each human being (Bergström cited by Haapasalo, 2000). Therefore, according to this definition, the power of creativity exists in all human beings and human beings can activate and take advantage of it in different ways.

Ultimately, the definition that writers consider based on what has mentioned above is: Creativity means the ability to find new ways to produce things or new solutions. The power of creativity lies in the existence of every human being from the beginning of birth and one of the ways to activate it in the design of architecture is to have a different perspective on design issues. On the other hand, it is always stated that designing is a creative profession and designers are creative people (Christiaans, 1992). So, it can be concluded that creativity is a key element in solving a design problem. Creativity is able to promote talented designer beyond his/her conventional knowledge in order to evaluate new ideas and concepts which may lead to innovative solutions (H. P. Casakin, 2007). On the other hand, because designing is one of the most complex activities of human brain

(Gero & Mc Neill, 1998; Liu & Group, 1996), the multiplicity of factors affecting design, makes it very difficult to discipline and unify activities. Therefore, exploring unfamiliar and unconventional design solutions along with creative skills also requires qualitative knowledge and experience.

6.2. Design knowledge

According to Goel (1995), design knowledge configuration is considered as a cyclic process comprising processing, recovery, research, classification, thinking and mental evolution of design information from long-term external memory to be utilized to frame design problem (Goel 1995, cited by Alhusban, 2012). In fact, creative people rely on their specific content knowledge to ratiocinate on the situations of essential issues and thus generate innovative solutions. This knowledge and expertise help designers make enriched and complex mental models to frame the design problem (Zeng et al., 2011). In general, design knowledge, further defines the information (Blosiu, 1999) which is used to communicate main ideas in each part of design process.

In architectural design training, knowledge is also an important factor to develop innovative thinking skills learned as a significant component (Oxman, 2004). Architectural design is a creative knowledge-based activity (Al-Sayed et al., 2010) and designer utilizes that to modulate design goals, define design subjects, and develop design solutions. Design knowledge plays an important role in reducing the probability of design error and enhancing the quality of design (Chiu, 2010). In other words, the design knowledge can be defined in two ways: a set of information designer acquires through different methods such as university studies and stores them in his/her long-term memory to be utilized when necessary. Second, a set of information designer gains on a particular subject through different ways such as interviewing with people.

6.3. Experience

In general, experience and knowledge in a particular field have been accounted as general preconditions for expertise development (H. Casakin & Goldschmidt, 1999). Architecture is not an exception. The importance of designer's experience in architectural process design has been ever confirmed by many scholars. They consider generation of ideas and concepts of architecture related to design knowledge, inspiration, intuition, imagination, analytical skills of analysis/combination, cognitive skills, training, creative thinking abilities as well as experience (Alhusban, 2012). They also believe that design is based on acquiring skills, exercise and experience (Goldschmidt & Weil, 1998) and designer's thinking about the design process is based on personal experiences (Kokotovich & Purcell, 2000). Designer's experience in architecture can affect his/her design's inherent approaches and characteristics. Furthermore, cultural background and life experience of designer can also play an important role to structure his/her ideas during the design process. It should be noted that the architectural knowledge is required to be broadly and interdisciplinary expanded for a unique design solution in order to cover all subjects proposed by design problem; hence, designers are expected to have various architectural experiences and backgrounds considering different educational methods and design projects they are exposed (Al-Sayed et al., 2010). Rittel & Webber (1984) as cited Chiu, (2010) found that students who lack sufficient design experience may face two challenges when they compile knowledge references to solve (ill-defined) design problems. First, they do not know where to begin gathering relevant knowledge. Second, a unique formula does not exist for a design problem. The design problem formulation depends on design knowledge and information gathered by the designer (Alhusban, 2012).

Thus, it is clear that the main issue in the knowledge of design is the direct training of the designer in an academic process; but in the discussion of experience, the designer should refer to his or her personal findings indirectly from the professional workplace (whether at the university or outside the university).

According to aforementioned subjects, on the distinction studies step, designer should specially response to design problem (specific challenge exists in design problem) within scheme using his/her creativity, design knowledge and experience (the term specific response is used because

the response for each project is unique which causes difference among designs). In this paper, the word approach is utilized for response. In fact, on distinction studies step, designer should determine his/her project approach. After selecting approach, a physical plan should be correspondingly provided. This physical plan is called special program which is different for each project, because it is derived from the project approach. Special program contains spaces (and their characteristics including dimensions and qualities) which are added to general program regarded to the project approach. In summary, an analytical diagram is presented below (Figure 4):

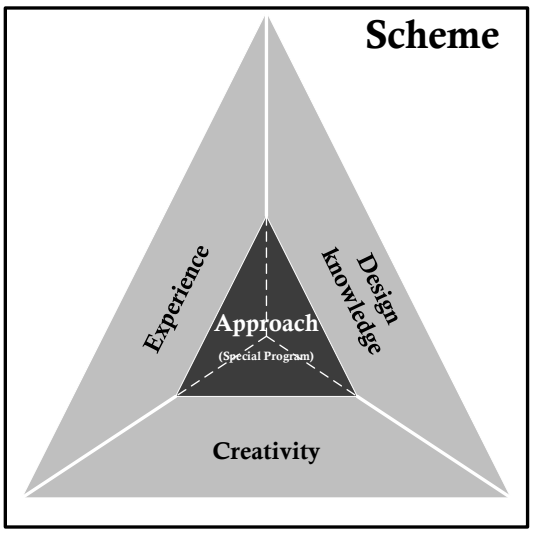

Figure 4 Distinction studies (formulation of approach, formulation of special program)

Here, example of special program to be shown (Table 4):

Table 4 Example of special program

Sub-phases	specific explanation for project	Distinction studies
Creativity	-	1. The design is inductively conducted. Firstly, significant elements of form are configured; then, others will be designed associated with those of form. In addition, a recursive design is established between the plan and the volume. When the plan and volume are accepted to some extent, it is possible to design the plan in detail. 2. Using an organizing component for the whole set 3. Utilizing the cubes in form design so that each cube set represents a specific section. 4. Symbols and signs of research centers are incorporated for volume. 5. The walkway is to be designed associated with building form, becomes prominent and visible to pedestrians. * I believe that this phase of process is very intrinsic, specific to designer, and maybe not stated in any forms even the manuscript in detail. (Ideas expressed in this section, are detailed, while the approach should be general).
Design knowledge	-	
Experience		
Approach (Special Program): Research-based design of the architecture faculty Specific research areas such as search spaces (library, site), laboratory spaces (wind and solar labs, etc.), and workshops (modeling workshops, materials) along with the number and dimension		

7. Spatial-physical program

In this section, "spatial-physical program" is discussed. As mentioned in two previous sections, a general program is obtained from cognitive studies. I addition, specific program is derived from distinction studies. In order to comprehensively define spatial-physical program that involves specific and general program, first it is necessary to review some definitions:

Cherry (1999) uses the term "programming" in his book entitled "Planning for Design," which describes it as a research and decision-making process to define the issues that should be solved through design (Cherry, 1999). Pena & Parshall (2012) stated that planning is a process that explicitly explains an architectural issue and the requirements that must be considered in providing

a solution (Pena & Parshall, 2012). It is understood from this definition that planning in general is a process in which design issues are defined. On the other hand, (Bogers et al. (2008) consider planning to identify and formulate the requirements of the employer in the construction process (Bogers et al., 2008). El Reifi et al. 2013) also consider it as a process by which employers express their demands in detail, and design team develops the plan according to it (El Reifi et al., 2013). Hershberger (2015) considers architectural planning to be the first stage of the architectural design process in which the values of the employer, users, architects, and society are identified; important project goals are accurately stated; project facts are discovered and comfort requirements become apparent (Hershberger, 2015). These opinions expressed on architectural planning have also somehow helped to clarify the definitions above, in that they consider planning as a process in which the design requirements include the requirements of the employer, the needs of the user and the values of the society. Therefore, it can be argued that the program is a very important communication tool in the interaction between the employer and the designer. Therefore, employers and their consultants tend to spend a lot of time for planning, and architects, in turn, spend a lot of time in studying and analyzing the program (Bogers et al., 2008).

Duerk, (1993), in his book "Architectural Planning," considers briefing as a process in which, on the one hand, the appropriate information for the project is provided for the designer to make the best decisions regarding building design; and on the other hand, it also meets the expectations, goals, and aspirations of the people involved in the project. This definition is chosen as the base definition in this article, because it covers all aspects of the above definitions. According to chosen definition, the authors' intent of spatial-physical program is a process in which the designer obtains the whole information about the project through collecting, organizing, analyzing, interpreting and combining in order to make the most appropriate decisions within different phases of design. The information obtained by the designer has been achieved from two sources- cognitive studies and distinction studies- in terms of general program and specific program, respectively.

In general, two theories about the performance of the program can be generally considered. The first theory considers the program as a static development document, which does not change during the design process. The second approach considers the program as a dynamic process, which is developed over several stages in the process (Ann et al., 2007). According to the categories proposed for program in architecture, it is said that spatial-physical program is categorized in the second class; it means that spatial-physical program is considered as a dynamic process that cannot be changed during the design process. An analytical diagram related to spatial-physical program is provided as below (Figure 5):

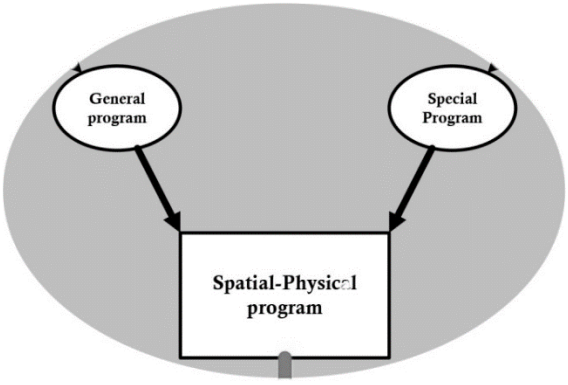

Figure 5. Spatial-physical program

Here, example of spatial-physical program to be shown (Table 5):

Table 5. Example of special-physical program

Spatial physical program	*General program: T*heoretical classes, practical classes, auditorium, administrative and service sectors *Special Program:* Specific research areas such as search spaces (library, site), laboratory spaces (wind and solar labs, etc.), and workshops (modeling workshops, materials)

When design program entitled spatial-physical program is implemented, we must step into the phase leading this program to become operational. Based on the authors, this phase, “design protocol", will be introduced in the following paragraph.

8. Design protocol

One of the problems that architecture professors always face is explaining the various factors involved in the design process to students. However, doing conceptual design itself brings a new challenge for architecture students in the design process. Because on the one hand, students should pay attention to the objective and physical factors involved in the design project, and on the other hand, they should be able to express their mental concepts in the design. Therefore, to respond to this critical issue in the design process, we need a design protocol that can organize the designer's thinking on the one hand and consider the influencing factors in the design project. To configure this protocol, we first need to find the primary factors and their component-to-component interface, as well as to know the structure of the elements themselves, so that the general framework can be formed based on the relationship of the components. Finally, the design protocol will be developed with a structure that creates order step by step and provides integration in the whole process. In other words, not only does it include the project's sub-factors, but it also regulates and creates unity in the relationship of all factors.

In this section, design protocol is presented as a final step of design process. In Webster's dictionary, the word "protocol" means "the original draft, document registration, preliminary agreement, conference record, negotiation summaries, etc." Numerous comments by scholars have been presented In connection with design protocol in architecture; Cross, (2001) believes that among all empirical research methods to analyze design interaction, "protocol study," is one of the widely used approaches which has received the most attention. As well, it has been considered as the most likely method (perhaps the only one) to reveal mysterious cognitive abilities of designers (Cross, 2001). Newell, (1966) demonstrates that the term protocol generally refers to record chronological events (Newell, 1966). Akin & Lin, (1995) has concluded the supplementary relationship between two forms of oral-conceptual data and visual-graphical data is one of the remarkable features within design protocol studies (Akin & Lin, 1995). Despite the direct definitions of the protocol in the field of architecture, Duerk, (1993) in his book entitled "Architectural programming" has defined and explained some features of the word "concept" which is very close to the authors' purpose of the term design protocol; such that it considers concept as an expression of ideal relationships which is created among the controllable elements (forms, materials, textures, colors, etc.) under the architect. As well, the concept is mentioned as patterns, design ideas or "design diagrams". Hence, concept is considered as an idea that defines ideal and proper relationships among different phases of a project. Based on Duerk, (1993), a concept may encompass the whole problem; so, concepts have been known as ideas that seamlessly assemble a variety of elements in an entirety like a special organizing idea, major concept, theme and sketch. The concept may also provide an ideal solution for a minor part of the project, such as circulation patterns. Here, it is suggested that initially a general and organizing concept is initially proposed for design; then, "sub-concepts" are to be presented consistent with the overall concept. In order to illustrate an overall concept of the project, some methods have been noted such as "expressing a concept diagram", using deductive methods, and presenting a concept scenario (literal image with text writing). To make the designer' purpose more clearly and transparently transferred to other people involved in the project, as well better understanding of pre-construction project, it is better to integrate concept scenario or concept diagrams (Duerk, 1993).

As mentioned above, in summary, the authors' intend of design protocol is writing a concise manuscript that creates a "literal image" adopted with designer' ideas on the project. This definition of design protocol matches with means that came in Webster Dictionary. The word protocol in the Webster Dictionary (2017) has been defined as the original draft, the document registration, the preliminary agreement, the conference minute, the summary of the negotiations, and so on. So,

design protocol should be extensive enough to encompass many points about the project; as well, to provide ideal solutions for any level of details within different parts of the design project.

Here, example of design protocol to be shown (Table 6):

Table 6 Example of design protocol

Design protocol	We decide to design a faculty of architecture so that research is to be considered as a main priority and education and research are defined together. So, a field of scientific search within architecture data and other areas of science (humanities, social, cultural, environmental, education, etc.) should be provided to be feasible for the students to be incorporated in architectural design. Also, the students should test their ideas to generate knowledge; consequently, they will be able to transform theoretical knowledge into practical work. It is better to use attractive forms in the building design to be kept in mind. At last, the faculty should be firmly designed as the same as laboratory and research buildings, but not be spiritless, as well as inspiring inviting and welcoming feelings for the society and citizens.

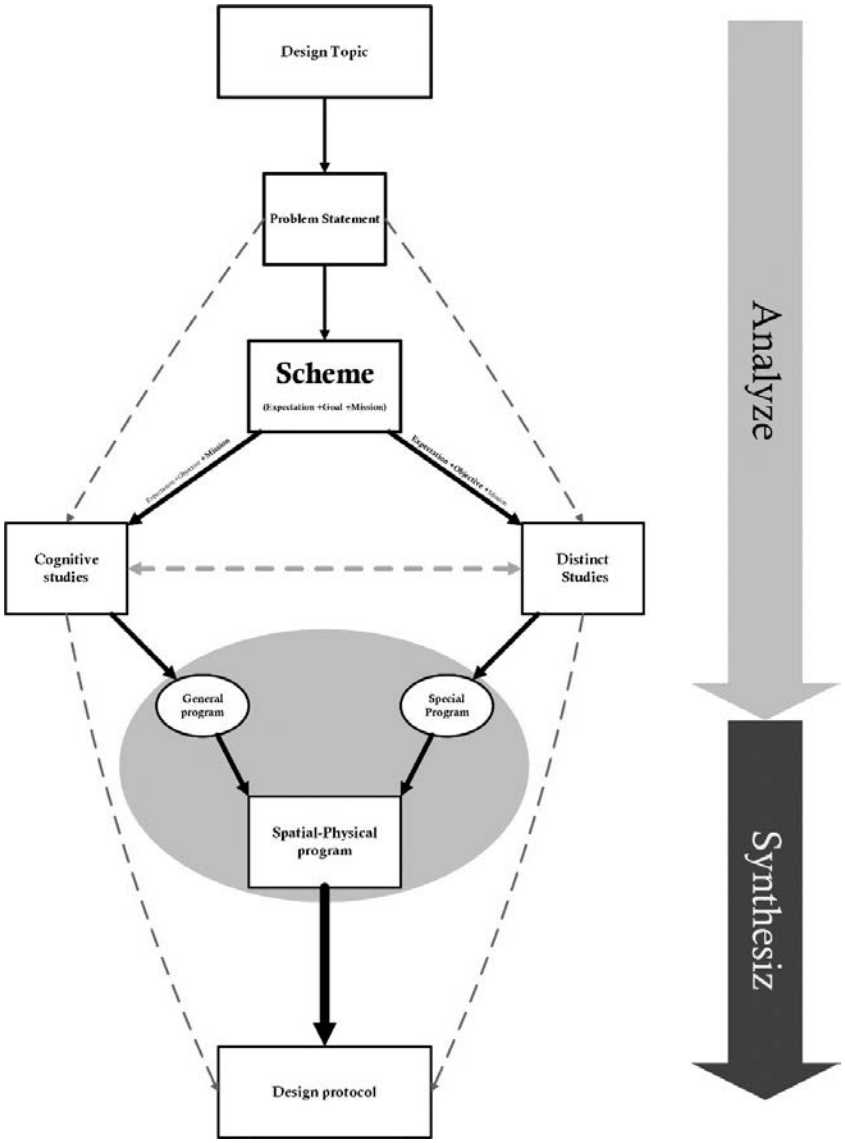

Figure 6 Research–based design process

In order to clarify the process further, a case study in which this method is conducted for the graduate students of architectural design (2) will be presented in appendix1.

Furthermore, during teaching architectural design 2 at master's degree for 3 semesters (which was conducted for a year and a half during the years 2015-2017 at Hakim Sabzevari University), through informal interviews with students, they stated having used this process, they could classify

information needed for design better. They also were able to use this information easier in designing.

Some of the student's statements are as follows:

- A student who had carried out his plan in accordance with this process for one month said that this process has led to further clarity of the matter in his mind in a way that the process of shaping the design statement for him is systematic and traceable.
- One student, after two months of the academic term and using this process, believed that the main dimensions shaping the design statement (problem statement, scheme) were identified in his mind.
- Another student, after spending two months of the semester with the use of this process, stated that he/she has found the importance of the stage of shaping the design statement and the importance of this stage has become clearer to him.
- Besides, a student who used this process for three months, stated that the factors influencing the formation of design statement - field, thematic and topical studies, and the physical spatial program - were well defined in his mind during this time.
- One student, after completing all the steps in the process, stated that the proposed process would help him to predict the design horizons and clarify the next steps of design in his mind. He also confirmed that he can more easily predict the next steps in design and therefore collect more relevant information for the next steps.

Consequently, it seems that the proposed process is a desirable way of designing and can help in the formation of design statement in the minds of students and architect designers, so that they recognize the main dimensions shaping the design statement as well as the factors affecting it and also make it easier to rotate the horizon of plan and draw the design to the end.

9. Conclusion

One of the most important aspects in design methodology and related areas of research-based design is a great deal of effort made in order to represent systematic models derived from design process, as well as proposals for structured methodologies and approaches that should effectively guide designers towards a suitable solution. However, it seems that, in practice, lots of plans move forward in an ad hoc and unsystematic approach (Cross, 2006). Thus, this research intended to provide a systematic pattern of design process emphasizing on process rather than the final product. The following paragraph has been derived from final diagram of the process (Figure 6), so, determining design subject is considered as the first step in architectural design process. The designer should achieve sufficient knowledge of design subject; for this purpose, it is necessary to initially deal with the design problem; then, analyze and configure it. In order to configure the design problem, the factors making the problem and influencing it should be also identified. Design problem may originate from context. Based on the classification by Palmer, (1981) and Lawson, (2006), factors affecting design problem have been also investigated in terms of sociocultural and human factors which individually impose restrictions on design solution. The designer configures design problem to understand it; then, he/she offers the scheme, reflecting the goals, expectations and mission of given the project. In research-based design, designer is concerned with two categories of information. The information entitled cognitive studies which are related to the project mission; and, also the information entitled distinction studies which are related to the goals and expectations of the project. The cognitive studies are the information that help the designer recognize the design subject. In fact, cognitive studies are prepared according to the building's usage comprising a checklist of spaces' names and dimensions which are provided with regard to per capita, regulations and standards specified for each usage. This checklist is called general program. Distinction studies are certain responses to design problem. Since, the design problems may have multiple answers due to their qualitative nature, so each individual designer responses distinctly to design problem and selects specific approach based on his/her creativity, design knowledge and experience. Hence, it can be concluded that distinction studies are the reasons of

differences among designs. When the project approach is selected, the corresponding physical program namely specific program should also be provided which is called Specific program. Specific program contains spaces (and their characteristics including dimensions and qualities) which are obtained based on the project approach. Finally, general program and specific program are integrated to make spatial-physical program of design including a process through which the designer acquires all information about the project to make the most appropriate decisions within different design phases. When the design program entitled spatial-physical program is prepared, designer must lead it to be operational; that is as a kind of conclusion of implemented phases which can be achieved. So, an overall pattern/idea is required that encompasses all these factors. Design protocol as an overall concept of the project" is a brief manuscript that declares designer's ideas on the project including the project overview as well as details of various phases of the project. When designing the design protocol is proposed in terms of a "text", the designer can propone a "sketch" reflecting all the ideas expressed in the previous step.

For future research, it is possible to analyze the problem statement stage as the most elementary stage in the design protocol and how to transform the design statement into architectural sub-concepts. At the problem statement stage, it is necessary to plan a quantitative and qualitative process that will give the architecture student the ability to understand the design problem and create a clear path. Since the design protocol is a written structure, its transformation into a visual and architectural form requires the explanation of regular steps with a simple and understandable construct, so turning the design protocol into architectural concepts can be considered a necessary research topic for the future.

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Appendix 1 (example 2)

Conceptual design table			
Analyze			
Problem statement			
Sub-phases	**specific explanation for project**	**Sub-problems**	**suggestion**
legislator	1. Height constraint up to 10 meters. 2. The coverage constraint up to 40 percent of site 3. Using materials consistent with walls 4. Ability to be harmonic with environment and sustainability of design	1. Mass expansion considering space limitation. 2. Limited access of site from square margin with high-density of vehicles and pedestrians. 3. Lack of easy access to the uses due to farther distance of the entrance from main spaces 4. Limitations on the use of preferred forms and materials due to its location in obsolete and historical texture of city.	1. Moving in depth along with providing coarse spaces in the floors beneath the ground. 2. Using underpass and overpass routes distributed from surrounding crossings in order to provide access of vehicles and pedestrians to the site 3. Using materials and characteristics of indigenous architecture 4. Utilizing Euclidean volumes with a legible combination
client	1. Providing live and dynamic space 2. Ability to communicate with citizens	1. Limited interaction with surrounding environment due to the lack of site proximity with surrounding streets, and comprehensively enclosed within urban time-worn and dense textures. 2. Restrictions on the use and design of walls in order to create communal spaces and inviting feeling.	1. Designing sections to create diverse and dynamic landscapes 2. Designing spaces within the site to interact and engage local residents in faculty 3. Providing an outstanding and familiar entry in the neighborhood for residents 4. Designing within the human scale
user	1. Creating exhibition spaces 2. Creating specific spaces for the faculty 3. The possibility of holding classes in open and semi-open spaces 4. Creating interactive spaces with other students	1. Inappropriate and unusual geometry of site. 2. Limits of coverage and shortage of areas for the given infrastructure	1. Environmental design priority and mass layout based on design demands 2. Considering spaces with complex and multiple uses within the site. Using the site's failure in order to define specific space 3. Using porous volumes, porches and terraces on floors to define interactive spaces 4. Utilizing temporary structures so as to exhibiting and collective spaces if necessary.
Cultural values	Rehabilitation of the area	1. Cultural heterogeneity of student environment with social and cultural structure of the site 2. Lack of easy interaction with local communities, due to neighborhood residents' resistance to communicate.	
Problem Statement: In the present study, the most important problem is site isolation within a dense and impermeable texture which on one hand makes the possibility of visual and physical relationships with surrounding environment through the walls impossible and adversely			

affects the process of interactive inviting the audience. On the other hand, access of vehicles and pedestrians have been restricted and reduces the interaction with environment.

scheme

Sub-phases	**specific explanation for project**	
expectations	-	Creating a live and dynamic environment to engage students and residents in the faculty of architecture.
Goals	-	Rehabilitation of old textures and contribution to the development of cultural and social infrastructures with the help of faculty of architecture.
Mission	-	Constructing the faculty of architecture that meets project goals despite limitations.

Scheme:

Constructing a familiar space in form of faculty of architecture in order to establish a base for development of cultural and social characteristics and texture rehabilitation.

Cognitive studies

Sub-phases	**specific explanation for project**	
Regulations and standards	-	-
Per capita	-	-
Subspaces	-	-

General program:

A List of spaces within architecture faculty such as theoretical classes, practical classes, auditorium, administrative and service sectors as well as the number and dimension

Distinction studies

Sub-phases	**specific explanation for project**	
Creativity	-	1. Emphasis on design within human scale 2. Priority of environmental design 3. Using floating spaces 4. Using Euclidean volumes with a legible combination 5. Cross design along with use of semi-open spaces within the floors 6. Using traditional architectural features, such as arrays in viewing to create a familiar environment in order to provide a sense of community. 7. Interaction with surrounding environment with the aim of developing cultural and social characteristics in order to achieve sustainable development goals.
Design knowledge	-	
Experience	-	

Approach (Special Program): Designing architecture faculty to create an interaction between residents and students

Specific program: providing facilitating interactive spaces such as exhibiting spaces (exhibition of handicrafts, local products, and students' works, etc.), gathering spaces (open and semi-open spaces within the site), educational and cultural spaces (spaces so as to discuss, workshops for common activities between residents and students, workshops to train individual, cultural, and social skills, as well as workshops so as to train students with local residents' art and vice versa, amphitheater, etc.)

Synthesize

Spatial physical program	**General program:** educational spaces (studios, theoretical classes, workshops and laboratories), service, welfare, and office spaces. **Special Program:** exhibiting spaces, gathering spaces, educational and cultural spaces
Design protocol	We decide to create a familiar environment within an old physical and cultural texture. A modern environment which is intimate and lovely for people using indigenous architectural features. A charming and outstanding entry which attracts all people which transforms that space into a local symbol. Environmental spaces with a variety of uses and placid and solemn volumes with a legible combination. These areas do not push back the audience and the perception is not complicated. Indeed, this design provides an interactive space to be simple and constructive for the students and residents. In this regard, the architecture student will be practically situated in a real work out. In addition, educational process and space are defined from a new perspective. On the other hand, the residents feel close to it while influencing from different cultural and social areas.

Resume

Shahab Abbaszadeh, I graduated in 2003 with an M.A. in architecture. Then I participated in the design competition at Herat University, and in 2004, I designed two faculties of economics and law at that university. Consequently, I joined the University Putra Malaysia to complete my Ph.D. I was awarded for selecting my Ph.D. thesis as the best thesis in architecture in South Pacific Asia by the Ministry of Science, Research and Technology in 2008. After getting my Ph.D., I was a permanent university lecturer at the Architecture Department of Hakim Sabzevari University in May 2010. After 11 years of working as a university lecturer, designer, and researcher, I got many valuable achievements, such as; "Supervised more than 50 postgraduate research theses in architectural studies, Published more than 70 journal and conference papers & four books, Received letters of appreciation for my high marks in teaching in several semesters, Awarded as a well-known professor in teaching Design Process, Research Methodology, Conceptual Design, and Design Studio courses, Nominated as the top professor in my faculty for more than six years, Assigned as the reviewer in several top-ranked journals relevant to my research fields, such as the Journal of Housing and the Built Environment, Supervised eight practical and applicable research–design projects for different state and private organizations in various cities and provinces such as the municipalities of Sabzevar, Kashmar, Shirvan, Tabas, and City Council of Razavieh towards solving architectural and urbanism challenges and issues (I conducted five research - design projects and contributed to two research projects), Leading some university campus projects., I acquired the rank of associate professor in 2017, which introduced me to the youngest associate professor at the university. Shortlisted for the final stage in the category of sea-level rise and nominated as one of the best projects in international competition, the Jacques Rougerie Foundation international architectural competition, in 2021 in French.

This is Behrooz Khosrowjerdi, a graduate of the field of architecture at the master's level, a researcher, and an architect designer. I started my studies in architecture in 2009 at the undergraduate level, and in this regard, I focused my analysis on the spatial qualities of children; as a result, I completed my thesis on the topic of designing quality-oriented spaces for children. After that, I started my master's degree in 2014 at Hakim Sabzevari University, where I limited my studies to quantifying architectural factors and the effects of digital spaces in environmental psychology. In this regard, I chose my topic on the quantification of factors affecting the design process, which led to the publication of an international and a national article. Currently, I am continuing my studies in the field of artificial intelligence application in the research-based design process.

This is Zohre Sadat Seyedmoradi. I started my bachelor's degree in architectural engineering in 2010 at Hakim Sabzevari University and finished it in 2014. I immediately studied for a master's degree, and in 2016 I graduated with a master's degree from Hakim Sabzevari University. In my master's, I did research work and completed my thesis titled "Designing the Faculty of Architecture and Urban Planning with a research-based design approach." During my thesis, I wrote some articles titled "To Development an Analytical Model for the Formation of a Design." "Scenario" in the Research-based Design Process in Architecture" has been published in an international journal. Currently, I am also doing research in the field of the research-based design process.