EVALUATION OF THE IMPACT OF PUBLIC SPACE DESIGN ON THE LAND SURFACE TEMPERATURE BY USING GEOGRAPHICAL INFORMATION SYSTEMS: THE EXAMPLE OF TAKSIM SQUARE URBAN DESIGN COMPETITION

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ABSTRACT

EVALUATION OF THE IMPACT OF PUBLIC SPACE DESIGN ON THE LAND SURFACE TEMPERATURE BY USING GEOGRAPHICAL INFORMATION SYSTEMS: THE EXAMPLE OF TAKSIM SQUARE URBAN DESIGN COMPETITION

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Urban areas are heating due to climate change and anthropogenic heat release. Increasing temperature negatively affects people, nature, and ecosystems. Many factors trigger the temperature increase in cities, including traffic, increasing population density and surface temperatures, etc. Public spaces are urban areas where increasing temperatures affect daily life most. Therefore, the materials and elements preferred in public spaces covering most city surfaces are crucial in controlling Land Surface Temperatures (LST). Thus, LST should be an important parameter in urban design and public space design principles. However, LST is not yet considered a parameter that guides the design process in the urban design process. This thesis emphasizes that LST is a variable that needs to shape the design process of cities (especially public spaces). However, there is not enough study in the literature on LST analysis in high resolutions for serving the urban design process to achieve this goal. For this reason, it is aimed to develop a practical and low-cost analysis method to (1) identify design elements and materials that affect LMS in public space design and (2) disseminate LST analysis in public space design. Accordingly, one of İstanbul's historical squares, Taksim Square, was chosen as the study area. In recent years, decision-makers in public space design processes have widely preferred urban design competitions in Turkey. Taksim Square Urban Design Competition, held in İstanbul in 2020, was chosen as the study area due to the number of participants and the importance of the square.

The LST of the winning and runner-up projects were evaluated. The surface temperature of the field was measured with the Benetech G300. The potential surface temperature of Project 15 (winner) and Project 19 (runner-up) and current surface temperature of the square were modeled with GIS analysis tools; Analyzed with Kernel Density and Map Algebra tools, and then compared. As a result of the LST analysis, the land use of the square and the average surface temperatures of Project 15 and Project 19 were found as 41℃, 35℃, and 32℃ under the same conditions, respectively. The percentages of areas covered by surfaces with a temperature of 40 degrees and above are in order of 48%, 38%, and 26%. As a result of the study, it is observed that the winning project in the Taksim Square Urban Design Competition had a surface temperature approximately 3℃ warmer than the runner-up project, thus emphasizing the importance of the LST analysis in the urban design process. With the steps applied in this study, the experts working in urban design may analyze the LST of the designed areas with basic operations at low costs in any GIS environment.

Keywords: Land Surface Temperature (LST), Geographic Information Systems (GIS), Public Space Design, Taksim Square

ÖZ

KAMUSAL ALAN TASARIMLARININ ARAZİ YÜZEY SICAKLIĞINA ETKİSİNİN COĞRAFİ BİLGİ SİSTEMLERİYLE DEĞERLENDİRİLMESİ: TAKSİM MEYDANI KENTSEL TASARIM YARIŞMASI ÖRNEĞİ

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İklim değişikliği ve antropojenik sıcaklık salınımından dolayı şehirler her geçen yıl ısınmaktadır. Artan sıcaklıklar hem insanları hem de doğayı ve ekosistemleri olumsuz yönde etkilemektedir. Kentlerdeki sıcaklık artışını tetikleyen birçok faktör bulunmaktadır ve bunlardan bazıları, trafik, hava ve su kirliliği yaratan kentsel aktiviteler, artan nüfus yoğunluğu ve yüzey sıcaklıklarıdır. Kentlerde artan bu sıcaklıkların günlük hayata en çok etki ettiği mekanlar ise kamusal alanlardır. Bu nedenle, kent yüzeylerinin çoğunu kaplayan kamusal alanların tasarımında tercih edilen materyal ve elemanlar, Yer Yüzey Sıcaklıkları (YYS) kontrolünde önem taşımaktadır. Bu sebeple, kentsel tasarım prensibinde ve kamusal alan tasarımında YYS önemli bir parametre olmalıdır. Fakat, dünyada ve Türkiye'de, kentsel tasarım sürecinde YYS henüz tasarım sürecine yön veren bir parametre olarak değerlendirilmemektedir. Bu tez çalışmasının odak noktası, insan hayatını ve doğal yaşantıyı olumsuz etkileyen artan yüzey sıcaklıklarının, kentsel (özellikle kamusal alanların) tasarım sürecine yön veren bir değişken olduğunun vurgulanmasıdır. Fakat bu amaca ulaşılabilmesi için kentsel tasarım ölçeğinde LST analizi ile ilgili yazında gerekli ve yeterli çalışma bulunmamaktadır. Bu nedenle, çalışmada (1) kamusal alan tasarımında YYS'yi etkileyen tasarım elemanlarının ve materyallerinin tanımlanması ve (2) kamusal alan tasarımında YYS analizinin yaygınlaşması için pratik ve düşük maliyetli bir analiz metodu geliştirilmesi hedeflenmiştir. Bu nedenle, İstanbul'un en uğrak ve tarihi meydanlarından olan Taksim Meydanı, çalışma alanı olarak seçilmiştir. Son yıllarda kentsel tasarım yarışmaları, Türkiye'de kamusal alan tasarım süreçlerinde karar vericiler tarafından yaygın olarak tercih edilmektedir. 2020 yılında İstanbul'da düzenlenen Taksim Meydanı Kentsel Tasarım Yarışması, katılımcı sayısı ve meydanın önemi nedeniyle çalışma alanı olarak seçilmiştir. Kazanan ve ikinci olan projelerin yüzey sıcaklıkları değerlendirilmiştir. Alanın yüzey sıcaklığı Benetech G300 ile ölçülmüştür. CBS analiz araçlarıyla modellenen Proje 15 (kazanan) ve Proje 19'un (ikinci olan) potansiyel yüzey sıcaklığı ve meydanın mevcut yüzey sıcaklığı; Kernel Density ve Map Algebra araçları ile analiz edilmiştir ve sonrasında karşılaştırılmıştır. YYS analizi sonucunda meydanın mevcut durumu, Proje 15 ve Proje 19'un ortalama yüzey sıcaklıkları sırasıyla 41℃, 35℃ ve 32℃ olarak bulunmuştur. Sıcaklığı 40 derece ve üzeri olan yüzeylerin kapladığı alanların yüzdeleri ise sırasıyla %48, %38 ve %26'dır. Çalışma sonucunda Taksim Meydanı Kentsel Tasarım Yarışması'nda kazanan projenin, ikinci olan projeden yaklaşık 3℃ daha sıcak bir yüzeye sahip olduğu görülmüştür ve böylece YYS analizinin süreçteki önemi vurgulanmıştır. Bu çalışmada uygulanan adımlar ile, kentsel tasarım alanında çalışan uzmanlar, CBS ortamında basit işlemlerle ve düşük maliyetlerle, tasarlanan alanların yüzey sıcaklıklarını uygulamalı olarak analiz edebileceklerdir.

Anahtar Kelimeler: Yer Yüzeyi Sıcaklığı (YYS), Coğrafi Bilgi Sistemleri (CBS), Kamusal Alan Tasarımı, Taksim Meydanı

Dedicated to my bellowed family

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LIST OF ABBREVIATIONS

GIS	Geographical Information Technologies
IMM	İstanbul Metropolitan Municipality (İstanbul Büyükşehir Belediyesi, İBB)
LST	Land Surface Temperature
MGM	Meteorological
PCI	Park Cool Island
PPS	Project for Public Spaces
SUHI	Surface Urban Heat Island
UBL	Urban Boundary Layer
UCL	Urban Canopy Layer
UHI	Urban Heat Island

CHAPTER 1

INTRODUCTION

Urbanization, population pressure, and urban activities (such as industrial activities or traffic) are drivers of warming in urban areas. Rapid urbanization boosts the local temperatures up to 5° C by increasing the hard surface areas ratio over the cities (Chapman & Watson, 2017). Such an alteration in urban areas' surfaces increases the Land Surface Temperatures (LST) and causes the formation of Surface Urban Heat Islands (SUHI) concentrated on the cities. SUHI causes the formation of urban heat islands (UHI) due to the interaction and correlation between surface properties, LST, and air temperature. Therefore, designing and planning cities by considering LST as a major driver of UHI is crucial to minimize global warming's impacts on urban areas, human beings, and nature.

Public spaces cover nearly 80% of cities. Thus, these areas have the most significant impact on temperatures. Masses of people come together and socialize in public spaces. Such sites consist of various common areas such as children's playgrounds, bazaars, shopping centers, neighborhood markets, squares, streets, roads, entertainment and sports areas, celebrations, and areas where speeches are made (Karayilmazlar & Çelikyay, 2018). While green spaces and water bodies reduce urban temperatures, other open public spaces have a boosting impact on LST due to their hard surfaces. Hard surfaces such as roads, pavements, and squares absorb the incoming sun rays, causing an increase in surface temperatures and the formation of SUHI. Arguably, squares have the most heat-absorbing type among the rest of the public spaces, so their LST is relatively high.

The problem of heating and related extreme weather events has been one of the urban planners' most significant problems for decades. Several developed countries aim for sustainable cities to prevent and adapt to climate change effects, and they plan the cities by providing climate-friendly policies (Oke et al., 2017). As one of the drivers of heating, surface temperatures need to be considered for the climate adaptive city plan. Planning policies in Turkey are still ignoring global warming and its effects. In other words, global warming is either not perceived as a problem or takes place solely in upper scale plans and is not reflected in practice. The warming issue is not considered an important variable on a scale that can serve the urban design process.

Urban design needs to address the warming issue by focusing on areas exposed to heat, such as public spaces. By using typical square designs, green spaces that provide regulatory ecosystem services and hard floors with a high albedo that can positively affect LST can be built. However, Turkey and other urban countries have not developed a standardized understanding that prioritizes this approach.

Municipalities are one of the important actors that can put heat mitigation strategies in urban design into practice. Further, they are key actors in raising awareness in heating and its impact management. In Turkey, decision-makers, planners, and urban designers are the key actors in solving the warming problem. Municipalities are the essential auditors during the implementation of the city plans and urban designs. However, they are also the ones who will enable the criteria and requirements to be determined. Urban design competitions held in the country are of great importance in terms of supervision and awareness of the concept of heat-sensitive cities. However, heat-sensitivity compatibility is not a criterion in projects, and it is up to the contestants to decide their design attitude on warming. This situation often results in ignoring the issue of climate change. When examining the spatial distribution of the urban design competitions held in Turkey, it is observed that most competitions take place in İstanbul province (Ketboğa, 2015).

When the content of the competition guidelines is reviewed, it can be observed that there is no comprehensive clause on climate change or warming. The "producing solutions for climatic conditions" pattern, one of the Taksim Square Urban Design Competition specification articles, is insufficient. This phrase is incomplete to emphasize the significance of global warming and to make contestants think about this problem. Evaluation criteria and themes of urban design competitions held in the country raise awareness among planners, designers, and the public about increasing temperature.

In the urban design process, studies are carried out on the scales of 1/1000 or 1/500. These scales have a puzzle-piece effect on the construction of cities. The city's surface materials are defined with urban design. Therefore, the urban designs have the greatest impact on the LST. However, the literature review has shown that studies on LST modeling at the resolution for urban design are not satisfactory. Thus, developing an awareness of surface temperatures in the analysis stage of urban design is difficult.

In this context, the two finalist projects of the Taksim Square Urban Design Competition in İstanbul were selected.

Aim of the study and research questions

The study's main objective is to guide the urban design process with the developed design control tool to reduce urban temperatures by minimizing LST in cities. However, LST analyses made in higher resolutions are not suitable for evaluation in the urban design process. The maximum resolution of LST analyses obtained by the Remote Sensing method, widely used in studies carried out to date, is 3m (Solanky et al., 2018). This resolution is not sufficient for the details required by the urban design principle. There is not enough work in the literature on an LST analysis method with technical details that can serve the urban design process.

To reach the aim of the study, an LST analysis method has been developed on a scale that can serve the urban design process. The winner and the runner-up projects (Project 15 and Project 19) of the Taksim Square Urban Design Competition were chosen as the case study. The surface temperatures of the projects were compared.

In order to achieve the main goal, two sub-objectives must be fulfilled. The first Sub-objective is to develop a practical and low-cost method on LST modeling at a scale that can serve the urban design process, which is considered a literature gap. In this way, it is aimed to make LST analysis widespread in the urban design discipline by keeping the LST modeling process of experts simple.

The second sub-objective is to raise awareness of the importance of LST in urban design by evaluating the impact in the Taksim Square Urban Design Competition. By comparing the two winning projects (Project 15 and Project 19) of the Taksim Square Urban Design Competition and the LST analysis of the land use, investigate whether surface temperatures are important in this discipline. By focusing on the Taksim Square case in İstanbul, this thesis asks the following two research questions:

1. Which physical environmental attributes of the land use of Taksim Square affected the land surface temperature?
2. Compared to the land use of the square, do the two projects, which made it to the finals in the design competition, positively affect the LST values in Taksim square?

The thesis will answer the following questions to answer these main research questions:

1. How is the LST modeled at a scale that can serve the urban design of a square?
2. How do surface elements that form squares in cities affect LST?

1.1 Structure of the Study

In line with these objectives, Chapter 2, based on a comprehensive literature review, explains the definition of urban heating, LST, and its causes, effects, and mitigation methods. After determining the concept of urban public space, the importance of public spaces on surface temperatures and the factors affecting LST are discussed.

In Chapter 3, the related background information about Taksim Square Urban Design Competition and the methods for modeling LST in high resolutions for surface temperature analysis at the urban design process is provided. The case study area, Taksim Square, and the selected urban design proposals are introduced. In addition, step by step guide to model LST is given.

Chapter 4 compares the square's LST model results and the LST estimations of the 2 winning design projects. The results of the conducted study are provided in this chapter.

Chapter 5 summarizes the study's key findings, and the answers to the research questions are briefly provided. Interpretation of the results and the limitation of the study take place in this chapter. The study's main contributions to the literature are explained, and the study's limitations are discussed. Lastly, recommendations for future research were presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Background information

In this chapter, the basic concepts that the LST includes are explained briefly. Urban heating, including urban heat island (UHI), land surface temperature (LST), and the causes and impacts of LST explained. The relationship between surface and air temperature and UHI and LST is discussed in this chapter. The chapter also provides brief information about the main attributes of urban areas that lead to LST variations. Lastly, the necessity to mitigate LST is discussed.

2.1.1 Basic concepts related to LST

The study discusses the temperature values formed by the absorption of the sun rays reaching the urban surfaces. Since the thesis is based on the concept of LST, it is important to explain the physical structures of heat and light to the readers. In addition, material properties that affect the heating levels of surfaces are also briefly explained, such as albedo and emissivity.

2.1.1.1 Light, heat, and temperature

Light is the radiation of objects in various forms. Visible radiation is a special form of energy that allows us to see objects around us. The distribution of the radiation from a unit surface of a blackbody according to the wavelength is called the "Planck curve". Figure 2.1. shows black bodies' energy distributions (Planck curves) at different temperatures.

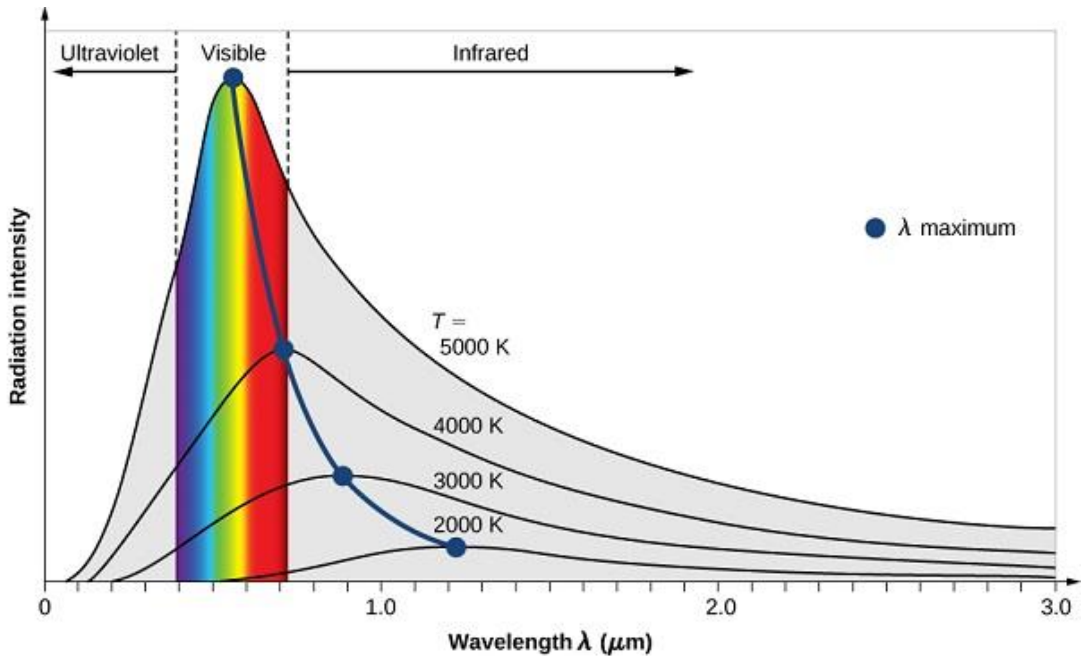


Figure 2.1 Spectrum of a blackbody with four different temperatures (Planck curves) (Source: “BCcampus”, n.d.)

Objects that illuminate their surroundings by spontaneously emitting light, such as the sun and other stars, are called natural light sources. The relationship of light with the concept of LST is through the sun's rays. These rays reach the urban areas and are stored as heat energy on urban surfaces, increasing the temperature values.

Heat energy is the sum of the kinetic and potential energies of the atoms or molecules that make up a substance. It occurs as a result of atomic or molecular vibrations. According to a certain measure, the quantity that indicates the coldness or warmness is known as temperature. The quantity proportional to the average kinetic energy of a substance is temperature. If the temperature of a substance changes, it either gives off heat to its surroundings or takes heat from its surroundings.

Heat Exchange

Heat exchange occurs between substances with different temperatures in a thermally insulated environment. If there is heat exchange between bodies, the heat taken equals the heat given off. Heat flows from a hot object to a cold object.

2.1.1.2 Albedo

The capacity to reflect electromagnetic energy falling on a surface, that is, the reflective power of the surface, is called albedo. The albedo of objects varies depending on the surface area, texture, and color. A white-appearing object has a high albedo and reflects most of the light hitting it, while a dark-appearing object has a low albedo and absorbs most of the incident light as heat (Nuruzzaman, 2015) (see Figure 2.2). In other words, objects with low albedo absorb light as heat energy, and their temperature values are higher than objects with high albedo.

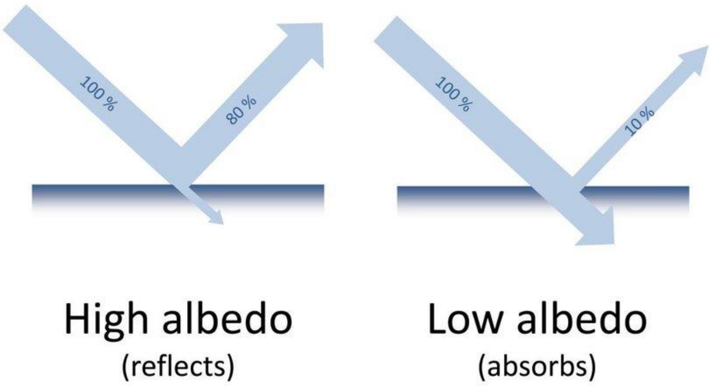


Figure 2.2 Indication of high and low albedo (Source: Van der Perre et al., 2018)

2.1.1.3 Emissivity

Emissivity is defined as the ratio of the energy emitted from the surface of a material to the energy emitted by a perfect emitter, known as a black body, at the same temperature and wavelength and under the same imaging conditions. In short, a material's surface can radiate energy proportionally. It is a dimensionless number between 0 (for a perfect reflector) and 1 (for a perfect emitter).

2.1.2 Urban heating

Global warming and rapid urbanization boost the local temperatures up to 5° C (Chapman et al., 2017). Surfaces typical of urban areas, such as impervious surface cover and buildings, cause excessive solar heat radiation and airflow inhibition due to their materials. These surfaces decrease the evaporation rate and thus lead to the alteration of energy balances and warming of the air. Urban surfaces absorb solar radiation during the day and store it as heat energy. Typically, about two to three hours after sunset on clear nights, this stored heat energy is released into the lower atmosphere, forming a "heat bubble" over the city. The dome formed by warmer air above the city is warmer at 1-3°C than the rural areas surrounded (Masumoto, 2015). The "heat bubble" formed in the microclimate of urban areas is called urban heat island (UHI). Thus, UHI causes the city to be warmer than the surrounding area. Three types of UHI differ in height and characteristics: surface UHI, canopy layer UHI, and boundary layer UHI.

The canopy layer UHI

The urban canopy layer is the atmospheric layer extending from the ground level to the average building height (Oke, 1976; Cleugh, 1995a). This layer consists of urban canopy elements, i.e., trees, buildings, lawns, roads, etc., and found in the atmosphere under the highest points of buildings and trees. Cumulated air in the canyon is affected by transmitted heat from the surface, and this heat transfer ensures the energy balance in the area (Oke, 1984). Furthermore, heat transfer between different atmosphere layers is possible. Layers might warm each other up during the day while they might cool one another down during the night. The canopy layer UHI is a local (neighborhood) scale phenomenon. It is the most studied of all heat island types, given its accessibility and relevance to human activities.

Boundary-Layer UHI

The urban boundary layer covers the part of the atmospheric boundary layer that is affected by the presence of the metropolitan area. For medium to large cities, daytime

UBL extends directly to the top of the boundary layer, including convective precipitation (Cleugh & Grimmond, 2012). The hot air released from the urban surface expands and starts to rise into the atmosphere, and the last point that this hot air can reach is the urban boundary layer. Air reaching the urban boundary layer is much hotter than the air in the atmosphere and forms a boundary over the city unaffected by outside airflow. The air clustered at this boundary is the urban layer heat island (Masumoto, 2015).

Surface Urban Heat Island (SUHI)

SUHI is defined by the temperature of the surface covering of all 3D elements. It is a phenomenon of surface energy balance. It covers the city's entire built and natural environment (street, vertical walls, roofs, trees, etc.), and it is the most effective during daytime.

2.1.2.1 Relationship between land surface temperature and urban heating

Materials utilized in urban areas release emitted heat and increase urban temperature. Heated surfaces increase the temperature of the air by heat dissipation, and this air rises and causes heat islands to form, which means air is warmed up from the bottom to top (Yilmaz et al., 2006; Bakar & Ariffin, 2012). Therefore, surface temperature and air temperature are two highly correlated values in the canopy layer (Nichol, 1994; Arrau & Pena, 2010). However, due to the many factors that affect the air temperature, such as wind, pressure, humidity, the rising hot air begins to mix with the atmosphere as it warms up. Therefore, surface and near-surface temperatures are not the same (EPA, 2009a). At night, surface temperatures and atmospheric temperature values are close and parallel to each other, while during the day, there is more difference between these two temperature measurements (see Figure 2.3). Atmospheric temperatures remain constant, but surface temperatures fluctuate (Hendel, 2015).

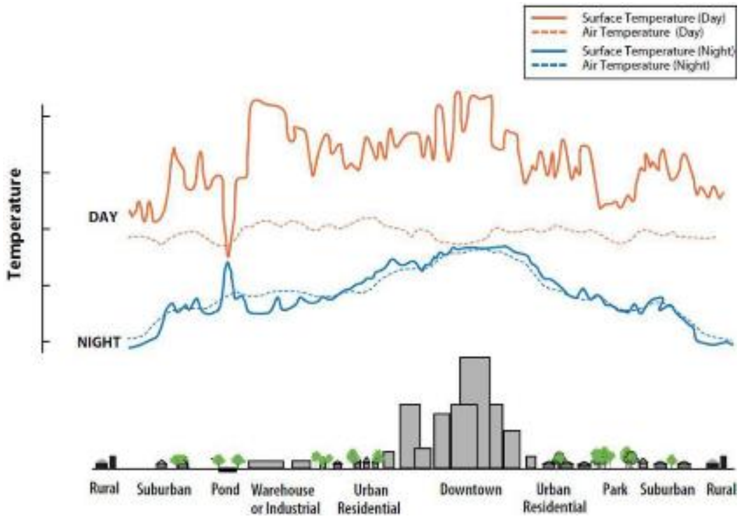


Figure 2.3 Variations in Surface Temperatures and Atmospheric Temperatures (Source: EPA, 2009a)

2.1.3 Land surface temperature (LST)

Land Surface Temperature is crucial in determining the Earth's surface's solar energy reflected and emitted (Hulley et al., 2019). It has a significant role in weather forecasting, global ocean circulation, and determination of climatic changes and SUHI due to energy transfer and water cycle between earth surface and atmosphere changes (Valor & Caselles, 1996; Kant & Badarinath, 2000). Therefore, it is an essential parameter in calculating the energy balance on the earth's surface. Although various meteorology stations (operating on a point basis) have been established to calculate LST, they can be estimated globally with the help of remote sensing data (Şahin & Kandirmaz, 2010). Moreover, the most preferred method for the recent studies is remote sensing.

Understanding the UHI effect is necessary to describe the different climatic layers of the atmosphere and surface of the earth (Jamei & Tapper, 2018).

2.1.3.1 Urban microclimate

Urban microclimate can be defined as the state of the atmosphere in the layer directly affected by the characteristics of the underlying urban area (Rotach & Calanca, 2003). Urban climates are affected by land-use decisions in urban areas and cause temperatures in different layers of the atmosphere to rise. The atmosphere cools with distance from the surface due to the structure of air particles and gravity. However, the increasing temperature in the atmosphere on urban surfaces is seen even in air masses relatively high from the ground. Oke (1989) states that these air masses are separated according to their microscale, local scale, and mesoscale (see Figure 2.4).

(a) Microscale – It is the scale closest to the surface of the urban microclimate, determined by the dimensions of urban elements: trees, roads, streets, buildings, squares, parks, etc. This layer can extend up to hundreds of meters, forming the urban canopy layer (UCL).

(b) Local-scale – This scale includes climatic effects of landscape features such as topography but excludes microscale effects. In cities, this means the climate of regions with similar types of urban development. It is usually between one and several kilometers.

(c) Mesoscale – Urban areas affect the weather and climate on a global or regional scale for tens of kilometers. The impact area of the city's climate is evaluated in the mesoscale (Cleugh & Grimmond, 2012).

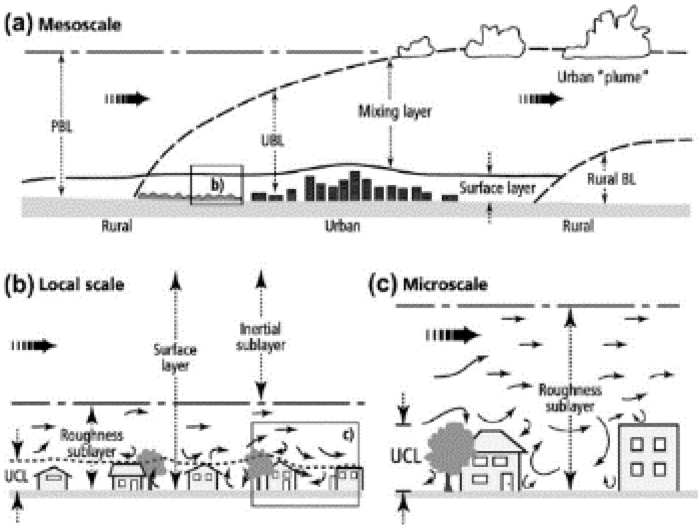


Figure 2.4 Scales in the urban environment (Source: Piringer et al., 2002)

Heat islands are affected by urban activities and are directly affected by the properties of surfaces in the city. Thus, heating starts from the surface and increases air temperatures. Examining the relationship between land surface temperatures and air temperatures to measure the effect of surface materials on temperatures in public spaces is significant.

2.1.4 Causes of surface urban heat island

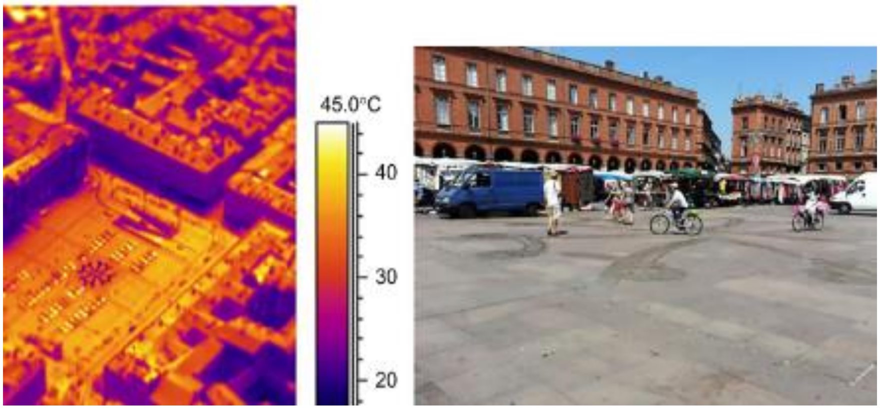


Figure 2.5 (Left) Thermal Drone Image of the Toulouse Square (Right) Photograph of Toulouse Square, France (Source: Hulley et al., 2019)

The main reason for urban warming is eliminating soil and vegetation cover in urban areas by constructing roads, buildings, and pavements (see Figure 2.5). These structures prevent the evaporation of water from the soil and plant leaves. Evaporation is essentially a cooling process. Ultimately, reducing evaporation causes cities to warm up. In addition, darker buildings and surfaces absorb more sunlight, causing the city to heat up more. In addition to these reasons, obstruction of airflow and a high anthropogenic heat release due to high or incorrectly positioned structures cause surface warming. However, several factors contribute to the formation of the Surface Urban Heat Island, and the aspects that play an important role are described below (see Figure 2.6). LST is impacted by impermeable and green areas in larger and smaller spaces. It was also noticed that the orientation, complexity, and aggregation of impervious cover and green cover highly influence average LST.

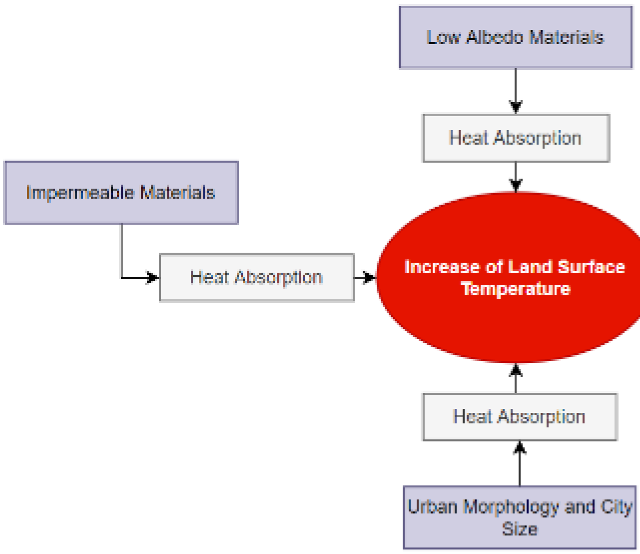


Figure 2.6 Causes of Land Surface Temperature Increase

2.1.4.1 Gradual loss of urban forest cover

Forests are destroyed on a large scale by changing land uses to meet various urban needs. Fewer trees mean less cooling efficiency because trees increase evaporation and provide cooling with the water they hold in their leaves. Trees create shade by blocking sunlight and cool the environment by absorbing CO2 for photosynthesis (Akbari et al. 2001; Nuruzzaman, 2015). Because of destroying plant life or reducing the surface area that vegetation covers, the capacity of the cooling system decreases, which results in an increment in urban temperatures.

2.1.4.2 Impermeability of materials

The intensification of urbanization in recent years has also caused changes in land uses. Natural soils have been replaced by impermeable materials such as asphalt and stone and building materials that alter the natural course of rainwater as they do not provide water filtering and absorption functions (Rushtone, 2001; Coutts et al., 2008; Mailhot & Duchesne, 2005; Giguère, 2009). While the rate of infiltration of water into the soil in cities is only 15% and the amount of rainwater runoff is 55%, in the natural environment, about 50% of the rainwater infiltrates into the soil, and 10% flows into the waterways (USEPA, 2007; Cyr et al., 1998; Giguère, 2009). Restricting water availability in urban areas limits natural cooling processes such as evaporation of soil moisture and water from vegetation, and urban cooling cannot be achieved. Water has a cooling impact on surfaces due to evapotranspiration. In addition, impervious surfaces contribute to the contamination of collector waterways in the following ways:

- Runoff carrying chemical pollutants such as hydrocarbons and pesticides;
- Sewer overflows caused by heavy rains;
- Coastal erosion due to the high velocity of runoff (Frazer, 2005; Brattebo and Booth, 2003; Giguère, 2009)

To summarize, by regulating the ratio of solar energy reflected from the surface to incoming solar energy, preventing the retention of solar energy in the city's atmosphere depends on the planning decisions such as surface materials, pavements, etc.

Tall buildings and narrow streets or the positioning of these elements can interfere with the ventilation of cities as they create corridors where heat generated by solar radiation and human activities accumulate and is trapped (Coutts et al., 2008). In addition, urban morphology can affect transport and traffic, thus promoting temperature rise and air pollution (Oke, 1988; Giguère, 2009).

2.1.4.3 Urban morphology and city size

Tall buildings and narrow streets or the positioning of these elements can interfere with the ventilation of cities as they create corridors where heat generated by solar radiation and human activities accumulate and is trapped (Coutts et al., 2008). In addition, urban morphology can affect transport and traffic, thus promoting temperature rise and air pollution (Oke, 1988; Giguère, 2009).

To explain, according to a study by Zhou, Rybski, and Kropp (2017), the effect of urban morphology on temperature has been evaluated with size, compactness, and shape. According to the results, it has been observed that large, compact, and rotund cities increase the urban temperature. Scattered cities with high travel demand bring more anthropogenic heat release and CO2 emission. In addition, although compactness means less travel demand related to heat release, a high-density population also causes warming.

2.1.4.4 Anthropogenic heat release

Anthropogenic heat release forms mainly from three variables: commercial or residential energy consumption, industrial activities, and transportation (Narumi et al., 2009). The cooling and heating demand of buildings cause a temperature rise in two ways: energy use and releasing hot air directly outside the building by air conditioners. Industrial activities also cause an increase in temperatures by boosting energy use and creating air pollution.

2.1.5 Impacts of increased land surface temperatures

The results of increased land surface temperatures (LST) on urban areas can be examined under four headings: heat stress, air pollution, water resources, energy consumption, and natural and agricultural life (see Figure 2.7).

It is essential to analyze all the effects successfully and eliminate the negative aspects by preserving the positive elements of warming. To illustrate, due to increasing temperatures, the energy consumed for heating decreases in the winter.

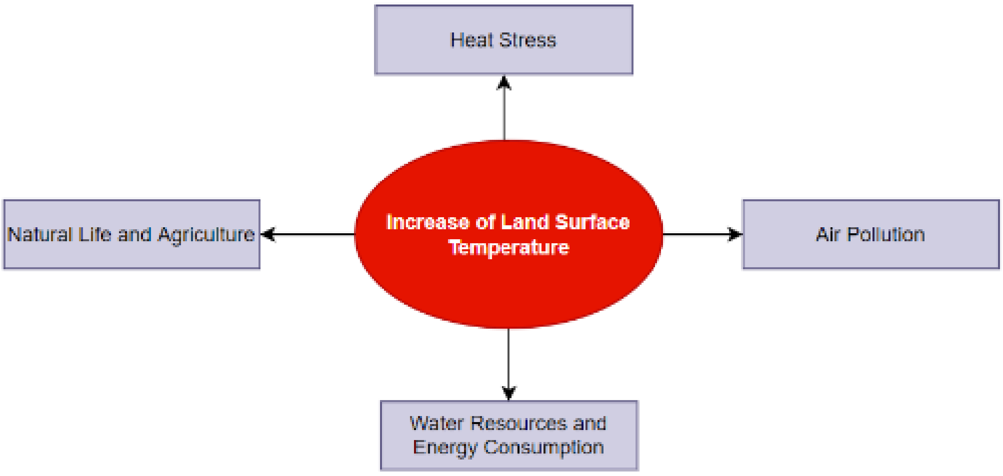


Figure 2.7 Impacts of Increased Land Surface Temperatures

2.1.5.1 Heat stress

High-temperature periods, which are perceived more intensely with the effect of urban heat islands, may cause heat stress. This concept addresses the unfavorable results of extreme temperatures on human health and other living, resulting in serious health problems. While heat stress commonly causes diseases, it can lead to associated mortality. Although hypothermia-related mortality rates decreased through warming, sweltering days or heatwaves have fatal effects on health.

Additional to conditions and mortality, heat stress can cause sleeping disorders or a decline in productivity (Kleerekoper, 2016).

2.1.5.2 Air pollution

Air pollution is the second harm of heating. The presence of solid, liquid and gaseous foreign materials in the air and the atmosphere will harm human health, living life, and ecological balance due to their amount, density, and presence time (Baklanov et al., 2016). Summer smoke occurs during heat waves which means an increment of air pollution. Sunlight is the source of smoke production because its chemical reaction with nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the atmosphere accumulates airborne particles at ground level. The wind is usually low during warm periods, which means that air pollution is not dispersed or reduced during these periods (Kleerekoper, 2016). However, the number of hot days in a year rising by warming and anthropogenic pollutant emission in connection with this air pollution is reaching dangerous levels.

2.1.5.3 Water resources and energy consumption

The third impact is the water and energy consumption issue. Langner et al. (2006) stated that growing temperatures due to climate change would lead to more significant CO2 emissions due to an additional cooling system. In addition to this, designers' and decision makers' choice of surface materials is now more critical than before. These surfaces should decrease the inner building temperatures while decreasing the radiance rate of their facade material to minimize the radiated sunlight. Otherwise, energy consumption may be more significant as warming reaches irrepressible levels. Due to heating, the sea level rises with the melting of glaciers, causing an increment in salt in water, and growing the danger of depletion of freshwater resources day by day by causing an increase in evaporation. Furthermore, the spawning need for energy and drinking water will attain levels that will put the economy in trouble today and in the future. The resource tension between countries will begin to be on the agenda.

2.1.5.4 Natural life and agriculture

The outcome can be observed in natural life and agriculture. As the weather gradually warmed, the number of days suitable for agricultural activities increased by an average of 25 days during the year. However, the acceleration of evaporation due to warming is beginning to lead to the rapid depletion of underground and earth water resources, drought, and water poverty (Klein Tank & Lenderink, 2009). In addition, evaporation is a threat to the availability and quality of drinking water as it causes salinization. Water is also a basic need for other living things, and some flora and fauna species that disappear during the warming process cause the balance in nature to deteriorate. This imbalance can lead to epidemics, as experienced in 2020.

To summarize, in this section, the basic concepts of urban heating, namely UHI and types, microclimate terms, and the relationship between the land surface and air temperature, are explained. Then the leading causes and effects of increased land surface temperatures are revealed. Consequently, some of the outputs of the decisions taken by politicians, planners, and designers are as follow:

- Increasing greenhouse gas emissions,
- Gradual loss of urban forest cover,
- Spreading of impervious surfaces,
- Changing urban morphology and city size, and
- Increasing anthropogenic heat release

The factors listed above can be shown as the leading cause of warming. Thus, the discussion in the next chapter indicates that urban design elements and interventions can be used as a tool for heat mitigation in cities.

2.2 Urban heat and LST mitigation strategies

Urban design and urban planning are the sources of the problem and the solution for heating. Although some portion of urban heating is affected by global warming, its primary source is cities. Reducing the effects of UHI, LST, and urban warming depends on the different components and parameters that build cities. Therefore, arguably, urban design is the most effective tool that can be used to eliminate this problem. This part of the study discusses how urban design can be used for heat mitigation (specifically minimizing the LST).

Warming is one of the impacts of climate change, and cities are vulnerable to climate change. But at the same time, they also negatively affect their microclimate, making the effects of climate change even more intense. In studies investigating this two-way relationship between cities and climate, the following conclusions were reached: designing climate-resistant and adaptive cities can eliminate climate change or warming-based issues in cities and the effects of urban areas on climate change. Thence, the concept of climate-sensitive urban design has been put forward. Heat mitigation is one of the most crucial climate-sensitive urban design principles. In this context, the subject of urban design as a tool for heat mitigation is vital in this period that irreversible effects of climate change have begun to be monitored.

2.2.1 Urban design as a tool for heat mitigation and land surface temperature reduction

Urban design is a detailed organization or reorganization method that includes multi-dimensional subjects. Making thorough examination and analysis in physical, socio-cultural, and socio-economic contexts in urban space is in the scope of urban design. It covers the regulation, design, and implementation actions carried out at the city scale. A significant part of urban design is to bring flexible and sustainable solutions to urban problems, unique to the region, sensitive to the data in the environment, responding to interdisciplinary issues.

Urban warming is affected by many climatic and spatial variables. Spatial variables must be determined by the design and plan of a city. Thus, designing cities for heat reduction is an action that will significantly improve the quality of life, despite the effects of climate change. There are many urban heat island mitigations and LST reduction strategies. They draw on the expertise of various professional fields, including urban planning and design, architecture, natural resource management, and transportation. These strategies have a positive impact on both the local and global climate. In addition to promoting urban cooling, it also has benefits such as reducing water and air pollution, including minimizing energy demand and greenhouse gas emissions. There are mainly four different measures for heat mitigation in urban areas. These measures are reducing anthropogenic heat release, urban greening, actions related to urban infrastructure (road, drinking, and utility water, sewage (wastewater), stormwater drainage, solid waste and garbage, electricity, natural gas, central heating, etc.), stormwater management and surface permeability measures (Giguère, 2009). The strategies aim to increase two factors: albedo, and the second is evaporation (Mobaraki, 2012).

Various urban design elements can increase the albedo and vegetation surface cover to prevent temperature rise because these elements also constitute the heating source. According to the study on heat mitigation strategies by Lai et al. (2019), urban design elements and their effects on reducing the temperature are listed. In this part, urban design elements that affect LST variations are defined (see Figure 2.8). These elements change the LST is explained in detail under the section entitled "Attributes of Public Spaces That Affect LST."

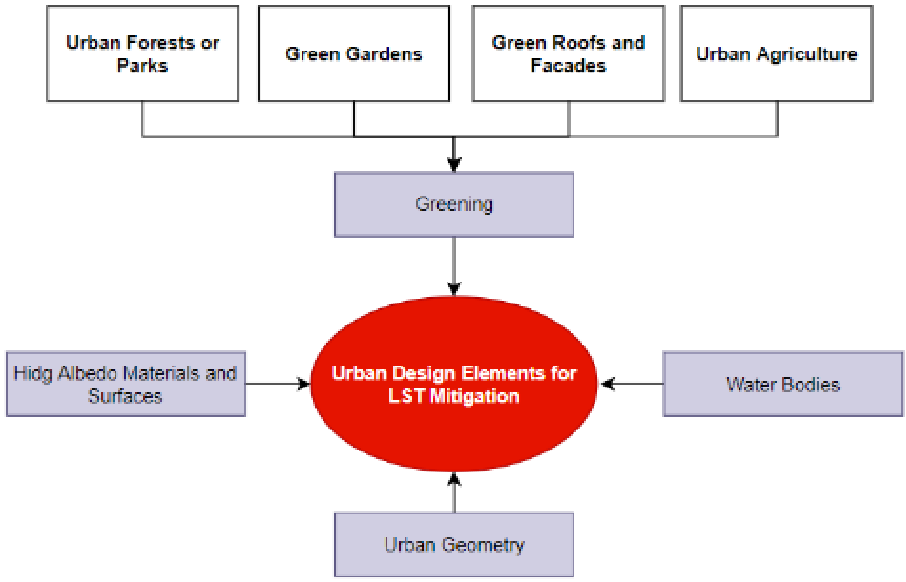


Figure 2.8 Urban design elements for heat mitigation

2.2.2 Greening

Vegetation affects radiation, wind speed, air temperature, humidity, and thermal comfort. The direct impacts of vegetation on urban temperature are increasing evaporation, blocking radiation, slowing wind, and lowering the air temperature. The presence of trees leads to aesthetically appealing spaces in the urban environment. Green spaces contribute significantly to lower air temperature (Lai et al., 2019). The secondary effect is the capacity to hold particles suspended in the air and gases that cause air pollution. Preventing the accumulation of these gases in the atmosphere prevents the trapping of sunlight reflected from the earth. However, according to studies, vegetation has a seasonal effect on temperature and UHI intensity (Colunga et al., 2015). Accordingly, factors such as the periods when the foliage remains leafy and the amount of water it needs, which varies according to plant's type, are essential for urban temperature regulation. Numerous studies have been accomplished on this subject so far. A review of this literature shows that various design strategies can be used to mitigate urban heat:

- *Designing urban green spaces*: The most effective cooling strategy in urban areas densely composed of trees like urban forests or parks. Surface temperatures and air temperatures are pretty low in these areas, thus creating the Park Cool Island (PCI) effect (Kleerekoper et al., 2012).
- *Designing green gardens:* Gardens are private or semi-private green urban areas. In addition to the direct cooling effect in the region where the gardens are located, it cools the residential areas nearby in the summer. It prevents excessive cold in the winter. In this way, air conditioning in residential areas is minimized, and energy savings indirectly decrease urban temperatures.
- Street trees commonly affect temperature since they are located individually and scattered in the city. Still, when the whole city is considered, it is seen that they have an effective cooling influence. However, these trees can sometimes negatively affect LST/air temperatures. During colder seasons, they can block sunlight or contaminate parked vehicles. For these reasons, the choice of location for trees and their frequency are the elements that the designer should pay attention to (Kleerekoper, 2016).
- *Green roofs and facades*: Green roofs cover approximately 20–25% of the cities. Greening the roofs have a cooling impact on average air and surface temperatures thanks to evaporation and shading. Additionally, by having a heat insulation influence on the exterior of the buildings, green roofs and green walls minimize the energy need both in summer and in winter (Besir & Cuce, 2018).
- *Urban agriculture:* Urban agriculture is also a vegetative surface in cities. For this reason, the significant effect on temperature in parallel with other green surfaces is to increase evaporation and create a cooling effect.

  The most critical cooling period created by agricultural areas is the growing season. In that period, the moisture of the soil and water capacity of the plants is the highest. While the region contributes to urban cooling by evaporation, it reduces the energy requirement for ventilation (Eriksen-Hamel & Danso, 2010; Rovers et al., 2014; Meulen & Deltares, 2014).

Additionally, urban farming has an advantage over urban forests and parks, having a higher albedo. Albedo varies according to different parameters, such as the color and height of the plants. At the same time, the plant's height decreases its albedo increases. According to this situation, crops are shorter and have a higher albedo than trees, so their performance to reflect short wave solar radiation is more elevated than forests (Habeeb, 2017).

However, urban agricultural areas are more sensitive to green places regarding sun exposure time, water demand, soil, and air quality. Healthy production and cooling effect can be achieved only when the necessary conditions are met (Meulen & Deltares, 2014).

Designing green spaces in urban areas with the given green urban elements is only possible with government policies, conscientious designers, and public awareness. Promoting private space green areas and regulating planning policies related to greening/vegetation is necessary for LST reduction.

2.2.3 Water bodies

Water impacts radiation, air temperature, humidity, and thermal comfort. Water is a design element that slowly heats and cools because it is a liquid substance, compared to the impermeable and solid materials used in urban areas. It has been proven by many studies to have a cooling effect in urban areas, as during the daytime, it heats up slowly and is generally cooler than the surrounding surfaces (Achmad et al., 2019; Cai et al., 2018; Uddin & Mondal, 2020; Guha & Govil, 2021). However, the size of water bodies in urban areas is directly related to their effect on temperature. Small urban water bodies such as ponds or canals are often assumed to provide adequate cooling during hot periods and improve thermal comfort in surrounding areas

(Jacobs et al., 2020). However, recent studies show that the cooling effect of sizeable urban water bodies on hot summer days is quite limited and may cause a warming effect at night due to the late cooling feature (Climatelier, 2018).

In 2020, within the scope of a project called REALCOOL, the possible local cooling effects of combinations of shading, evaporation, and ventilation interventions of small urban water bodies were investigated. Sixteen representative virtual urban water body settings were explored and redesigned. It was revealed that the cooling effect could be increased by considering the project designs, the aquatic environment as a whole: the water body and vegetation, together with adjacent spatial elements such as ground cover, water mist, or fountains (Jacobs et al., 2020).

Using water infrastructures, using different water bodies as public design elements, and improving water management systems can help reduce the temperatures by using water (Kleerekoper, 2016). Aspects of water use in different scales and creating water bodies in urban design improve the urban climate in public spaces (Oke et al., 2017). To illustrate, strategies that can reduce heat by using water elements at different scales in urban areas are listed below.

- In urban facades: green roofs, rainfall harvesting
- Streets and blocks: permeable paving with rain gardens and water features
- Neighborhoods: limiting permeable surface cover, linear parks over river courses, use of retention ponds, irrigation management
- City: groundwater management, flood protection by tough defenses or land-use management, efficient use of water resources.

2.2.4 Urban geometry

Urban geometry results from the quantitative relationship and spatial configurations of building volumes and open spaces and is an essential modifier of the urban microclimate (Chatzipoulka et al., 2015). Urban geometry effectively determines the intensity of short-wavelength solar radiation reaching buildings and other urban surfaces from the sun and the atmosphere and long-wavelength radiation (infrared) reaching the atmosphere from these surfaces. The speed of wind and level of energy absorption on complex city surfaces are also determined by the geometry of the city. The ability of long-wavelength radiation to be removed and, therefore, heat losses to occur depends on the sufficient level of spaces in the urban environment (Canan, 2017). Moreover, since the proportions of urban canyons (streets) affect airflow, air temperature, and thermal comfort, they have long-term effects on the energy consumption required to heat, cool, and illuminate the buildings that define them. Also, urban canyons affect the environmental qualities of the streets, squares, courtyards, or gardens that form them (Strømann-Andersen & Sattrup, 2020).

Lastly, urban geometry is a significant factor in urban temperatures by determining radiation and shading, airflow, volume, and the surface ratio of public spaces. For this reason, during the design process of public spaces, the direction and speed of the wind, sun exposure angles, and proportions of the surface to be created in the area should be the elements that direct the design. Thus, the urban airflow, the required amount of sun and shading, and the ratio of the surfaces that absorb the heat have been determined, and temperature increases can be kept under control (Kleerekoper, 2016).

2.2.5 High albedo materials and surfaces

Specular surfaces affect radiation, air temperature, and thermal comfort. The absorption of solar heat by urban surfaces causes the condensation of urban heat islands (Santamouris, 2013b). Albedo or solar reflectance is the percentage of solar energy reflected by a surface. Most solar energy is found in visible wavelengths; therefore, solar reflection is directly related to a material's color. Dark-colored surfaces have lower albedo values than light-colored surfaces (Environmental Protection Agency, 2011). Suppose the surface materials that make up the built environment in the city are built with materials that have high albedo values. In that case, they have a reducing effect on the urban temperature. However, while reflective surfaces effectively cool the city, many simulation studies claim thermal comfort is negatively impacted by increased solar radiation reflected on the human body (Lai et al., 2019). Therefore, the albedo values of the surface materials should be adjusted so as not to affect the thermal comfort adversely. Cool pavements, cool roofs, high albedo-colored surfaces are feasible and effective methods for urban designers to create a cooling effect in a metropolitan area.

In summary, the urban temperature can be reduced by using urban geometry, materials and surfaces, vegetation, and water elements. It is possible to regulate the high temperature by using these elements, but not enough for cool cities. City planners and urban designers should consider the issue of reducing urban temperatures in several different dimensions. The first dimension regulates the urban actions that trigger the temperature rise. Traffic density, industrial actions, and energy spent for heating are urban actions. Another dimension is designing all the elements that make up the city surface and reducing or preventing the temperature rise. In this study, the main issue is to develop the public spaces that make up the city surface and cover a significant part of it to reduce the temperature. Accordingly, the role of public spaces and LST reduction in the next chapter is discussed.

2.3 Public space and land surface temperature

Public spaces can be regarded as the surfaces of the cities, and in this respect, they are urban areas responsible for anthropogenic heat release and most exposed to increasing temperatures. For this reason, the management and design of public spaces are vital to adapt to rising temperatures in the future and to prevent temperature rise. Before discussing the subject of heat mitigation in public areas, the definition, history, and importance of these areas, types of public spaces, and their design within the scope of LST reduction are discussed.

2.3.1 The definition of public spaces

According to the user profile, there are mainly three kinds of spaces in an urban environment: private, semi-private, and public. While private space usage only belongs to their residents, public spaces are utilized by everyone regardless of age, race, gender, or income level. Public spaces are accessible to all, social and cultural textures consisting of organized common living spaces. These areas integrate people with the city, society, and environment. Furthermore, public spaces regulate and direct this integration process through various structures. Sidewalks, avenues, streets, parks, sports fields, shopping malls, and squares are exemplary public spaces structures (Karayılmazlar & Çelikyay, 2018). Examining how these areas reached their present form is necessary to examine the history of functional and formal changes over time.

2.3.1.1 Importance of public spaces for cities

Public spaces are where many people come together, communicate, socialize, and create cultural interactions. In this way, social texture has emerged unique to that urban area in playgrounds, bazaars, shopping streets, neighborhood markets, squares, streets, roads, entertainment and sports areas, celebration areas, and prestigious areas where speeches are made. With their artificial and natural environment and physical structures, public spaces increase people's sense of belonging to the places they live. The public sphere is the concept used in modern social theories to indicate the social activity area where thoughts, discourses, and actions for the common benefit of society are produced and developed (Özbek, 2004). As the city's social hub, public spaces are one of the most critical parameters for culture to thrive (Kishore Rupa, 2015). Therefore, frequent use of these areas is valuable for cities and citizens.

2.3.1.2 Types of public spaces

Open public spaces can be grouped as external usage areas and circulation channels. Open public spaces provide light, air, opportunities to spend time outside and increase the livability of indoor spaces. Exterior areas are playgrounds, sports fields, parks, and other functional gathering and activity areas (Karayılmazlar & Çelikyay, 2018). Each type has different physical environmental attributes (like shape or micro-scale urban design features) and may show other LST characteristics.

The circulation areas are places where people flow between the buildings and various parts of the city. Establishing vehicle transportation and communication relations; They are complementary spaces such as passage, street, avenue, boulevard, square. In addition, there is a gradual gradation of open space use from private outdoor areas (balcony, garden) to channel spaces that transmit movement (street) and spaces where movement gathers and disperses (square). Urban open spaces in the urban framework are strategic spaces with collecting and integrating features (Özbek, 2004).

Although public spaces are used for various purposes, they are essential tools that direct urban growth (Özdirlik, 2000). Urban spaces have become common usage areas that vary in line with the cultural characteristics of societies over time. These common areas are;

- Organized pedestrian areas: Parks, recreation, entertainment, and sports areas
- Shopping areas: Bazaar, shopping street, marketplace
- Crossing areas: Streets, roads, transportation areas, sidewalks
- Zones: Squares, open prestige areas

Besides being significant socially and culturally, public spaces have great importance due to their physical functions in cities. They allow citizens to benefit from daylight, fresh air, and the psychological relief feeling provided by the natural environment, especially in dense urban areas (Kandemir, 2010). Additionally, they provide habitat for wildlife and animals. Therefore, their design and functionality affect citizens' healthy urban life.

In this study, a square has been chosen as the case to understand the surface materials impacts on land surface temperatures. The squares have a high ratio of pavement surface utilization which has a high effect on SUHI. Impermeable surfaces are urban surface materials with a higher heat capacity than natural materials such as trees, dry soil, and sand (Vujovic et al., 2021). The structure and design of the square with its importance in heat mitigation are explained in Chapter 3 in detail.

2.3.1.3 The role of public spaces in urban heating

Global warming is accelerating, winters are rainier, summers are drier, and extreme precipitation is more frequent. The consequences of urbanization and climate change have begun to reach threatening levels. According to current estimates, global warming will get 1.5°C between 2030 and 2052 and about 3°C in 2100, which will destroy cities (Intergovernmental Panel on Climate Change, 2019). In urban settings, climate change means increased temperatures and more frequent flooding. Dry periods will occur more frequently and last longer (Crow, n.d.).

Urban and landscape design has a significant impact on climate change. Open public spaces, which are important elements of urban design, have an important role in reducing high temperatures and, at the same time, mitigating the effects of climate change (Djukic et al., 2016). The climate-sensitive design of public spaces has many expected benefits, leading to increased resilience of urban areas, improved air, water, and quality of life, and improved biodiversity (Santos Nouri & Costa, 2017).

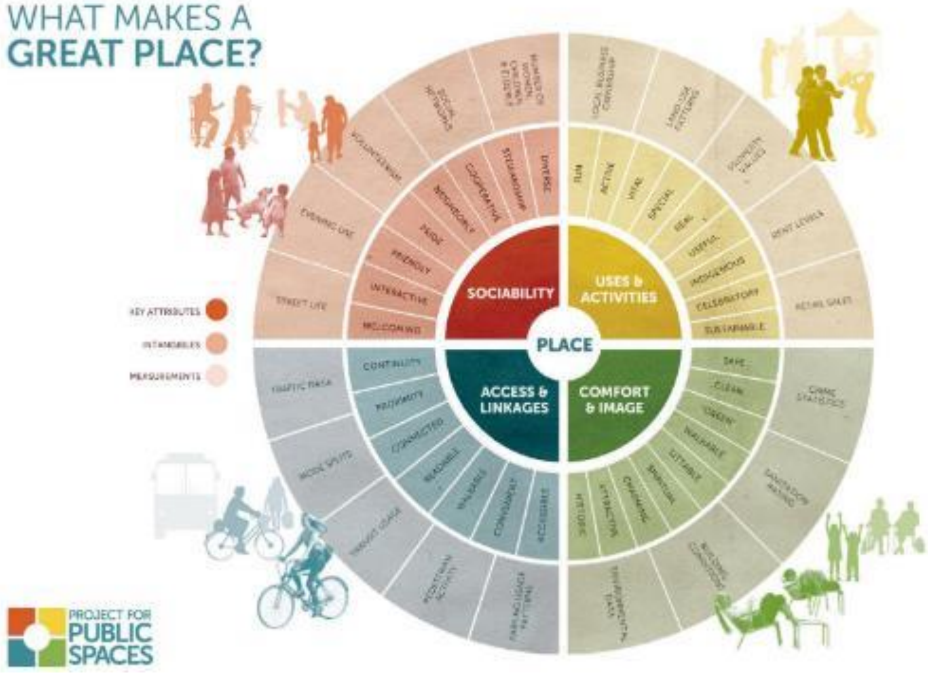


Figure 2.9 Place Diagram by PPS (PPS, 2003b)

Moreover, according to Project for Public Spaces, public environments should have the features indicated in Figure 2.9 to be accepted as successful places. UHI effects and heatwaves' influences threaten the concepts of comfort, safety, usage, and activities (Santos Nouri & Costa, 2017). On the other hand, the designs of public spaces should show the effect of reducing the UHI effect and the effect of heatwaves so that comfortable, safe, and suitable conditions for the activity defined in the area can be provided to the city. One way to minimize these effects is to design by considering the surface temperature as an essential parameter (Santos Nouri & Costa, 2017).

Theories have been developed to design successful public spaces and criteria covering the needs (Whyte, 2001; Gehl, 2010; Vukmirovic, 2013). The most inclusive one among these principles is comfort. It is necessary to calculate many factors, including the benefits of designing an open space. Therefore, there are many different types of comfort: visual comfort, ease of movement and sense of security, thermal convenience, acoustic comfort, odor, tactile comfort, air pollution, and allergens (Ovstedal & Ryeng, 2002). Decision-makers should consider safety, visual appeal, lighting, and accessibility of public spaces. However, since importance is not given to climate, weather conditions, and the factors that affect them in public areas (Vukmirovic et al., 2019), the vulnerability of public spaces to changing climate is increasing.

Therefore, in this study, the management of surface temperatures, which is one of the most important causes of temperature increase in public spaces, is discussed. The surfaces of open public spaces are evaluated in terms of surface temperatures, and the effects of different surface elements are investigated in this section.

2.4 Attributes of public spaces that affect LST

This part of the study examines the factors that affect the surface temperatures of public spaces with a detailed classification of the mentioned surface types: water, vegetative and hard surfaces. This classification is successful in observing the impacts at small scales. However, subclasses of these three surface types are necessary to study at larger scales. The information obtained from the fieldwork and literature search indicates that urban geometry (ref) and urban street furniture parameters are effective on LST. Therefore, unlike LST studies calculated using remote sensing methods at small scales, urban geometry and urban street furniture affect LST at the public space scale. Thus, 5 surfaces affect the LST in the design of public spaces;

- Vegetative surfaces
- Water
- Hard surfaces
- Urban geometry
- Urban Street Furniture

Vegetative surfaces and hard surfaces have sub-surface elements (See Figure 2.10).

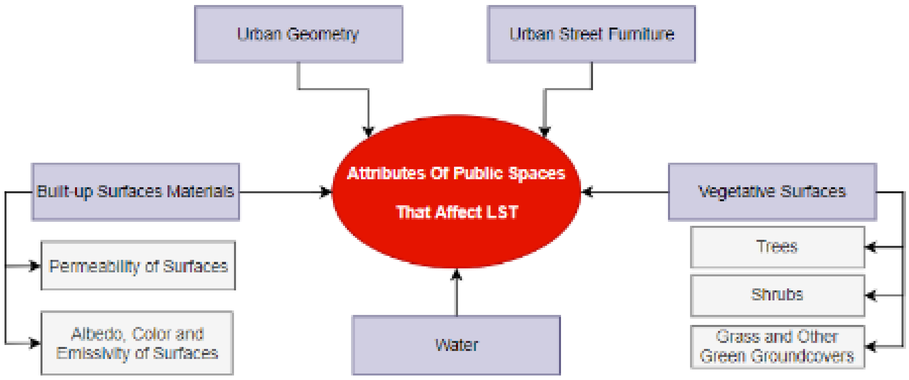


Figure 2.10 5 Attributes of public spaces that affect LST

As mentioned earlier, surface temperature and air temperature are two concepts with high correlation. Therefore, while explaining the palliative and aggravating influences of several surface types, their effects on air temperature and surface temperature have been provided.

A literature review was conducted, and the results recorded in the study areas with a temperate climate were compiled.

2.4.1 Vegetative surfaces

Bowler indicated that parks are 0.94 °C cooler than the urban areas during the day (2010), and Coutts and Harris (2013) have supported Bowler's study by indicating that a rise of 10% in all types of vegetation cover could diminish surface temperatures up to 1°C in the daytime. Moreover, vegetation has an average 1-6°C cooling effect on near-surface air temperature around them, but these numbers vary according to the type of the plant or tree (Langner et al., 2006; Kleerekoper, 2016). A detailed study conducted in the Netherlands proved that the increased vegetation surface reduced UHI. The most important cooling effect was observed on the hottest summer days (Steeneveld et al., 2011; Kleerekoper, 2016). One of the studies on the cooling effect of vegetation is Klok et al.'s work in Rotterdam in 2019. In the study, 10% of an area covered with the impervious surface transformed into green space, and it was observed that the temperatures decreased by 1.3°C on the neighborhood scale. In this instance, the average cooling capacity of vegetation surfaces varies between 1– 4.7 ◦C that impacts 100 to 1000 meters depending on the type (Langner et at., 2006; Kleerekoper et al., 2012).

Similarly, vegetation also affects surface temperatures since they have a high correlation. As mentioned above, LST is highly correlated with near-surface temperatures and connects with UHI. While the vegetation affects the air temperature through evaporation, it also affects the LST with the amount of water it holds. For this reason, the effects of NDVI and LST have begun to be investigated (Farina, 2012).

Vegetation can be classified into three: trees, shrubs, and groundcovers according to vertical height layers of plants. Shading, evapotranspiration, and block or change wind direction depending on their size, species, and location (Misni, 2018).

Trees

Urban trees have various benefits for cities. Some of them are providing food and nutrition security, increasing urban biodiversity, improving physical and mental health, regulating water flow, reducing carbon emissions, increasing property value, mitigating climate change, cooling the air, and filtering urban pollutants (Armson, 2012; Gillner et al., 2015; Kleerekoper, 2016). In the scope of this study, the cooling effect has been examined.

The main effects of trees on cooling the air are evapotranspiration and shading (Taha,1997; Misni, 2018). A study in the Netherlands shows that street trees have a cooling impact up to 5˚C by shading (Slingerland, 2012). Further, shading by trees is much more effective than by buildings. According to the study of Huang et al. in Phoenix, USA, increasing the 25% of the land cover by trees decreases temperatures by approximately 5.6°C in July at 2 p.m. Further, a 30% increment of tree cover of an area leads to 6°C diminishing air temperatures at 12 p.m. and a 2 °C decrease at night (Misni, 2018). In addition to trees' impacts on near-surface air temperature, Bernatzky (1982) and Buyadi et al. (2013) impact local temperatures by 2 to 4 °C in hot-humid climates. Nevertheless, the size and volume of the trees are significant for the cooling effect because shading area and evaporation amount vary accordingly (Dixon & Mote, 2003).

Gillner et al. Transpiration, stomatal conductivity, and leaf area density were measured in a study investigating the effects of different tree species on temperature, published in 2015. In the survey conducted in Dresden, Germany, on 3 hot days in the summer of 2013, the surface temperatures of the asphalt surfaces under the trees were measured in the shade and the sun. It has been noted that areas exposed to the sun are a maximum of 15.2 K warmer than canopies. In comparisons made on different trees in the study, the trees with the highest cooling potential were Corylus color and Tilia cordata "Greenspire," while the lowest effect was measured for Ulmus × hollandica. "Lobel" (Gillner et al., 2015). While trees cool the air temperatures by only 1-2 ◦C on hot summer days, the cooling effect they create on the surface temperatures of the areas they provide shade can reach up to 4.63 K as the leaf area density changes by 1 unit (Armson, Stringer, & Ennos, 2012; Gillner et al., 2015). Like the leaf density area, increasing the crown diameter of the tree also increases the cooling effect because the shaded area of the tree grows in this way (Wang & Akbari, 2015).

Shrubs

Shrubs contain various plants, woody bushes, and small trees (Richards et al., 2020). Shrub vegetation is commonly used for creating semi-private areas within residential areas, but additionally, they have a cooling effect on the microclimate level. They have been utilized for windbreak, wind funnel, and shading (Spirn et al., 1981). During periods that solar radiation comes directly, temperatures of hard surfaces shaded by bushes are 1,5 to 4,5 °C cooler (Parker, 1987).

Zhang et al. has investigated the different shrubs' cooling impacts in 2014. The measurements in the study have been collected in July as the hottest month of the year. Pavement temperature in the area has been considered as the reference. Five different shrub species are measured: Hibiscus rosa-Sinensis Linn, Duranta repens, Carmona microphylla, and Ficus microcarpa' Golden Leaves' and Murraya exotica. The results of the shrubs cooling effect have been found respectively as 40.3 ± 3,9 °C, 40.3 ± 3,9 °C, 38.8 ± 3,7 °C, 37.0 ± 4,7 °C and 36.6 ± 4,7 °C while the average temperature of the reference pavement was 47.0 ± 4,7 °C (Zhang et al., 2020). Consequently, diverse species of shrubs have different cooling values, but they are approximately 9°C cooler than a concrete surface without shading.

Grass and other green groundcovers

Turfgrass is generally planted for aesthetic concerns in urban areas, and the most utilized grass species is Axonopus compressus (Richards et al., 2020). Studies showed that turf irrigation effectively diminishes the land surface temperatures during the day. When irrigated and non-irrigated grass areas have been compared, it has been observed that irrigated land is 3.58-5.19°C cooler than non-irrigated areas at daytime (Richards et al., 2020). In Majidi's (2015) study, the asphalt surface and the grass surface temperatures have been compared. The results for different hours have been measured and indicated in Table 2.1.

Table 2.1 Average measured values of temperature (T), relative humidity (R.H.) in the surfaces, and the above surfaces (height of 1.2 m) of grass and asphalt (Majidi, 2015).

Quantities \ Hours	6	8	10	12	14	16	18	20	22	24
Grass										
Mean T(s)*	18.3	22.1	27.2	33.5	35.6	34.6	31.9	28.9	25.5	21.3
Mean (a.s.)**	18.2	21.0	26.5	31.2	34.0	36.0	35.0	30.1	26.5	23.3
Mean R.H.(s)	54.1	61.7	45.5	41.2	29.7	25.4	18.8	22.3	26.5	37.0
Mean R.H.(a.s.)	51.0	51.4	31.6	20.0	14.0	10.7	12.7	21.0	27.5	31.9
Asphalt										
Mean T(s)*	19.6	21.5	27.0	34.6	37.7	39.6	38.0	31.5	27.8	24.9
Mean T(a.s.)**	19.0	24.1	29.8	33.8	37.4	36.7	35.2	30.6	27.3	24.9
Mean R.H.(s)	49.2	45.4	28.8	15.5	10.0	8.5	10.5	18.9	22.6	28.0
Mean R.H.(a.s.)	49.1	40.6	27.6	15.5	9.6	8.5	9.0	18.9	25.5	28.0

(s)* surface
(a.s.) ** above surface

According to the study results, the relationship between the surface heat of the asphalt and the grass is unstable, so the measuring hours must be considered when carrying out a study. The warming effect or the cooling effect must be evaluated accordingly. Because as opposed to the trees and shrubs, the grass is not always having a cooling impact on urban areas.

The cooling or warming effect depends on the size of the turf. Instead of large grass surfaces, small areas are much more effective in cooling the air. To illustrate, according to the study by Gill et al. (2007), grass plots with 0,1 ha area is 24°C cooler than the concrete while in a large park with 7,8 ha concrete and asphalt surfaces are 18°C warmer than the air temperature, and the grass is also 3ºC more generous. This contrast can be the oasis effect in the small plots of turf area. In the study at Arizona State University about the oasis effect in urban parks, Vivoni et al. (2020) explain the situation by analogy the impact of a water body surrounded by palm trees in a sandy desert. Oasis creates a cooler microclimate than its surrounding arid area due to soil and irrigation water evaporation levels in that grass-covered area. However, the oasis effect has two results besides cooling. The first one is high evaporative losses during the night. Second, as mentioned, the water that evaporates when the oasis effect occurs is the water in the soil or from irrigation. It is not the water that the plants store. Therefore, if the parks are irrigated at night, the water loss can be massive, leading to increased carbon dioxide emissions and higher global warming potential called Oasis Effect (Vivoni et al., 2020).

Regular irrigation systems in grass areas are needed to provide maximum cooling benefit. Strategies like stormwater harvesting and water-sensitive urban design can help green infrastructure consolidation of a city.

After investigating different vegetation types' effects on urban surface temperature, it can be observed that forest-like green areas combined with multiple layers of bushes and vegetations have the most substantial cooling influence in urban areas (Richards et al., 2020).

2.4.2 Water

Throughout history, rivers and their tributaries have been a center of attraction for people. "Urban blue spaces" (Tominaga et al., 2015) are waterbodies in urban areas. In today's cities, rivers, lakes, and water bodies of different sizes serving various purposes have undertaken essential tasks such as creating a recreation area, protecting the urban flora/fauna, and regulating the urban ecology. Furthermore, water is the only element utilized for cooling purposes in urban design, especially while designing public spaces. Water surfaces regulate microclimate by diminishing the air temperature through latent heat (evaporation) or warm air's heat flux to cool the water surface (Al-Qeeq, 2010).

There are various water bodies in urban areas, such as fountains, cascades, sprays, ponds, lakes, rivers, canals, sea, waterfall, and many different artificial water bodies. However, water bodies' impacts on cooling cities differ according to their size, geometry, spread, deepness, etc. (Jamei & Tapper, 2018). To illustrate, according to the study by Zhou et al. (2011) in China, it has been observed that rounded or square forms in water bodies are much more effective in cooling than irregular-shaped water. The size differences of water bodies are also an essential variable on the cooling effect. A sole large water body by volume is much more effective in cooling than the effect created by many smaller water bodies (Steeneveld et al., 2014). Depth of the water bodies also significantly influences cooling the air, and deep-water bodies are more efficient in cooling the air than shallow water bodies (Jamei & Tapper, 2018).

The features mentioned above of different water bodies are all had significant effects on temperature, but the size is the most prominent and most influential feature on cooling for measurements. In the scope of the REALCOOL project, to comprehend large, intermediate, and small size bodies of water's effects on surface temperature, remote sensing studies are held in the daytime when water is cooler compared with the air temperature (Jacobs et al., 2020).

The median of the cooling effect is 3.3 °C in larger water bodies such as large water cisterns and rivers, while it is 2.1 °C in medium-sized water bodies such as inland lakes. With the effect of smaller water bodies such as small ponds, the surface temperatures decrease by about 1.6 °C. Another scale has not been mentioned, which, despite being a relatively small body of water, shows the highest cooling effect. The fountain has been the water body with the most significant impact in this group, with a median cooling result of 4.7 °C (Jacobs et al., 2020).

Since water is liquid, it heats up and cools down much later than other solid elements in the city. For this reason, while it is colder than the air during the day and has a cooling effect due to evaporation, it is warmer than the air at night and creates a warming effect. To illustrate, in a study investigating the impact of typical Dutch water bodies on temperature, Singel's maximum warming impact has been found as 0.2 °C (Jacobs et al., 2020). However, since the heating effect is much lower than the cooling effect created during the daytime in summer and prevents excessive cooling of the air temperatures in the cold winter months (Al-Qeeq, 2010), it should be ignored and continue to be considered as one of the most important elements within the scope of climate-sensitive urban design.

2.4.3 Hard surfaces

Vegetative surfaces, water bodies, and soils are accepted as the most convenient surface elements to use in urban design; however, these types of surfaces cannot meet the complex and smooth ground requirement for vehicles, pedestrians, and all other various urban activities (Kubo et al., 2006; Haselbach et al., 2011; Li et al., 2013). Pavements are the best option for these urban activities, but their albedo is low because of their dark colors (Synnefa et al., 2011). Pavements cover nearly 40% of surfaces in cities (Akbari et al., 209). As covering most of the open public spaces of urban areas, pavements greatly impact UHI (Santamouris, 2013b). Remotely sensed mesoscale satellite imagers indicate that these surfaces are a powerful source of heating (Gorsevski et al., 1998).

One of the most used surface types in public spaces is built (instead of natural) surfaces such as asphalt, concrete, and bricks for constructing roads, parking lots, pavements, hard surfaces of parks and squares, etc. The majority of built surfaces absorb heat more than vegetation or water surfaces in daylight and creates a warming effect on urban microclimates as its warmer than the air by convection, solar infrared radiation, and conduction (Oke, 1982; Douglas, 1983; Smithson et al., 2002; Gui et al., 2007, Litschke & Kuttler, 2008; Armson, 2012).

Concrete and tarmac, one of the conventional materials used in urban open spaces, reflect the incoming sunlight at a minimum of 5% and a maximum of 40%. It absorbs 95% to 60% of the remaining daylight. On hot summer days, the surface temperature of these materials reaches up to 60°C (Mohajerani et al., 2017). However, these rates vary according to wear and contamination. In a study conducted in the U.S., a municipality used paved surfaces that reflect 75% of the solar radiation (Santamouris et al., 2011). This study showed that albedo and emissivity have a significant role in surface temperatures.

Currently, few studies have measured the role pavements play in reducing LST or the impact cooler pavements can have on reducing the heat island effect. Lawrence Berkeley National Laboratory researchers found that concrete surfaces increase solar reflectance by 10%, and asphalt surfaces excellent surface by 4°C. Furthermore, if the reflectance rose from 10% to 35%, the air temperature could be decreased by 0.6°C (Santamouris et al., 2011).

Pavement surfaces vary in color, form, texture, albedo, permeability, etc. All of the features have different effects on changing surface temperatures. Although the impact of each component on temperature has not been studied in detail in the literature, it is imperative to understand the effects of these features by gathering them into two groups. There are mainly two groups of parameters that affect the surface temperatures. These are (1) permeability of surfaces and (2) albedo, color, and emissivity of the surfaces (Stewart & Oke, 2009; Perera, 2015).

2.4.3.1 Permeability of surfaces

The most commonly used pavement materials in city surfaces are concrete or asphalt. According to their content or structure, the paved surfaces might be permeable and impermeable. Permeability is significant for the surface's influence on temperature. Porous pavements have voids and pores. The water passes through these pores/holes and eventually reaches the soil underneath. If the temperature of the material increases, the water stored in the pores evaporates, which keeps the surface cooler. The cooling effect of this process varies concerning the materials' pore and void density (Haselbach, 2009). Studies indicated that permeable pavements without water or moisture have higher warming effects than cooling, even more than impermeable surfaces (Haselbach, 2009). In regions with a hot-humid climate, it is ideal to use permeable pavements for cooling effect because water availability (wastewater, rain, and air humidity can help the surface retain moisture). Yet it may not be convenient to use permeable surfaces in dry climates due to water problems (Santamouris, 2013). Porous surfaces accumulate less heat than impervious surfaces. One of the benefits of permeable surfaces is fewer night-time emissions.

The permeable surface is kept moist and irrigated. The maximum surface cooling capacity is in the range of 15–35 °C at noon during the hottest summer days. 25 hours after irrigation, the cooling effect of the same surface is 2-7 degrees less than the previous one, and it was observed that the surface still did not create a warming effect on the third day after irrigation. However, since permeable surfaces need moisture and irrigation, the continuity of the cooling effect can only be achieved by continuing the irrigation processes regularly (Li et al., 2013).

Permeable pavements directly affect the air temperature due to increased evaporation on the surface and indirectly change the air temperature. Thanks to the layered structure and pores on the porous surfaces, stormwater is filtered by the material used and reaches the soil at the bottom. In this way, surface waters reaching larger water bodies by being transported positively affect the water cycle in the city and contribute to the decrease in air temperatures (Li et al., 2013; Hendel, 2015).

Permeable coated surfaces often have a rough texture. This feature reduces the speed of precipitation falling on the surface by increasing friction. The surface absorbs the water that decreases in speed, and both the character remains moist for a long time, and the absorbed water participates in the cycle as mentioned. On the other hand, impervious surfaces are generally smooth and negatively affect the flow rate of the water. The cover cannot absorb moisture and heats up quickly because it dries quickly, and the water with a high flow rate increases the risks of flooding, and imbalances may occur in the city's water cycle (Buyung & Ghani, 2017).

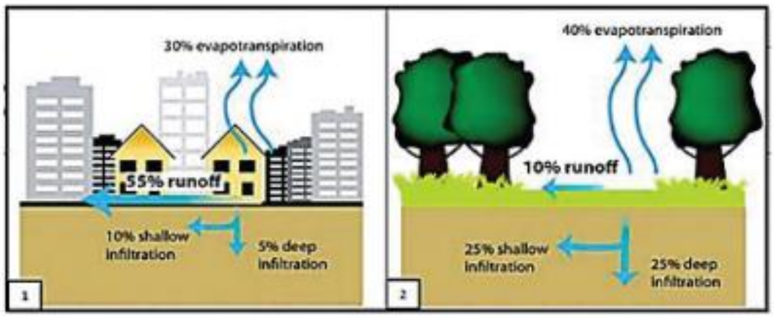


Figure 2.11 (1) shows highly developed urban areas, where 75% to 100% are impervious surfaces and fewer surfaces (Buyung & Ghani, 2017)

2.4.3.2 Albedo, color, and emissivity of surfaces

Building materials such as steel, stone, iron, cement, and asphalt have much higher heat capacities than materials such as soil and sand. As a result, cities often tend to store solar energy as heat. Metropolitan cities can absorb and keep twice as much heat as their rural surroundings (Environmental Protection Agency, 2011).

The amount of absorbed or reflected solar radiation varies according to the materials' spectral and broadband absorption or reflectance properties. The materials used for pavements and roads have different reflective properties, affecting surface temperatures—the reflection rate of sunlight changes according to the color and roughness of the material. Tiles with smooth and flat surfaces are cooler than tiles with rough and anaglyphic surfaces (Santamouris, 2013).

Colour and albedo

Light colors absorb less in the visual spectrum of sunlight and absorb less heat. To investigate the various colors impact surface temperature, studies comparing black granite surface and white marble have measured the maximum temperature difference at 19°C (Doulos et al., 2004). Synnefa et al. (2011) have also emphasized their albedos' different colors' influences. Yellow, beige, green, and red asphalt materials with albedo in the visual spectra of 0.26, 0.31, 0.10, and 0.11 have a maximum surface temperature of 9.0, 7.0, 5.0, and 4.0°C lower than black asphalt, respectively. With these studies, it has been understood that the specific reflectance value of colored materials in the near-infrared part of the spectrum affects the surface temperature almost equally. Black street pavements reached 65°C during hot summer days while grey stone surface reached 48°C. Gray color stone is measured during shaded and non-shaded periods, and the results are 30°C and 60°C, respectively (Georgakis & Santamouris,2006; Niachou et al. l, 2008).

As an example of the Mediterranean climate, in Athens (Greece), diverse pavement materials' impacts on the surface temperature measured in the hot summer using remote sensing techniques (Sthathopoulou et al., 2009). The surface heat of asphalt was in the range 77 and 81°C, concrete was between 56 and 78°C, marble was 48 and 67°C, and the stone was between 47 and 75°C. After adding white paint to the asphalt, the surface temperature decreased by 16°C due to the white-cover effects of cooling (Santamouris, 2013).

However, attention should be paid to white color in pavements, especially in cold climates. Light-colored materials, which are very effective in reducing the surface temperatures in summer, lower the temperatures with the cooling effect, although lower in winter (Akbari, 2014). Studies on thermochromic change color in laboratories with increasing temperatures are carried out to eliminate this adverse effect. These covers will be able to take advantage of the cooling properties of high albedo in summer without affecting the energy demand in winter (Santamouris et al., 2011; Hendel, 2015).

Emissivity

Surface materials radiate longwave radiation as a result of their emissivity. High emissivity corresponds to significant emitters of longwave radiation and can quickly unleash the absorbed energy. In various materials, sensitivity analysis operated to comprehend the effects of emissivity on surface temperatures (Gui et al., 2007). Observations demonstrated that when emissivity rises from 0.7 to 1.0, the highest and the lowest surface temperatures reduce by 5.0 K and 8.5 K (Santamouris, 2013). While reflective surface materials with high emissivity cause cooling of 1°C at night at 2m above the ground, they cause a cooling effect that can reach up to 4°C during the daytime (Hendel, 2015).

2.4.4 Urban Geometry

LST is not only affected by the surfaces form the area. Building size, height, density, geometry, direction, and orientation (Li et al., 2020) are variables of urban geometry. Urban geometry impacts LST in air ventilation and the incident solar energy (He et al., 2019). Building density, which defines the physical properties of surfaces and the percentage of the building footprint, has the most significant annual effect on LST (Huang & Wang, 2019). In spring, the heating impact of building density on LST is 3.6 ◦C. Sky view factor (SVF) also significantly impacts LST due to air ventilation and solar radiation. However, the effect of SVF differs according to seasons because of the variation in angles of incoming solar radiation in accordance with seasons. To illustrate, it has a cooling impact in winter, spring, and autumn and a heating influence in summer (H. Li et al., 2021). Surface temperature differences obtained by incorporating the geometry effect can be up to 2 K in urban areas (Yang et al., 2015).

The case chosen in this study is a square design competition. The necessity of protecting the structures in and around the project area determined in the competition is stated in the specification. The thesis aims to compare the current LST model of the square with the LST analysis of the two proposed projects. Since the buildings in the area do not vary between projects, the urban geometry variable is excluded from the scope of the study. However, the effect of urban geometry on surface temperatures is as effective and important as other design elements mentioned in the urban design process.

2.4.5 Urban street furniture

Squares can have many small urban furniture such as telephone boxes, street lamps, post boxes, fountains, seating areas, statues, pillars, or railings, including wood, stone, and other materials. The effects of these elements on the surface temperature have not been adequately studied in the literature yet, due to their size and being more portable. However, due to the micro-scale of this study, features such as the shadows that this urban furniture cast on the surfaces, their height, and the sun rays they reflect may affect the LST. Therefore, the amount of this street furniture in a public space can be significant.

Types of furniture large enough to affect the surface temperatures were taken into account within the scope of the study and measurements made in the field, and the surface temperatures of this furniture were measured. For instance, benches were included in the analysis, while trash bins were excluded from the scope of the study. Chapter 3 explains which furniture is kept and eliminated for the analysis.

2.5 Concluding remarks

This section aimed to present the reader's relationship between LST, public space, and urban design concepts. In this context, after discussing the reasons for the formation of LST, its effects, and mitigation strategies within the scope of urban design, the factors affecting LST in public spaces are presented. (See Figure 2.12) Thus, it has been understood to what extent LST is affected by the elements used in public space design. LST calculation will be made over the Taksim Square Urban

Design Competition, selected as the study area in Chapter 3, using the information obtained in this section.

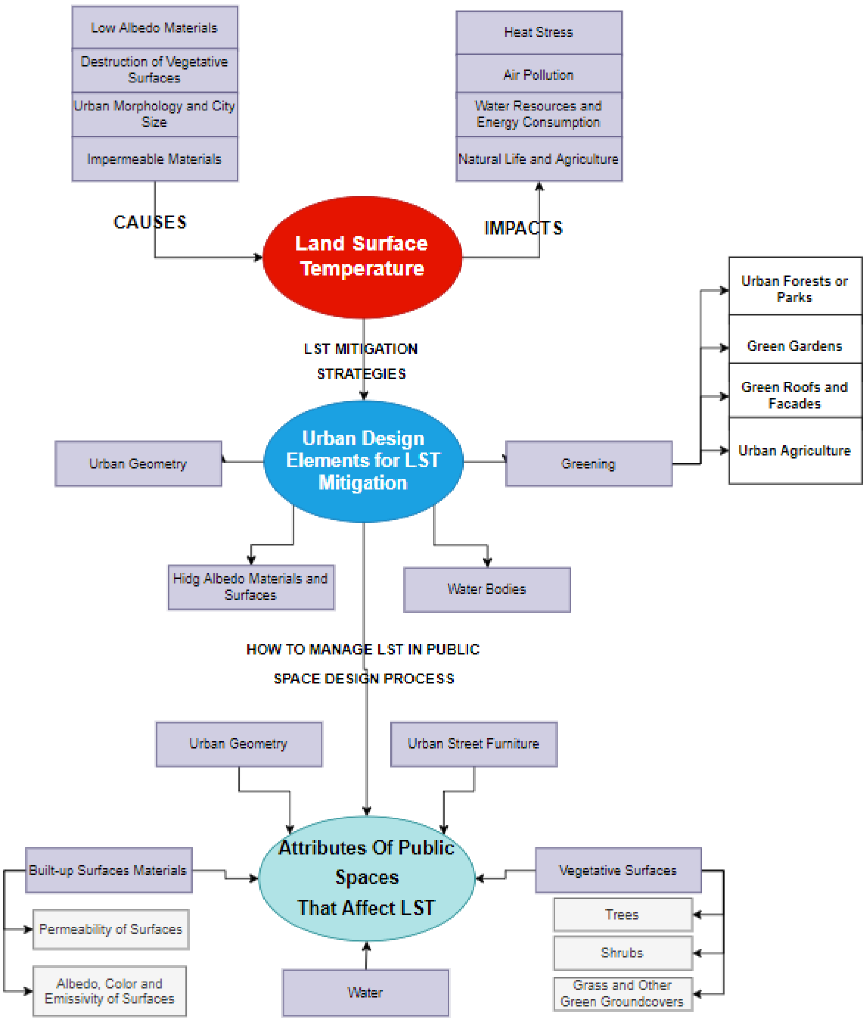


Figure 2.12 LST and Public Space Design relationship on the physical factors that affect and are affected by

The determining public space variables affect the LST measurements in different ways according to the method used, the study area's climate, and the area's size.

CHAPTER 3

METHOD

This chapter focuses on the method of this study. As mentioned previously, the thesis aimed to evaluate the surface temperatures in Taksim Square in İstanbul to reach the main objective of guiding the urban design process as a control mechanism for LST analysis. Did it question the role of each physical environmental attribute in this square regarding its contribution to LST and whether the two urban design competition projects that were ranked among the top three projects have any positive effect on LST values of the square? The thesis asked the following two sub-questions to answer the main research questions posed in the study:

1. How is the LST of a square modeled?

2. How do surface elements that form Taksim Square affect the LST of the region?

Structure of Chapter 3

Firstly, the reasons behind choosing the study area are explained, and brief background information for the site is provided. Secondly, detailed knowledge about the Taksim Square Urban Design Competition and the winning projects are provided. Next, the data pre-processing is mentioned for the data collected to analyze the LST of Taksim Square and the two winning projects. The next step explains the tools and applications utilized in the LST analysis process. Finally, the methods used in the comparison of these 3 LST analyzes are described.

3.1 The case study area: background information

İstanbul, Taksim Square, was chosen as the thesis's study area because recently, a series of urban design competitions organized by İstanbul Metropolitan

Municipality. This trend has been followed by big cities such as Bursa and Ankara Metropolitan Municipalities since the first half of 2020, and it continues (Eraydin & Yoncaci Arslan, 2021). These urban design competitions allow multi-disciplinary groups of participants, in other words, teams of competitors, to present their ideas, different from the traditional method of determining the future of cities by decision-makers. According to the study conducted by Ketboğa in 2014, 10 of the 52 urban design competitions held in Turkey from 1980 to 2014 were held in İstanbul. Therefore, the city was selected as the subject of the study.

As stated in Chapter 2, the increase in urban surface temperatures is a significant problem in climate change and urban heat islands. These competitions involve numerous projects, designers, and decision-makers to evaluate the approach to surface temperatures in Turkey's public space urban design principle. Accordingly, the Taksim Square Urban Design Competition, one of the most up-to-date competitions held in one of the most utilized squares in the country's largest city, was chosen as the area where the study was conducted.

This section gives general information about İstanbul, the squares, Taksim Square, and the urban design competition to provide background information about the study area.

3.1.1 General information about İstanbul

İstanbul is located in Turkey. The city acts as a bridge to the Asian and European continents, and it was established along the Marmara coast and the Bosphorus surrounding the Golden Horn. The European Continent city is either called European Side or Rumeli Side. The Asian Continent is called the Anatolian Side. Every state that conquered İstanbul in history surrounded the city with strong walls. The Turks captured Istanbul in 1453 with the sultan of the Ottoman Empire, Fatih Sultan Mehmet, who has expanded 4 times since then. The city, which currently has 39 districts, is expanding towards Tekirdağ with an increasing population every year.

İstanbul has the largest share economically in the development of the Marmara Region. The city faces the Black Sea in the north, and Kırklareli surrounds it in the northwest, Kocaeli in the east, Bursa in the south, and Tekirdağ in the west. The city covers an area of approximately 5,343 km² and is surrounded by the Sea of Marmara in the south and the Black Sea in the north.

The city is situated between 28° East latitude 58° longitude and 41° North latitude and 01° longitude. The population of the city is 15.46 million (TÜİK, 2020). İstanbul is the most populated and big city in the country. Further, it is more populous than many European countries. İstanbul is the city that receives the most immigrants in the country. The reason for this is both the job opportunities and the cultural and historical richness that the city offers. The city is recognized as one of the cultural capitals in Europe and Asia.

History of İstanbul

İstanbul has hosted numerous states, empires, and principalities as the capital throughout its history. Therefore, its cultural heritage and architectural history are diverse. Throughout its multicultural history, İstanbul has also been a center of attraction in terms of its strategic importance and accessibility to resources. The city is spread over both sides of the Bosphorus, one of the busiest sea routes in the world, and is located on the historical Silk Road (Gülbin Bağbaşı, 2010).

As the city hosted different societies, the historical structures from each culture were preserved. These structures have architectural, artistic, or historical value. Some of these structures are the Greek Patriarchate Ayasofya Mosque, Topkapı Palace, Bozdoğan Aqueduct, Basilica Cistern, Çemberlitaş, Galata Tower, Ahrida Synagogue, Rumeli Fortress, Yoros Castle, Yedikule Dungeons, Dolmabahçe Palace, and Hagia Yorgi Monastery, etc. These structures give identity to the city and constitute the most valuable areas of Istanbul's public spaces.

Climate of İstanbul

As the temperature is a remarkable parameter for the study, the city's climate is also significant. The city is located in a transition region from the Mediterranean climate, which is hot and dry in summers and mild and rainy in winters, to the Black Sea climate, burning in summers and warm in winters but rainy in all seasons. While the most densely populated southern parts show characteristics similar to the Mediterranean climate, the climate characteristics evolve towards the Black Sea climate as the city lies to the north. The difference between the maximum and minimum temperatures is around 6 °C in January, and it rises to approximately 12 °C in July. In this case, the difference between the warmest month's maximum temperature and the coldest month's minimum temperature is around 25 °C (The İstanbul Metropolitan Municipality et al., 2018). İstanbul is located in an advantageous position in terms of sunbathing, and the city's sunshine duration is an average of 2,446 hours per year (MGM, 2021).

3.1.2 Definition and features of squares

According to Kevin Lynch (1960), squares are intense activity centers created in urban spaces. Schulz (1980) defined the square as "*the most prominent and conspicuous element of the urban structure. Because it's a demarcated place, it's easiest to visualize, think about, and represent a goal for action*."

Although squares are classified in many categories such as size, utilization, relations with the street, style, dominant function, architectural form, settlement, function, and form are the two most widely used criteria equally important. The role of a square is essential for the square's life and visual appeal. It is possible to create endless size, form, and function variations courts (Erdönmez & Çelik, 2016). Different types should be defined by classifying them according to their shapes and functions to understand the squares.

Classification of squares according to their forms

One of the two accepted theories in the classification of squares was put forward by Paul Zucker. Zucker (1979) placed the yards that emerged from these primary geometric forms into five basic architectural constructs: closed, dominant, connected, nuclear and amorphous squares (see Figure 3.1).

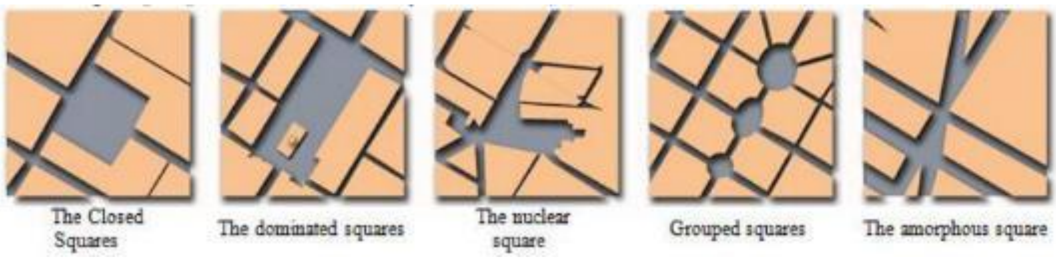


Figure 3.1 Classification of open public urban spaces according to Form (Source: Zucker, 2003)

The forms of the squares are also crucial in terms of surface temperatures. The surface material, orientation, and length of the squares' structures are essential parameters to be evaluated in the design process regarding the shaded areas falling on the squares and the reflected sun rays on squares.

Classification of squares according to their functions

Every square has a purpose; the number of functions of many squares can be quite large. The squares' social functions relate to the community's culture, which affects a broad aspect of urban life, including the economy, urban transportation circulation, agriculture, aesthetics, and leisure. Since the social function of the square spans such a comprehensive range of urban activities, it can be termed a community center. The functional classification aims to define the squares' social function analytically. This classification includes four types called "internal function" square, "associated function" square, "arterial node function" and "multifunctional" square (Peter, 1963).

Squares in rural areas in Turkey are small gathering centers formed around plane trees, village cafes, and mosques. In cities, it is the intersection points and intense activity centers that surround the monuments, fountains, buildings, statues, and religious structures, where the people of the city or visitors come together (Öztan, 1998; Erdönmez & Abay, 2018; İnceoğlu & Aytuğ, 2009; Edward, 1966; Acarli et al. 2018).

The function of the squares varies in terms of surface temperatures. An area with a recreational role will have a vegetation surface, but an area considered a gathering and ceremony area should be predominantly solid ground. For this reason, designers need to determine the weighted functions of the square and choose the surface material accordingly.

General information about Taksim Square

Taksim Square, located in the Beyoğlu district of İstanbul, was chosen as the research sample area (see Figure 3.2). Starting from Şişhane, Tünelbaşı and exhibiting a dense settlement on both sides of Istiklal Street, Beyoğlu reaches a vast perspective space for the first time in Taksim. The square divides the volume of people and vehicles in various directions. According to Zucker's square classification (2003), Taksim Square can be defined as the dominated square. As shown in Figure 3.2, the square is characterized mostly by structures such as the Taksim Mosque (1) and Atatürk Culture Center (2).

Figure 3.2 Taksim Square Drone Photograph (The İstanbul Metropolitan Municipality, 2020)

The first building here is a classical Ottoman-style water building. Mahmud's system of aqueducts built 1732-1733 to bring water to the city from the lush Belgrade forests in the north of the town ended here (Hatipoğlu 1994). The stored water was distributed in various directions from a stone masonry at the corner. The square and its surroundings take their name from this maksem and the water division (Bağbaşı, 2010).

The selected design competition area's size is approximately 210 m². Taksim Square is an important symbol of İstanbul's urban memory and identity. Today, it is at the intersection of the city's essential transportation links and includes many historical monumental structures and traditional architectural textures.

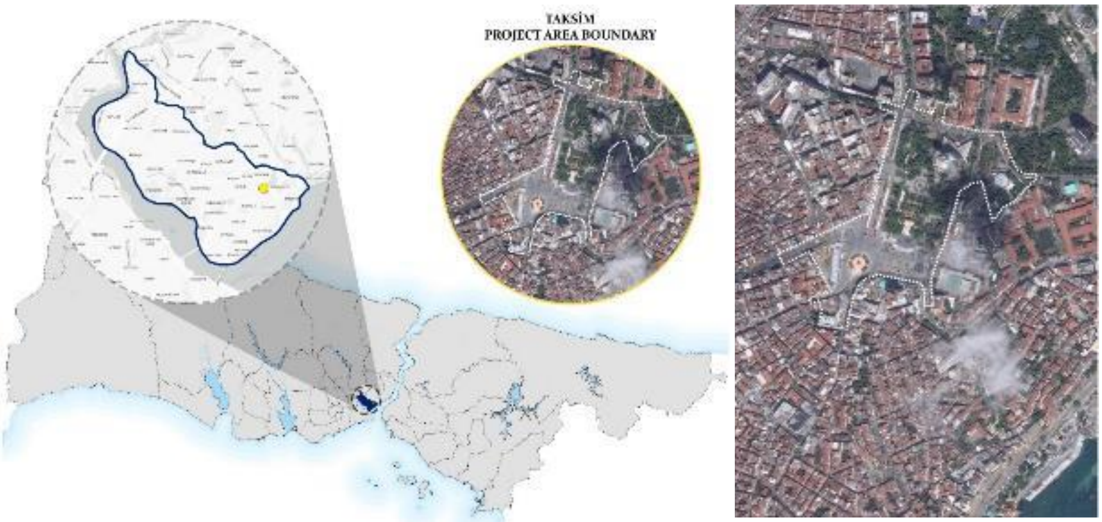


Figure 3.3 Location (left) and Plan (right) of Taksim Square (Source: İstanbul Metropolitan Municipality, 2020)

3.1.3 Taksim location, history

The square was first used as the commercial area of the region in the 15th and 16th centuries, and during the Ottoman period, it was a predominantly non-Muslim area.

With the increase of embassies in the region in the 16th and 17th centuries, the embassy buildings were settled in Beyoğlu, and wood materials were widely used in these buildings in the area during that period (Karaman et al. 2011). Cultural activities such as theater and cinema have increased, and one of the most important cultural structures of this period has been the Taksim Stage. It was demolished in the following years. Taksim became a square with the proclamation of the Republic. According to Gülersoy (1986), Taksim Square has become one of the essential focal points of the city. Taksim Republic Monument, Gezi Park, Atatürk Cultural Center were built. In 1985, Istiklal Avenue (a boulevard that intersects Taksim Square) was closed to vehicle traffic. In 2017, approval was obtained from the İstanbul No. 2 Cultural Heritage Preservation Regional Board to construct a mosque in Taksim, and the mosque was built.

Taksim Square Urban Design Competition

There are two main reasons why Taksim Square Urban Design Competition was chosen as the case study. The first of these is that in a city where the effects of climate change are intense, it offers the opportunity to measure and compare the impact of the square design on the surface temperatures through different designs made on the area in the worst case. The second is that the competition has the quality of giving information about the general approach of the urban designers at the national and international level due to the interest shown in the competition. The language of the competition is English, and as can be seen on the official website, a total of 143 groups participated in the competition. Since each group has an average of 4 members, approximately 580 participants from the departments of landscape architecture, city and regional planning, urban design, and architecture exhibited their plans and ideas.

The IMM Cultural Heritage Department organized the Taksim Square Urban Design competition in 2020. The subject of the contest is the preparation of the urban design project of Taksim within the given competition border. Expectations translated directly from the specification, which is among the documents provided to the contestants. The objectives expected from the competitors within the scope of the competition are examined.

After examining the requirements listed in the specification, it is seen that there are four main issues that the projects are desired to concentrate on;

- Designing with aesthetic concern,
- Preserving and highlighting cultural and historical structures,
- Regulating transportation infrastructure for pedestrian circulation and vehicle traffic,
- Keeping and maintaining the green space function of the square,

The mentioned points are significant for square design; the critical importance on functionality is not given. For example, infrastructural requirements were limited to transportation. However, it is inadequate for İstanbul, which is exposed to extreme weather events due to climate change and has a high earthquake risk since it is located on the 1st-degree fault line (Onur, 2014). The specification indicates that the square is not considered for disasters, water management, or climate change adaptation. The only article that includes climatic conditions in the competition specifications is given below:

> *(....)*
>
> "*7. Developing suggestions that respond to the 24-hour usage habits of the area, taking into account the needs such as lighting and urban furniture, and producing solutions for climatic conditions such as wind and sun*"
>
> *(....)*

The specification addresses the design issues by highlighting economic functionality, originality, functionality, and innovative solutions that can shed light on today's architecture. Climatic conditions and parameters such as temperature and wind are only mentioned in Article 7. However, the article mainly deals with lighting and street furniture, emphasizing the necessity of meeting the need for security to ensure 24-hour use of the square. The part of producing solutions against climatic conditions is only attached to the end of the article.

İstanbul Metropolitan Municipality is a signatory in several climate programs and conventions, including C40 and Compact of Mayors. These programs offer advantages such as establishing a certain standard, gaining technical knowledge, and providing the tools and guides required for climate studies. Apart from these, there are other sustainable, climate-resilient, and low-carbon cities. These include Making City Resilient (UNISDR), European Green Leaf (EU Program), No Regrets Charter, and 100 Resilient Cities (The İstanbul Metropolitan Municipality et al., 2018). In order to minimize the effects of climate change in İstanbul, it is necessary to comply with the action plans brought by these agreements and contracts. Herein, plans implemented, such as urban design competition winner projects, should be sensitive to climate change. However, as aforementioned, there is no statement on climate change in the Taksim Square Urban Design Competition specifications, and no expert is working in this field among the jury members.

143 projects participating in the competition were examined. It was determined that some projects evaluated climate change and urban heat islands as fundamental problems and carried out design studies for them. To illustrate, in project 41, attention was drawn to the green and blue infrastructure issues. Stormwater management, climatic comfort, porous surfaces, and UHI effect mitigation strategies are some of the aims that should be reached by the proposed project design. In the design catalog of Project 41, one of the objectives of the design is “Despite current temperature difference between the square and the park as 2-2.5°C, proposed project can decrease this around 1-1.5°C in the summertime”. The other project aimed to decrease the UHI effect by providing green spaces is Project 38. By changing the surface material, Project 38 targets being environmentally friendly with minimizing construction pollution, transportation carbon, emission depletion of the ozone layer, global warming, heat island effect, light pollution, and waste output. Project 54 takes carbon footprints as one of the parameters that direct the design process. In this way, decreasing carbon footprint indirectly helps minimize the UHI effect by decreasing

the surface temperatures and carbon emissions. Viewed from outside the context of design and functionality, these projects seek solutions to critical climatic problems. However, none of the projects made it to the finals due to the jury evaluations.

As a result of the competition, projects 15, 19, and 16 were selected as equivalents by the decision of the jury members and were entitled to be submitted to the public vote. According to the plebiscite results, project number 15 received the most votes (86,597) with small margins and was entitled to implementation (IMM, 2020).

The winning project, number 15, evaluated the landscape elements as sustainable features. Open Space Thermal Comfort was one of the significant issues in the design project. Thermal comfort is about temperature, so surface temperature and thus the surface materials were significant parameters in the designers' planning process. Shading, sprinkle fountains as water surfaces, and permeable surfaces are some of the design elements utilized to provide thermal comfort in the area. Moreover, planting selection as vegetative surfaces has been made by considering the climatic and environmental impacts. Thus, as can be seen from the project catalog, a sensitive square on urban heat islands and climate change issues was designed with the winning project.

The other two equivalent projects do not address these problems. In Project 19, one of the equivalent projects, the concept of greening and "Green Occupation" was emphasized. In this context, the vegetative surface increase was considered an actual output. Project 19 does not mention LST, UHI, or climate change in the catalog. In the other equivalent project, design number 16, there is no statement about climate change, surface temperatures, and urban heat islands.

Based on the information given in the project catalogs and the information given in the last part of this study, it can be predicted that the increased green area will positively affect the surface temperatures. These effects were reviewed in the Results chapter of this thesis.

3.1.4 Competition projects

This study aims to understand the importance of LST in urban design competitions by comparing Taksim Square's land use LST with the LST of the equivalent project and the winning project. Interviews were done with the İstanbul Metropolitan Municipality and equivalent project owners in this stage. Their project’s data and land use plan were requested. AutoCAD drawings of the designs were obtained from the owners of Project 19 and Project 15 (Winner) with their permission. Since the owners of Project 16, which was the 3rd selected project by public voting, could not be interviewed and did not accept data sharing, this design was excluded from the scope of the study. In addition, all documents provided by the municipality to the competitors and on the website where the competition was announced as an open-source were used in the study with the permission and cooperation of the municipality.

The group members of Project 15 are Şerif Süveydan (Architect), Burcu Sevinç Yilmaz (Architect), Rıfat Yilmaz (Architect), Süleyman Yıldız (Architect), Sezer Bahtiyar (Architect), Murat Güvenç (Urban Planner), and Herman Salm (Landscape Architect). Proposing a participatory strategy to transform the square into a sequence of public spaces responsive to the historical memory and contemporary public needs is the vision of Project 15. 6 guiding principles are proposed to reach that objective by the project that are;

- Avoid any physical intervention with cultural and ideological references.
- Avoiding imposes an overwhelming new character on Taksim and Gezi.
- Activating and nurturing public participation.
- Introducing an incremental design process that would be open to the public contributions.
- A Specific Organization for Taksim
- Creating space and areas for public forums and social interaction.

- To add a new construction load to Taksim, avoid massive interventions with high costs.

In the light of these principles, the square plan to be obtained at the end of the project is given in Figure 3.4.

Figure 3.4 Project 15, 1/1000 Plan

The group members of Project 19 are Kutlu İnanç Bal (Architect/ Team Representative), Hakan Evkaya (Architect), Barış Ekmekçi (Landscape Architect), Münire Sağat (Landscape Architect), and Olgu Çalışkan (Urban Planner). Preserving the historical elements and integrating the underground, aboveground, square, and park quad is the main focus of Project 19. In the scope of that vision, four strategies were set to reach the project's objectives.

- Spreading the green area starting from Gezi Park,
- Increasing the weight of green space use against the hard ground,

- Highlighting historical urban spaces and harmonizing them with modern architecture
- Integrating the underground and aboveground.

The final design, which was created by considering these strategies, is given in Figure 3.5.

Figure 3.5 Project 19, 1/1000 Plan

In order to compare the surface area temperatures of the two projects mentioned and the land use of Taksim Square, area measurements and modeling were used.

3.1.5 Analysis on different surfaces of Taksim Square

After giving basic information about Taksim Square and the projects evaluated within the scope of the study, the evaluation of different designs and surface elements in these areas is vital for detailing the surface temperature analysis.

Table 3.1 Surface Classification of Taksim, Project 19 and Project 15

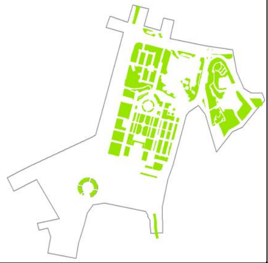
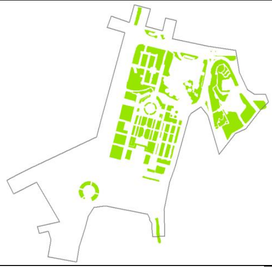
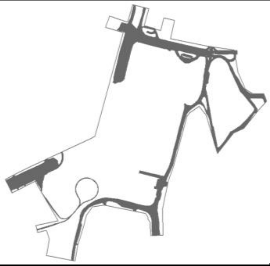
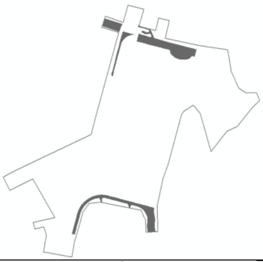
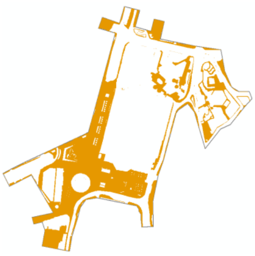
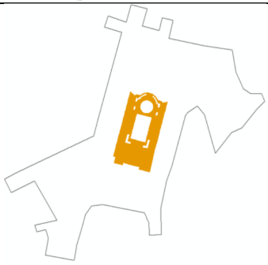
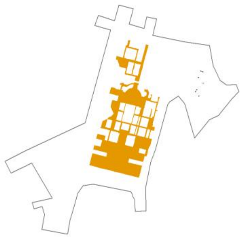
Urban Design Elements	Surface Types	Taksim Square land use	Project 19 (Equivalent)	Project 15 (Winner)
Vegetative Surfaces	Trees			
	Grass/ Turf			
Hard Surfaces and Buildings	Asphalt			
	Dark Grey Natural Stone Floor			

Table 3.1. (cont'd)

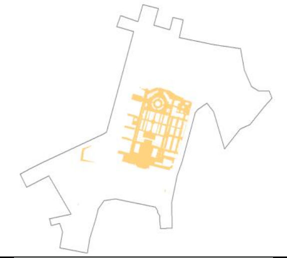
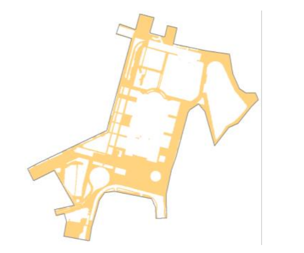
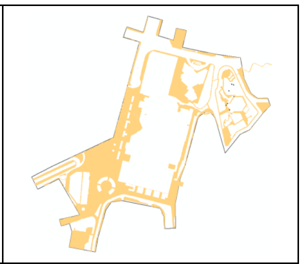
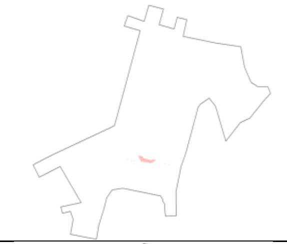
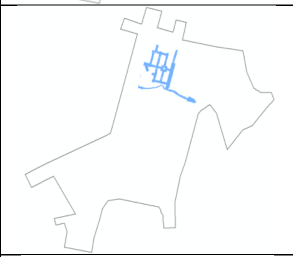
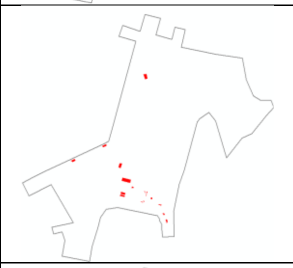
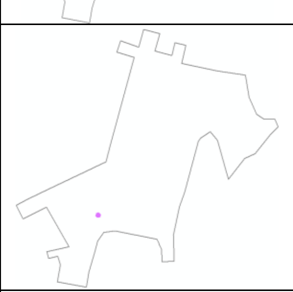
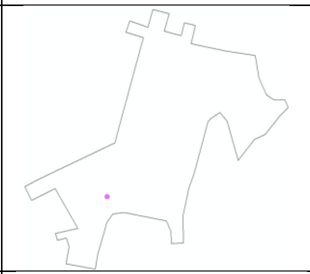
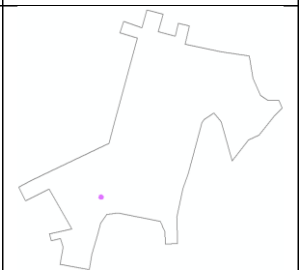
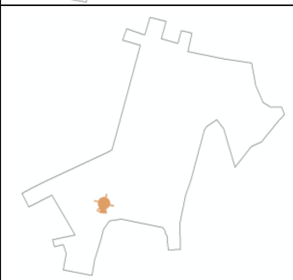
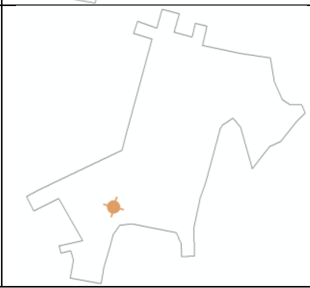
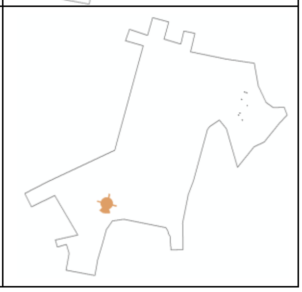
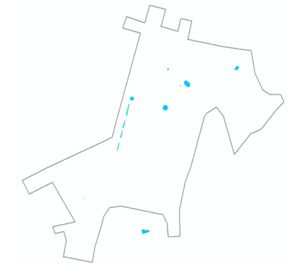
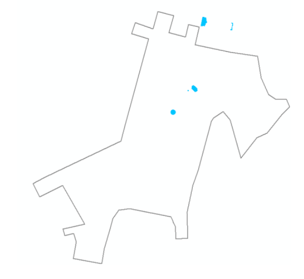
Hard Surfaces	Light Grey Natural Stone Floor			
	Marble		X	X
	Cobble		X	X
	Metal		X	X
	Gravel			
	Red Rubber			

Table 3.1. (cont'd)

Hard Surfaces	Buildings			
Water Element	Pool			X

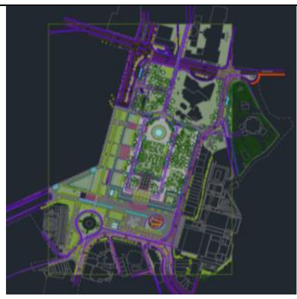
3.2 Data collection

Two primary data sources were needed to analyze and model the surface temperature of Taksim Square. The first is the raw drawing data and project catalogs obtained from the municipality and project owners. The second is field measurements, which form the basis of surface temperature models.

3.2.1 Base map and equivalent projects' drawings

The 1/500 scale plans of the project and the land use of the square in .dwg format, which is the output of the AutoCAD program, were obtained as a result of the interviews and the permissions obtained (see Table 3.2).

Table 3.2 Base map and equivalent projects' drawings

Taksim Base Map	Project 15	Project 19
		

3.2.2 Field survey and measurements

In this study, the effect of surface materials on land surface temperature is measured. A commonly used technique to measure LST is remote sensing methods by measuring the heat energy radiated from the earth's surface (Kavzaoğlu ve Çölkesen, 2011). The satellite images are used in the studies. The thermal satellite image with the highest resolution has a resolution between 3 and 100 meters. High resolution is significant since this study aims to model the effect of design elements used in public spaces on surface temperature. To illustrate, the impact of a tree's shadow is even significant in the study. However, this information cannot be obtained by remote sensing methods. Remote sensing techniques do not help measure the LST of a square because of the resolution problem. Therefore, the different surfaces in the area were analyzed in the field survey organized on 9th August, and surface temperature measurements of these surfaces were carried out following field measurement days.

3.2.2.1 Measurement date and time

The data obtained by studies, which examine the relationship between land surface temperature and surface materials, vary from one context to another. Differences in the studies are because temperatures and the sun's angle reaching the earth varies in different geographical locations. However, the common point of the date and time chosen for the measurement or obtaining satellite images is that the sunlight is closest to 90 degrees (Chatzidimitriou et al., 2006; Matzarakis & Amelung, 2008; Spanjar et al., 2020; Li et al., 2020).

This study aims to model the worst-case scenario for LST measurements. Since İstanbul's climate is hot and humid in summers and rainy and warm in winters (Turkish General Directorate of Meteorology, 2021), the month of August was selected as the worst-case analysis for measuring LST. Furthermore, in August, the heating effect is the highest f the year. The monthly average temperature data for the last 10 years in İstanbul were obtained from the General Directorate of Meteorology of the Republic of Turkey. According to the data examined, August was determined as the hottest month. Therefore, the LST measurements were carried out on 10th, 11th, 14th, 15th, 17th August 2021. August 12th, 13th, and 16th were cloudy or rainy, so measurements were not taken these days, as a clear sky was needed for high accuracy. On each measurement day, the study started at exactly 12:00. In addition, choosing 12:00 for the measurement was also essential for keeping the shadow effect at a minimum level in the study. Moreover, surface urban heat islands (SUHI) are present at any time of the day and are more intense towards midday in summer (Buyantuyev & Wu, 2010).

Due to the size of the field, some points were measured with a delay of several minutes. However, to reduce the deviation between the measurement times, the order of the measurement points was followed in the same way on each measurement day.

3.2.2.2 Surface temperature measurement process

As mentioned, open-source remote sensing methods cannot be used for surface temperature modeling and simulation at 1/1000, 1/500 scale due to resolution problems. Thanks to thermal cameras such as drones, it is possible to obtain very high quality and accurate data at this scale, but it is very costly. This study aims to create a practical LST modeling for urban designers and city planners. Therefore, an affordable device with high accuracy measures the temperature of surfaces was needed to create a surface temperature model. Benetech GM300 device is a laser infrared non-contact thermometer. It can measure the temperature of objects remotely with a laser pointer. The device has been used for studies that include thermal measurements such as Zheng et al. (2015), Zheng et al. (2019), and Zhao et al. (2019). The device, used in many other, has also been preferred in this thesis research because of its affordable price.

In the process of LST analysis, only the competition area provided by the municipality was evaluated. The significant point in the study is to compare the surface temperature analyzes of the designs and the land use. Since the inclusion of the areas that were not changed within the scope of the competition would not cause any change in the results, only the areas within the competition boundary were analyzed.

Data collection

After determining the measurement date and device, the next step is to develop the measurement method. On August 9, a field survey was conducted to classify and identify the different surfaces in Taksim. After the field trip, the base map provided by the municipality was printed out in portable sizes, and points were placed in areas with different surfaces. The factors to consider when choosing 66 measurement points are listed below (see Figure 3.6):

- Each different surface has been measured at least twice.
- Measurement points were determined on both the sun and shaded parts of each different surface, such as grass under the sun and grass under shade.
- Since the area within the project boundaries is large (approximately 210 m^2), changes in the same surfaces far from each other have been taken into account. For example, points were placed at such locations to investigate significant differences between the area's northernmost asphalt surface and the southernmost asphalt surface temperatures.

During the measurement, the temperature values taken from the same points and approximately 5 centimeters above the ground every day were recorded on the base map of that day. The weather conditions of the days were examined and compared according to the data obtained from the General Directorate of Meteorology (measurement days' temperatures are August 10th- 35℃, August 11th- 35℃, August 14th-34℃, August 15th- 35℃, and August 17th- 35. Rainy or cloudy days were around 32-33 ℃ and excluded from measurement days), and no significant variability was observed.

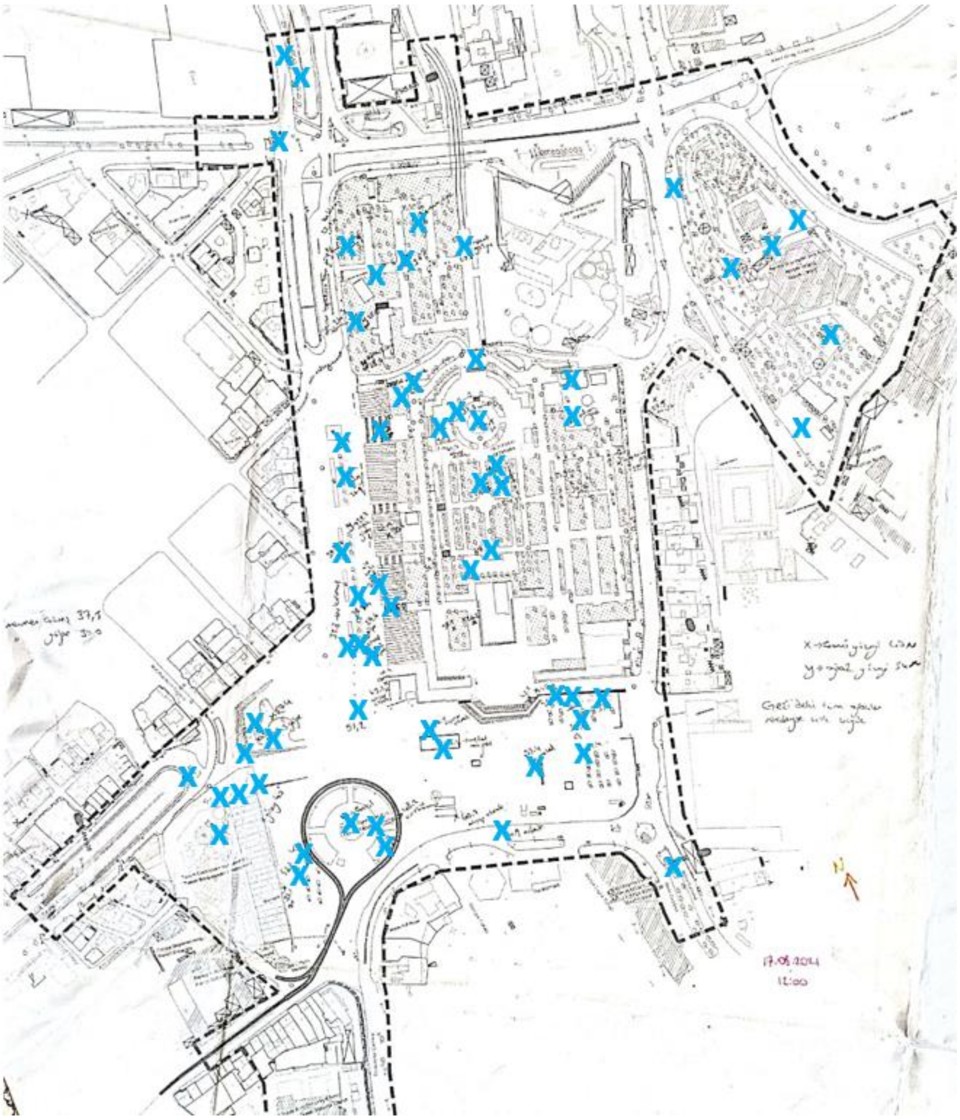


Figure 3.6 Land surface temperature field measurements

3.2.2.3 Classification of the site according to different surfaces and measurement points

The temperature in the sun and the temperature in the shade were measured for each surface observed in the field. A total of 66 points were measured. However, each of these points does not represent different surfaces. There are also cases where three different measurements are made for the same ground material due to the distances of the locations from each other. The number of classified surfaces on which the primary measurement is made is 25. These surfaces are presented in Table 3.3 with their visuals and surface temperature values created by five days of measurement and average values of different points. The sources of visuals in the table belong to the author's photographs from Taksim Square and Google Earth Pro.

The LST analyzed within the scope of the study is 2-dimensional. However, if a 3-dimensional analysis were made, the shadow effect was added to the study since the most major effect would belong to the shaded areas. Thus, the temperature values created by the shadow effect in the area were measured for each different surface in the area, as mentioned. This effect was measured by transferring the shadow silhouettes formed on the surface by the 3D elements in the plans of the projects to the area and adding the low temperatures of those areas to the analysis. The method followed at this stage is as follows:

- Tree shadows were obtained from detailed tree analyses provided to participants in the Taksim Square Urban Design Competition. Trees in the area are given as circles in the AutoCAD program with different diameters. These circles are projected onto the ground as shaded polygons. Since tree shadows temperatures were measured for each surface, these areas were also included in the analysis.
- Another shadow analysis was used to measure the impact of the main pedestrian bridge in Project 15. All bridge lines are included in the drawing provided by the owners. The bridge element is projected onto the area surface

in a polygon and included in the 2D analysis as canopy values of different surfaces.

- Finally, the awning element in Project 19 was projected onto the area, as in the example of the tree and bridge, and was included in the analysis as a canopy.

What is important in this part of the analysis is: Urban geometry could not be included in the analysis since the buildings could not be changed due to the competition. However, even if wind, canopy difference due to building orientation, and sky view factor are excluded from the analysis, they can be projected into the area with the mentioned method and included in the analysis in future studies.

Table 3.3 Surface Classification of the Taksim Square's land use

Layer Number	Surface Type	Temperature (Average, ºC)
1	Natural Stone (Sun)	40,4
21	Natural Stone (Shadow)	25,4
2	Wooden Sitting Furniture (Shadow)	29,6
13	Wooden Sitting Furniture (Sun)	59,8
3	Asphalt (Sun)	52,18
23	Asphalt (Shadow)	29,5
4	Dark Colored Natural Stone (Sun)	52,16
22	Dark Colored Natural Stone (Shadow)	35,43
5	Grass (Sun)	31,44
19	Grass (Shadow)	25,32
6	White Painted Cement (Sun)	48,7
7	Cobble (Sun)	47,1
20	Cobble (Shadow)	27,6
8	Subway Stairways (Metal, (Sun))	55,4
9	Metal Subway Cover (Sun)	55,3
10	Metal Embrasure (Sun)	40,2
11	Stone Sitting Furniture (Sun)	43,6
12	Bare Soil (Humid) Under the Trees (Sun)	39,8
14	Red Rubber Flooring (Sun)	48,2
24	Small Size Pool (Sun)	30,1
15	Medium Size Pool (Sun)	22,3
16	Gravel (Sun)	48,4
17	White Marble Staircase (Sun)	46,5
18	Grey Marble Sitting Furniture (Sun)	48,4

In figures 3.7, 3.8. and 3.9, Taksim Square, Project 19's, and Project 15's surface classification is provided. Tree, bridge, and awning canopies are also included in the classifications and can be observed in the images given.

Figure 3.7 Taksim Square land use classification

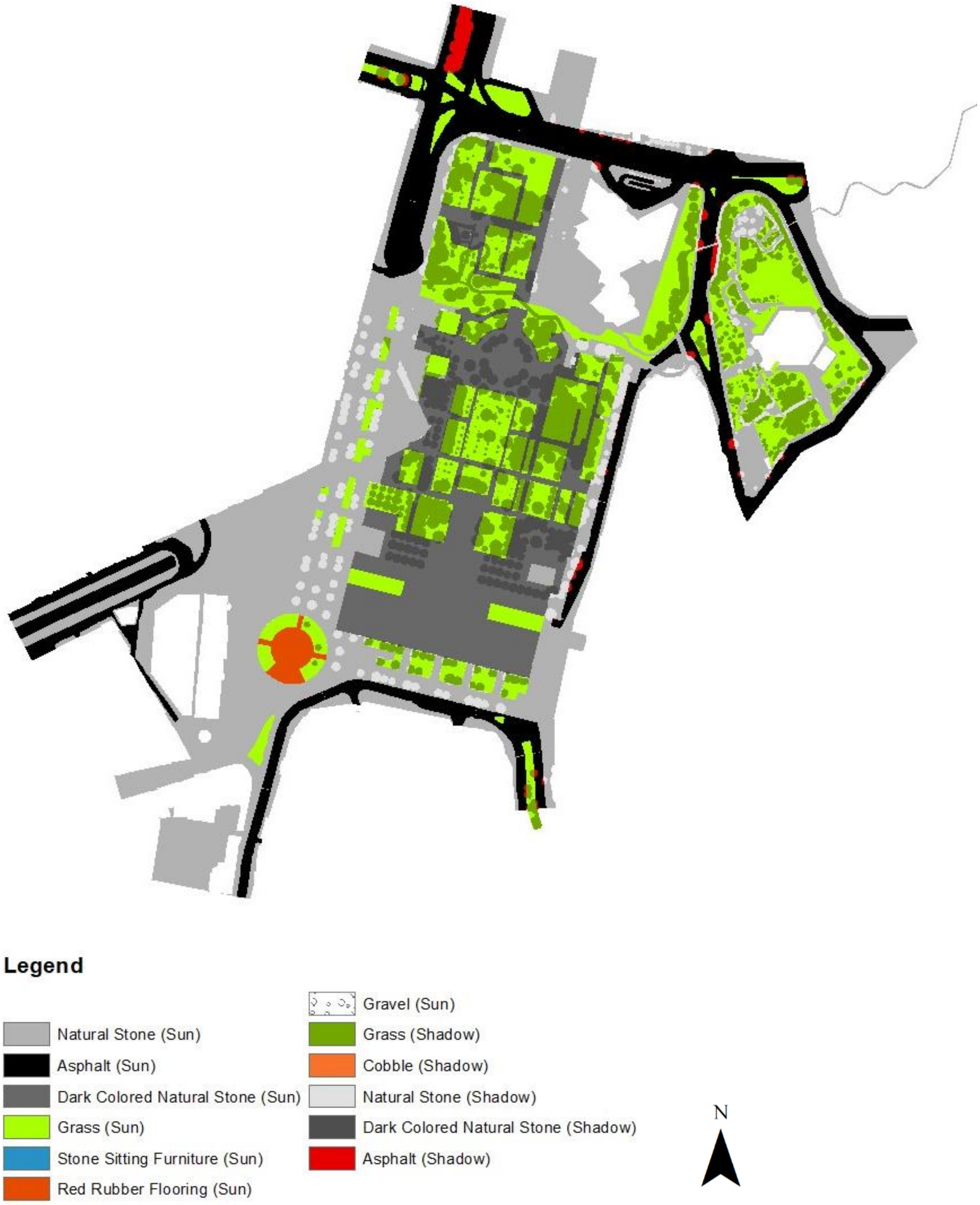


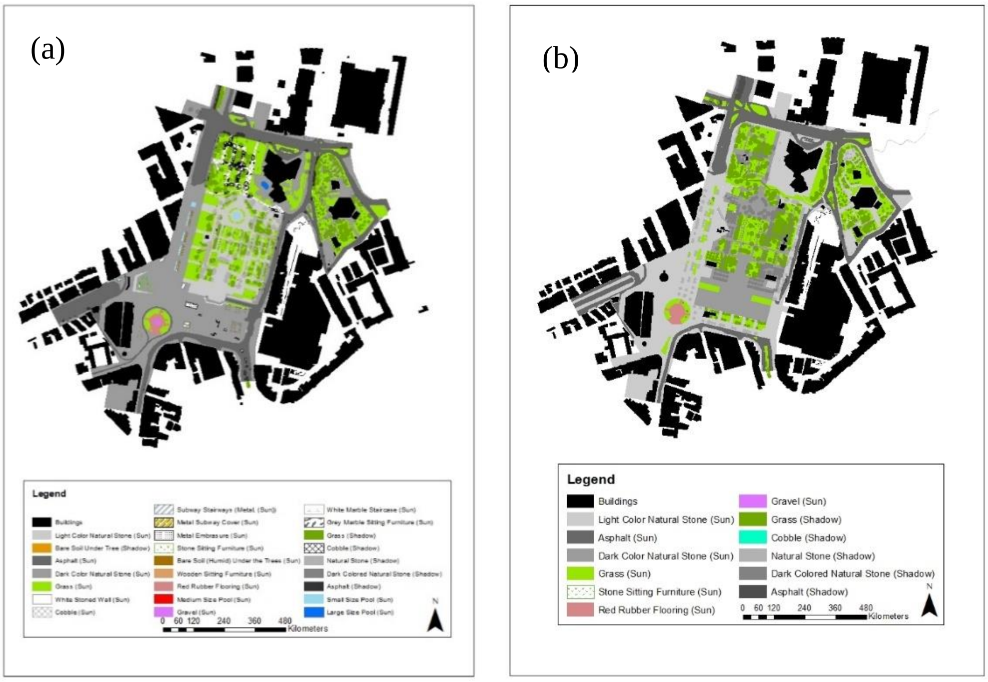
Figure 3.8 Project 15 surface classification

Figure 3.9 Project 19 surface classification

3.2.3 Data Pre-Processing

After classifying the surfaces, the first step is data pre-processing. Before the analysis, the plan and project data (which were received from the project owners and the municipality) were subjected to data cleaning, digitization, conversion, editing, projection, and scale adjustment processes. Taksim Square's land use and design drawings of the projects were taken in dwg format, which is the output of the AutoCAD program. Elements that do not affect the surface temperatures in these drawings are deleted and excluded from the scope. These elements are as follows: signs, trash cans, billboards, pontoons, buildings outside the project area, signs showing the location of security cameras, and lighting poles. Also, invisible elements that cannot be seen spatially, but can reference designers and planners, are deleted from the drawings. These invisible elements are property boundaries, sketch lines that guide the design, and island boundaries. After the elements that do not affect the surface temperature of the drawings were eliminated, the necessary scaling and projection processes were carried out in AutoCAD and ArcGIS programs. After the projects and the land use were transferred to the ArcGIS environment, the plans in the design catalogs of Project 15 and Project 19 were examined.

Due to AutoCAD's dwg format, drawings are not expressed as shapefiles but as lines in a combined layer in the ArcGIS program. Placing it in different layers is necessary for surface temperature modeling to analyze each surface. Using the ArcGIS program's SQL query method, the surface elements that came in a single layer were classified. The classification of each project is indicated in the figures shown below.



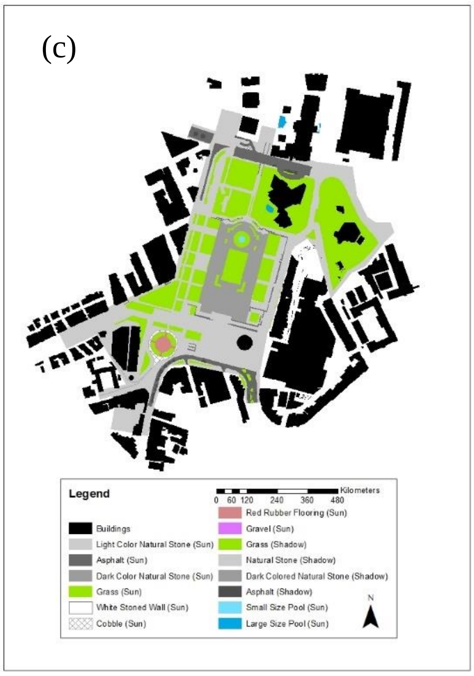


Figure 3.10 (a) Taksim Square Land use Surface Classification, (b) Project 15 Design Proposal Surface Classification, (c) Project 19 Design Proposal Surface Classification

Elements that may affect the surface temperature in the drawings were checked, and digitization was carried out to eliminate the deficiencies. All elements have been converted to polygons to express areas in the ArcGIS environment.

3.2.4 Digitizing Measurements

Locations of 66 surface temperature measurement points are indicated on the square map in Figure 3.11. One type of surface has been measured at least 2 times to ensure that the selected points are composed of various combinations of different surfaces. To illustrate, the surface temperature of a grass surface is expressed when it is shady and sunny.

Figure 3.11 Taksim Square surface temperature measurement points

Measurements recorded as points were digitized and converted to raster format in five different layers after each temperature value was assigned. The " Cell Statistics " tool took the average of five-point layers was taken using this format using the "Cell Statistics" tool. Thus, the accuracy of the surface temperatures for different days reached the highest values.

Measurements were recorded on different measurement days from 66 points in Taksim Square. Measuring points are recorded for different surface types. The surface temperature measurements for 10th, 11th, 14th, 15^{th,} and 17th August are in Table 3.5.

Table 3.4 Field measurements of surface temperature

Surface ID	Surface Type	August 10th	August 11th	August 14th	August 15th	August 17th
0	Asphalt	54,9	53,7	55,3	54,2	50,6
23	Asphalt	49,3	48,7	51,6	48,9	47,9
56	Asphalt	48,7	47,5	48,7	47,1	46,7
59	Asphalt	52,8	51,2	55	51	49,7
61	Asphalt	55	54,3	56,8	53,9	59,4
62	Asphalt	53,7	51,9	55,8	51,3	58,9
65	Asphalt	50,9	48,9	50	48,9	46,1
60	Asphalt (Shade)	37,5	38,9	39,6	38	38,6
31	Bushes	28,8	29	26,2	27,3	27,4
45	Cobblestone (Sun)	47,1	45,4	48,9	43,8	46,8
55	Combined Pavement (Shadow)	27,6	25,7	29,6	28,9	24,9
19	Dark Gray Marble (Sun)	50,4	49	51,5	49,7	48,6
5	Dark Gray Stone (Shade)	40,1	40,3	42,5	39,3	40,9
10	Dark Gray Stone (Shade)	33,4	32,1	30,9	37,5	32,9
11	Dark Gray Stone (Shade)	32,8	32,7	35,8	31,9	30
27	Dark Gray Stone (Shade)	28,8	27,5	28,9	27,8	29
33	Dark Gray Stone (Shade)	48,9	47,7	45,7	45,9	47,5
4	Dark Gray Stone (Sun)	53,1	52,3	51,9	54,8	50,9
20	Dark Gray Stone (Sun)	51,2	50,1	52,2	50,1	49,6
28	Dark Gray Stone (Sun)	47,5	47,7	48,5	46,7	46,7
34	Dark Gray Stone (Sun)	58,7	56,7	60,4	56,7	56,1
39	Dark Gray Stone (Sun)	50,3	49,3	51,3	49,8	51,3
17	Dark Gray Stone Seat (Shade)	28,3	27,1	29	27,6	26,7
18	Dark Gray Stone Seat (Sun)	43,6	43,2	45,7	42,7	41,8
38	Flower	37,7	36,8	37,7	36,9	35,8
12	Grass Field (Shade)	28	26,9	29,1	27,4	26,8
30	Grass Field (Shade)	26,2	24,2	27,9	25,5	25,9
36	Grass Field (Shade)	26,4	26,1	26,7	25,7	25,9
42	Grass Field (Shade)	25,9	25,9	27,9	24,1	20,4
50	Grass Field (Shade)	25	24,7	23,7	23,8	23,5

Table 3.4. (cont'd)

53	Grass Field (Shade)	19,8	18,5	21,9	18,4	18,4
57	Grass Field (Shade)	26	26,9	27,3	24,6	24,2
2	Grass Field (Sun)	37,7	36,9	38,9	36,9	36,2
13	Grass Field (Sun)	33,7	33	34,8	31,9	32,9
29	Grass Field (Sun)	38,5	38,2	39,7	37,4	40
35	Grass Field (Sun)	37,7	38,1	35,2	38,2	35,9
41	Grass Field (Sun)	37,7	35,9	38,5	35,4	37,9
43	Grass Field (Sun)	35,8	34,6	36,7	33,7	31,9
58	Grass Field (Sun)	36,7	35,6	27,3	35,2	34
1	Gravel	48,4	47,8	49,4	47,5	46,5
48	Gray Stone (Shade)	26,7	25,8	27,9	25,4	24,1
52	Gray Stone (Shade)	24	23,9	25,8	22,9	25,1
16	Gray Stone (Stairs)	44	43,1	45	43,2	47,5
49	Gray Stone (Sun)	43,4	45	46,7	42,6	41,7
54	Gray Stone (Sun)	37,4	36,8	39,7	35,9	32,9
46	Light Gray Stone (Sun)	41,3	39,7	43,7	38,9	40,9
21	Marble (Shade)	29,6	28,6	31,3	28	28,4
8	Marble (Sun)	46,5	46,1	45,9	45	40,3
22	Marble (Sun)	48,4	48,8	46,9	47,5	46,1
14	Marble Stairs	42,2	41	43,5	40,9	41,9
7	Metal Grill	40,2	39,7	41,7	39,4	38,4
9	Metal Sheet Cover	55,4	53,2	55,7	53,7	55,9
6	Pool 1	30,1	29,9	31,6	29,7	24,7
25	Pool 1	35,8	35,9	37,5	36,7	39,7
37	Pool 2	27,5	28,3	29,7	26,9	24,1
47	Pool 2	48,5	49,3	49,5	49	47,9
51	Pool 3	22,3	21,8	23,5	20,8	18,7
66	Pool 3	21,4	20,9	23,4	19,5	18,3
32	Red, Kids Playground Cover	67,1	66,9	69,5	66,7	69,7
3	Red Surface	48,2	47,8	49,3	48	46,8
63	Refuge Wood (Shade)	32,1	30,7	33,8	31,3	30,4
64	Refuge Woodship (Sun)	45,8	46,1	47,9	44,8	42,8
44	Tree	34,1	32,9	38,1	32,7	32,7
26	Wood (Shade)	29,6	28,2	29,5	28,6	27,9
24	Wood (Sun)	57,9	57	58,9	55	62,8
40	Wood (Sun)	61,7	61,2	61,7	60,3	59

Variance and standard deviation of the measurements

After the temperature measurements of the square, the average values were assigned to the polygons of those surfaces. Therefore, the variance between the measurement points on the same surfaces and the values of these points on different dates is very important. Variance and standard deviation were calculated (see Table 3.5).

Table 3.5 The variance and the standard deviation of the field measurements

Surface Type	Variance	Standart Deviation
Asphalt	**11,81**	**3,44**
Asphalt (Shade)	0,53	0,72
Cobblestone (Sun)	3,67	1,91
Combined Pavement (Shadow)	4,06	2,02
Dark Gray Marble (Sun)	1,33	1,15
Dark Gray Stone (Shade)	**48,33**	**6,95**
Dark Gray Stone (Sun)	13,42	3,66
Dark Gray Stone Seat (Shade)	0,85	0,92
Dark Gray Stone Seat (Sun)	2,11	1,45
Grass Field (Shade)	7,96	2,82
Grass Field (Sun)	6,74	2,60
Gravel	1,16	1,08
Gray Stone	1,26	1,12
Gray Stone (Shade)	2,21	1,49
Gray Stone (Stairs)	3,28	1,81
Gray Stone (Sun)	**19,44**	**4,41**
Light Gray Stone (Sun)	3,36	1,83
Marble (Shade)	1,75	1,32
Marble (Sun)	5,58	2,36
Marble Stairs	1,12	1,06
Metal Grill	1,47	1,21
Metal Sheet Cover	1,54	1,24
Pool 1	3,26	1,81
Pool 2	5,98	2,44
Pool 3	**39,48**	**6,28**
Red Kids Playground Cover	2,21	1,49
Red Surface	0,80	0,90
Refuge (Shade)	1,85	1,36
Refuge (Sun)	3,50	1,87
Wood (Shade)	0,58	0,76
Wood (Sun)	5,97	2,44

According to variance calculations of the field measurements, Asphalt, Dark Grey Stone (shade), Gray Stone (sun), and Pool 3 classes variance and standard deviation values are 11,81- 3,44, 48,33- 6,95, 19,44- 4,41, 39,48- 6,28 respectively. Thus, these surface measurements’ accuracy level is relatively nominal compared to the others. Deviations in the measurements were determined by checking the locations and possible causes. Measurements points on Asphalt and Dark Grey Stone surfaces are examined to explain the high deviations in the measurements.

Asphalt: Measurement points on asphalt surfaces are affected by the buildings' shadows. Due to measurement time (12:00), the building shadows have just moved away from some measurement points, and the cooling effect created by that canopy can continue. Therefore, the standard deviation between the measurements was high, but it is expected.

Figure 3.12 The surface temperature measurement points (cyan points) on asphalt surfaces (red surfaces)

Dark Grey Stone (shade): The measuring points on dark grey natural stone surfaces are located in two types of surroundings. The first is densely vegetated green areas, and one or two trees shade the other surrounding. Therefore, the points near green areas are cooler than the other measurement points.

Figure 3.13 Measurement points (cyan points) on dark grey natural stone surfaces (striped area)

Similarly, Gray Stone (sun) points are affected by features of the surrounding areas. However, the issue in Pool 3 is different. The pools in the area are separated into 3 groups according to their volumes. The third group has the smallest water volume and evaporates from water pools as measurement days pass. Water temperatures increased by increasing water temperature ranging from the sun as the volume of water decreased, and water temperatures increased and caused a deviation in the measurement.

The emissivity of the surfaces

Land surface emissivity (LSE) is one of the most significant parameters to measure LST. The potential LST error due to a 1% uncertainty in surface emission can reach up to S4˚K (Yin et al., 2020). For dry, bare fields, the effect of surface emission on the LST is even more significant and needs to be checked for accuracy. The emissivity values of the surfaces are essential for the accuracy of the measurements to be high.

As shown in Table 3.6, the emissivity values of all surfaces except the pebble surface are close to each other. Further, the surface temperature measurement device (Benetech GM300) utilized for the study's set emissivity value is 0.95, near the emissivity values of the square's surfaces. Therefore, solely the gravel surface's values were calibrated using the equation given in Formula 3.1 for temperature correction.

$$\frac{Q}{t} = \sigma e A T^4$$

Formula 3.1 Stefan-Boltzmann law of radiation (Source: Modest, 2013)

Table 3.6 Emissivity values of the surfaces in Taksim Square

Surface Type	**Emissivity**
Cobblestone (Sun)	0.85
Asphalt	0.93
Asphalt (Shade)	0.93
Bushes	0.98
Combined Pavement (Shadow)	0.94
Dark Gray Marble (Sun)	0.90 - 0.95
Dark Gray Stone (Shade)	0.90 - 0.95
Dark Gray Stone (Sun)	0.90 - 0.95
Dark Gray Stone Seat (Shade)	0.90 - 0.95
Dark Gray Stone Seat (Sun)	0.90 - 0.95
Flower	0.96 - 0.98
Grass Field (Shade)	0.96 - 0.98
Grass Field (Sun)	0.96 - 0.98
Gravel	**0.28**
Gray Stone	0.90 - 0.95
Gray Stone (Ladder)	0.90 - 0.95
Gray Stone (Shade)	0.90 - 0.95
Gray Stone (Sun)	0.90 - 0.95
Lıght Gray Stone (Sun)	0.90 - 0.95
Marble (Shade)	0.96

Table 3.7 (cont'd)

Marble (Sun)	0.96
Marble Stairs	0.96
Metal Grill	0.87 - 0.95
Metal Sheet (Cover)	0.87 - 0.95
Pool (Empty)	0.90 - 0.95
Red Kids Playground Cover	0.94
Red Surface	0.94
Refuge Wood (Shade)	0.935
Refuge Woodship (Sun)	0.935
Tree	0.984
Swimming Pool	0.95 - 0.963
Wood (Shade)	0.935
Wood (Sun)	0.935

3.3 Methods for LST analysis

After the pre-processing of the data, creating three different surface models in 2D, the classification of the surfaces, the measurement, and calibration of the surface temperatures, the LST analysis was carried out. As mentioned previously, due to the scale of the study (1/500), the methods commonly used for analyzing LST in the literature were not used in this study for the validity of the results. Again, as mentioned previously, remote sensing is widely used to determine the land use and changes in land cover and use (Kavzaoğlu ve Çölkesen, 2011). Thus, remote sensing is successfully used to determine the LST values and changes and investigate their effects (Yomralıoğlu, 2000; Arca, 2012; Liu et al., 2014). However, the study examines the impacts of design elements in Taksim Square (approximately 210 m^2), and even the highest-resolution satellite image (3m) cannot serve the study. Therefore, the surface temperature of the square was measured, and a method was developed to create the LST model according to these criteria.

The objectives in the development of this method are listed as follows:

- Providing a practical and cost-effective LST model to experts working in the field of urban design and urban planning

- The accuracy of the LST model is high and close to reality while maintaining the simplicity of the process
- Comparing LST models with each other and evaluating with impact analyzes.

The steps followed in the developed method are presented in Figure 3.14.

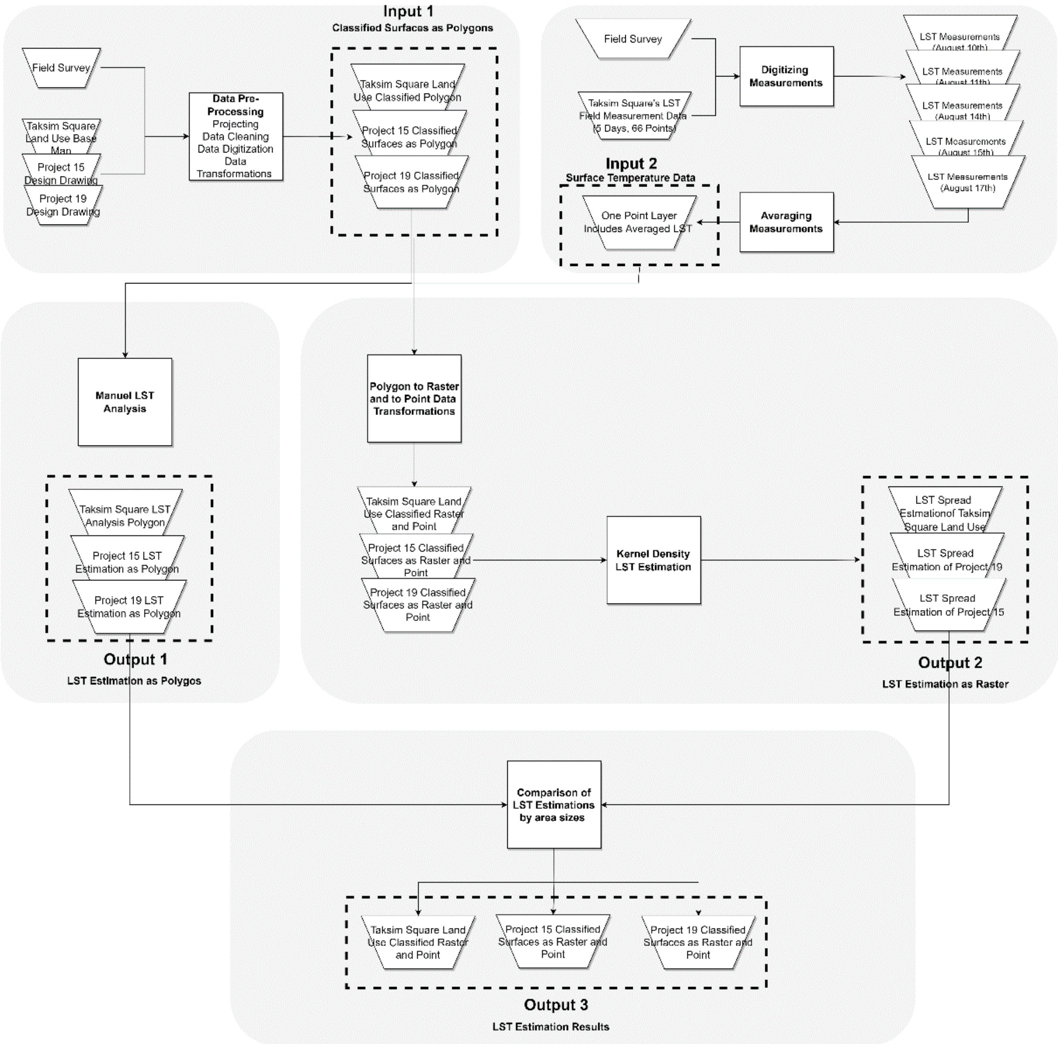


Figure 3.14 Stages of LST analysis method developed

The data pre-processing, surface classification parts, and LST field measurements are explained under 3.1. and 3.2. titles. In this part of the chapter, LST analysis and the comparison methods of the models are provided in detail.

3.3.1 Manual surface type identification

After data pre-processing and digitizing processes, polygon formats were created according to the determined surface classes of Taksim Square, Project 15, and Project 19. The temperature values of the points were averaged by overlaying 5 different point layers belonging to 5 different days containing the digitized surface temperatures. The averaging process is performed in the ArcGIS application. As a result of the averaging, the temperature values based on the LST analysis of land use were obtained (see Figure 3.15.).

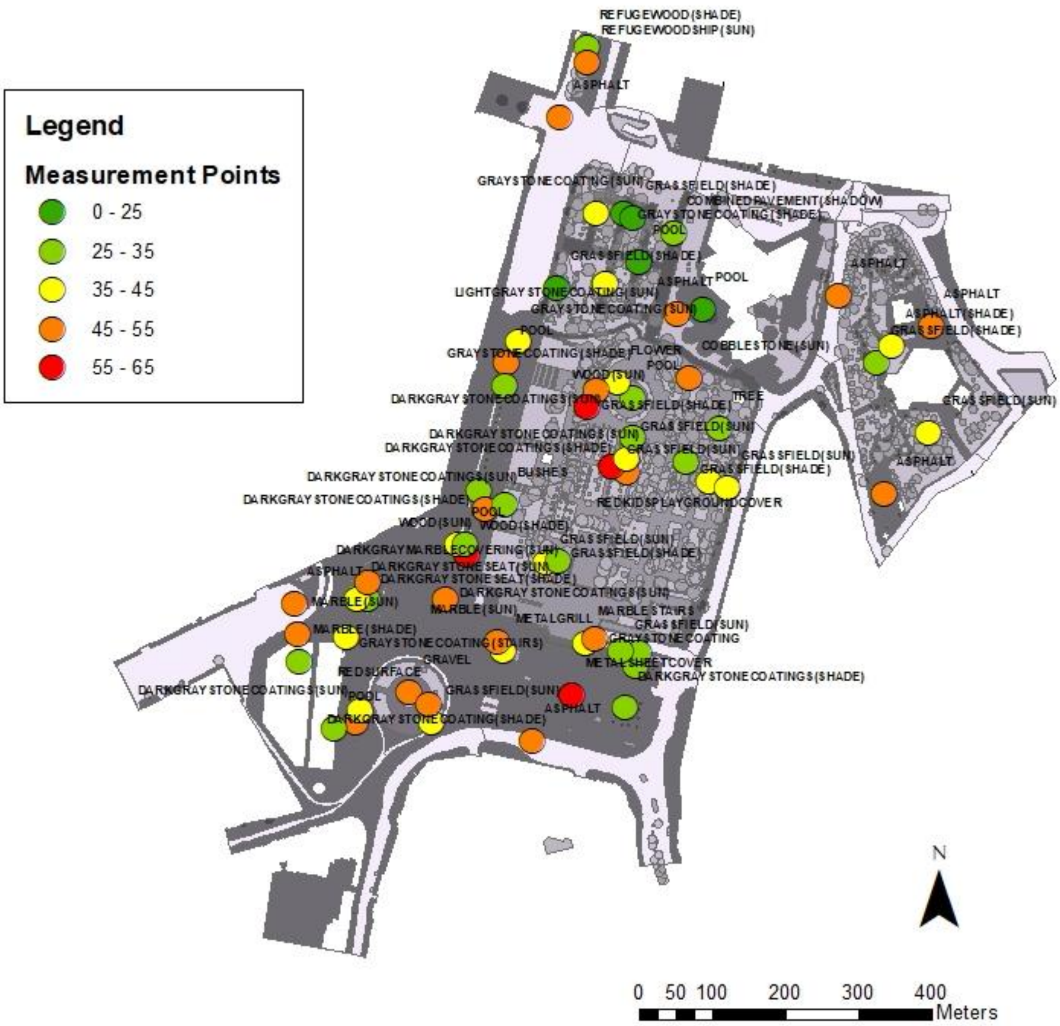


Figure 3.15 Taksim Square measurement points and their temperature values with surface types as labels

Thus, each averaged point provided the temperatures for each classified surface. For example, for the Asphalt (Sun) class, the temperature of 5 different days at the same point is accepted as 55.5 degrees. This temperature was then manually assigned to each Asphalt (Sun) surface in 3 planes classified by polygons for LST analysis. Thus, different surface temperature values were obtained for Taksim Square, Project 15, and Project 19 (see Figure 3.16).

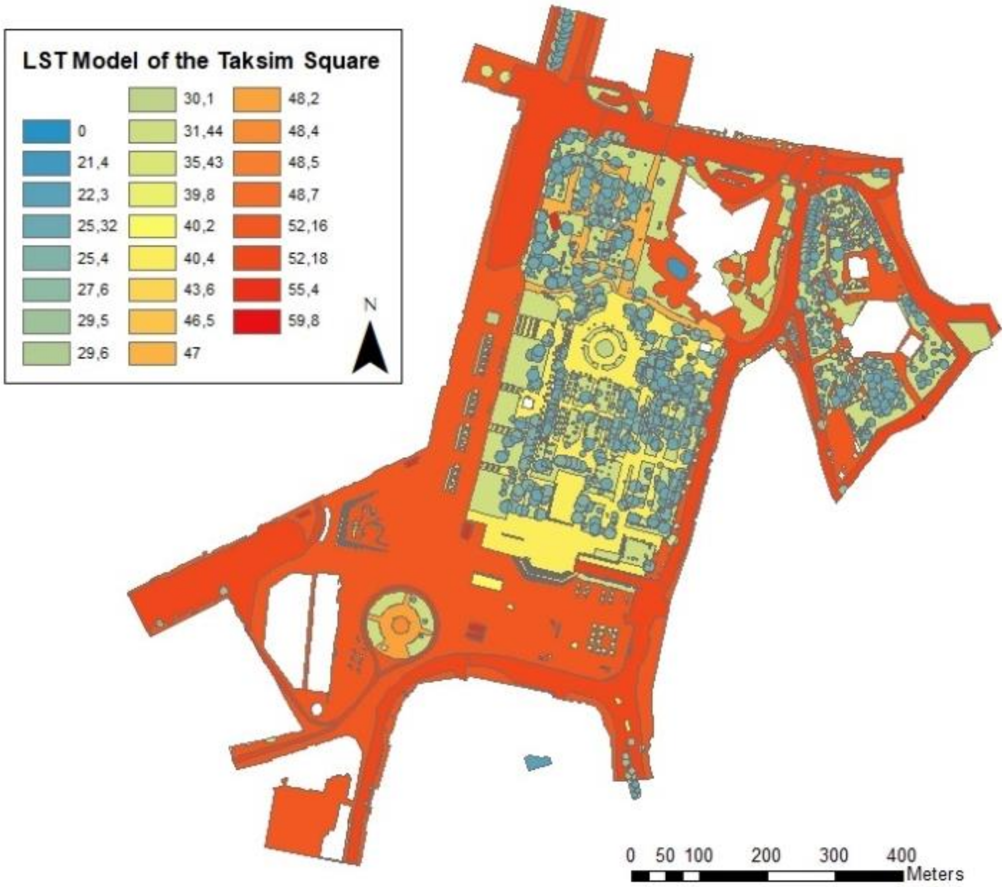


Figure 3.16 Taksim Square LST model

3.3.2 Kernel density analysis

After the surface temperatures were defined and modeled on the polygons, the diffusion model was created since the temperature is an energy that can spread. In addition, both polygons and smoothed measurements were used to obtain a highly accurate analysis comparing the LST values of the plans. Estimation was made using the Gaussian Kernel Density tool of the ArcGIS program over Point Density and Line Density.

The difference between the Point Density and Line Density tools is that the former applies to point properties and the latter to linear properties. Calculates the amount specified by the Population area, both of which enter the specified neighborhood, and divides this amount by the neighborhood area (ESRI, n.d.).

The main difference between these two tools' output and the Core Density's output is that a specified neighborhood calculates the population's density around each output cell in the dot and line density. The core density radiates the general population for each location, analogous to heat dissipation. The resulting surfaces surrounding each point in core density are based on a quadratic formula with the highest value at the center of the surface (point location) and tapering towards zero at the search radius distance. For this reason, the Kernel Density tool of the ArcGIS application was preferred to calculate the LST spread in the area (ESRI, n.d.). Since the analysis resolution is 1 meter, the cell size was determined as 1 meter while performing the Kernel Density analysis (see Figure 3.17).

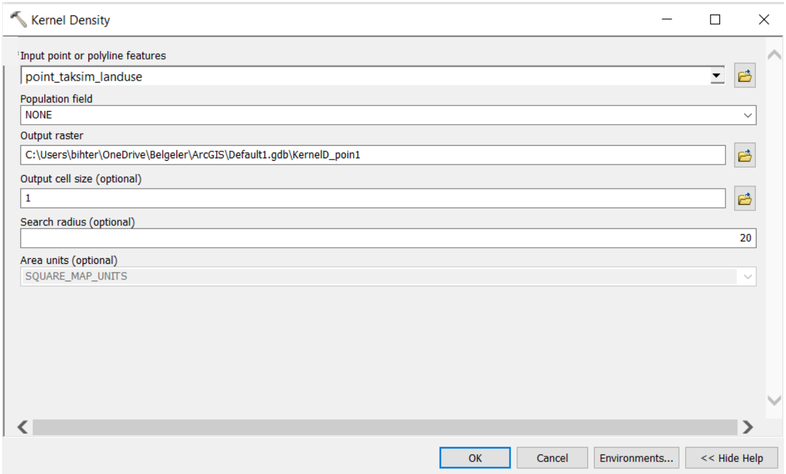


Figure 3.17 ArcGIS, Kernel Density analysis input variables for LST analysis

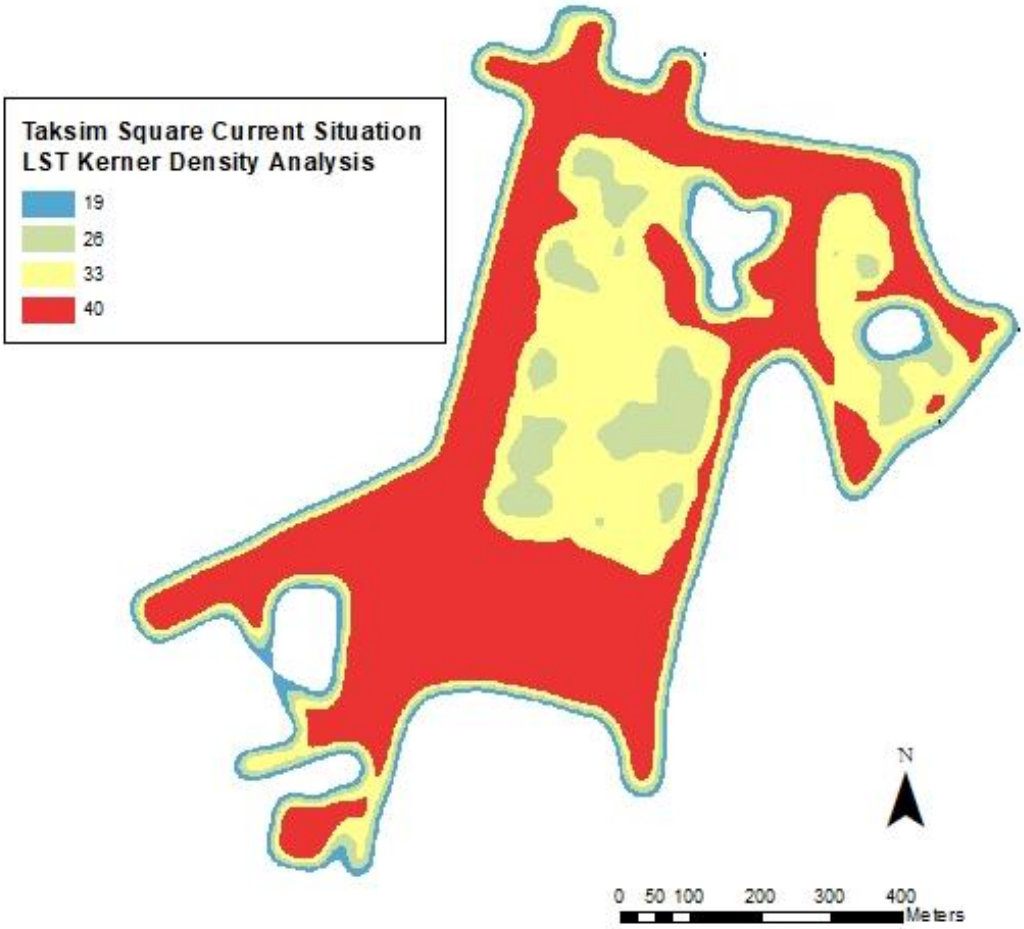


Figure 3.18 LST Kernel Density analysis of Taksim Square

Kernel Density analysis requires point class input data for processing. Thus, the three LST models' polygon format is first transformed into raster and then point format with temperature values and processed. The kernel density analysis of Taksim Square's land use LST analysis is shown in Figure 3.18. Different colors can understand the effect of different surface distributions on the temperature. The temperature distribution of the area is also quite different in the 3 plans.

3.3.3 The application procedure of the developed method

One of the thesis aims is to develop a practical and low-cost method for analyzing the LST parameter in the urban design process. Therefore, in this topic, the steps to be followed by an expert who wants to make LST analysis in the urban design process are presented.

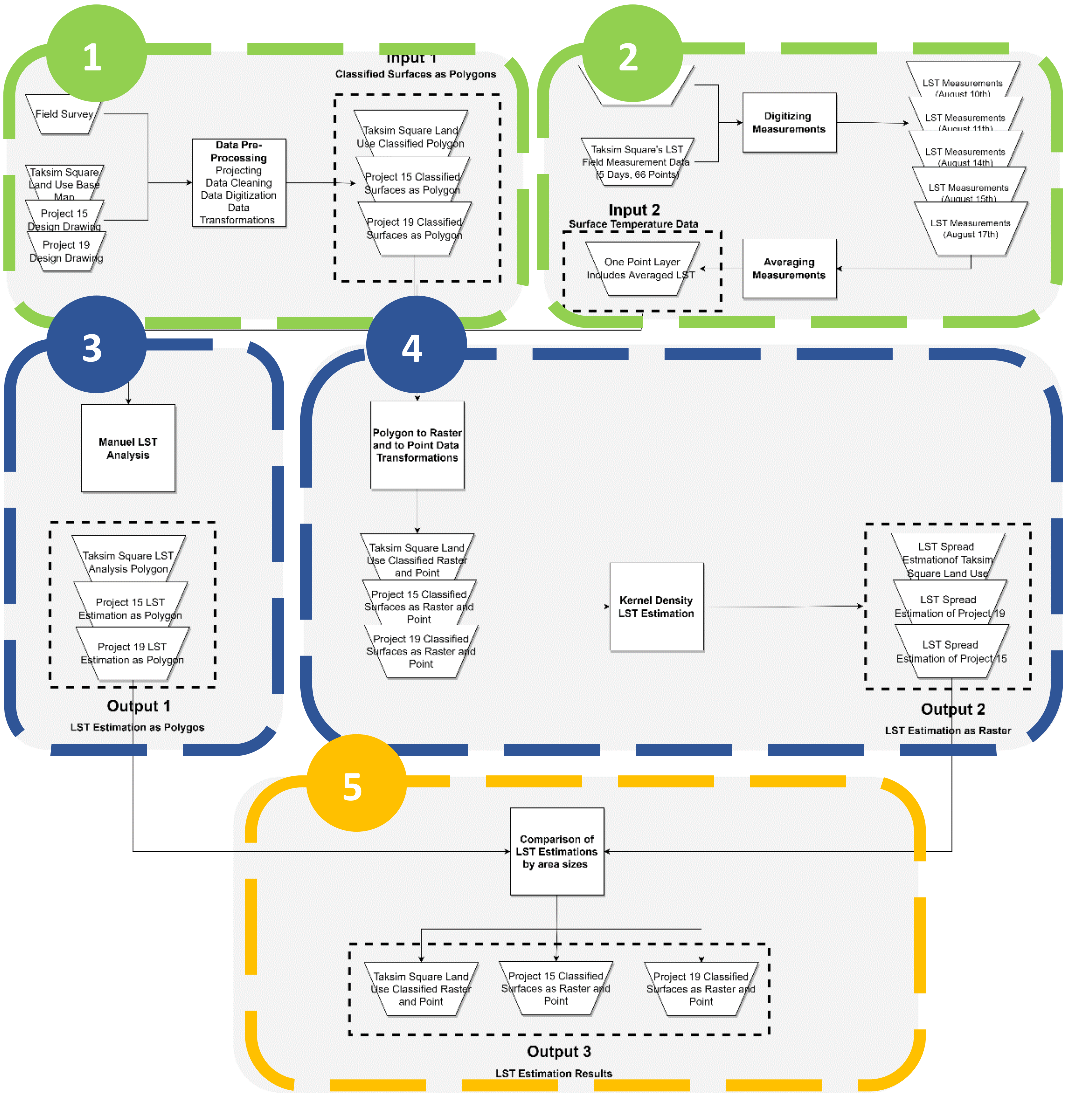


Figure 3.19 Flowchart's main parts for the procedure in LST estimation method

The five basic processes mentioned in the procedure section of the flowchart, where the LST estimation model is explained, are emphasized (see Figure 3.19).

Procedure

The stages that the developed LST Estimation Model must be followed to guide an urban design process are listed under five main headings. In preparation for the LST analysis, the following should be done;

- The effects of climate change and urban warming on the designed city should be evaluated, and the purpose of performing the LST analysis should be clearly defined
- The general climatic characteristics of the location where the LST analysis will be performed should be investigated to determine the date, time, and season

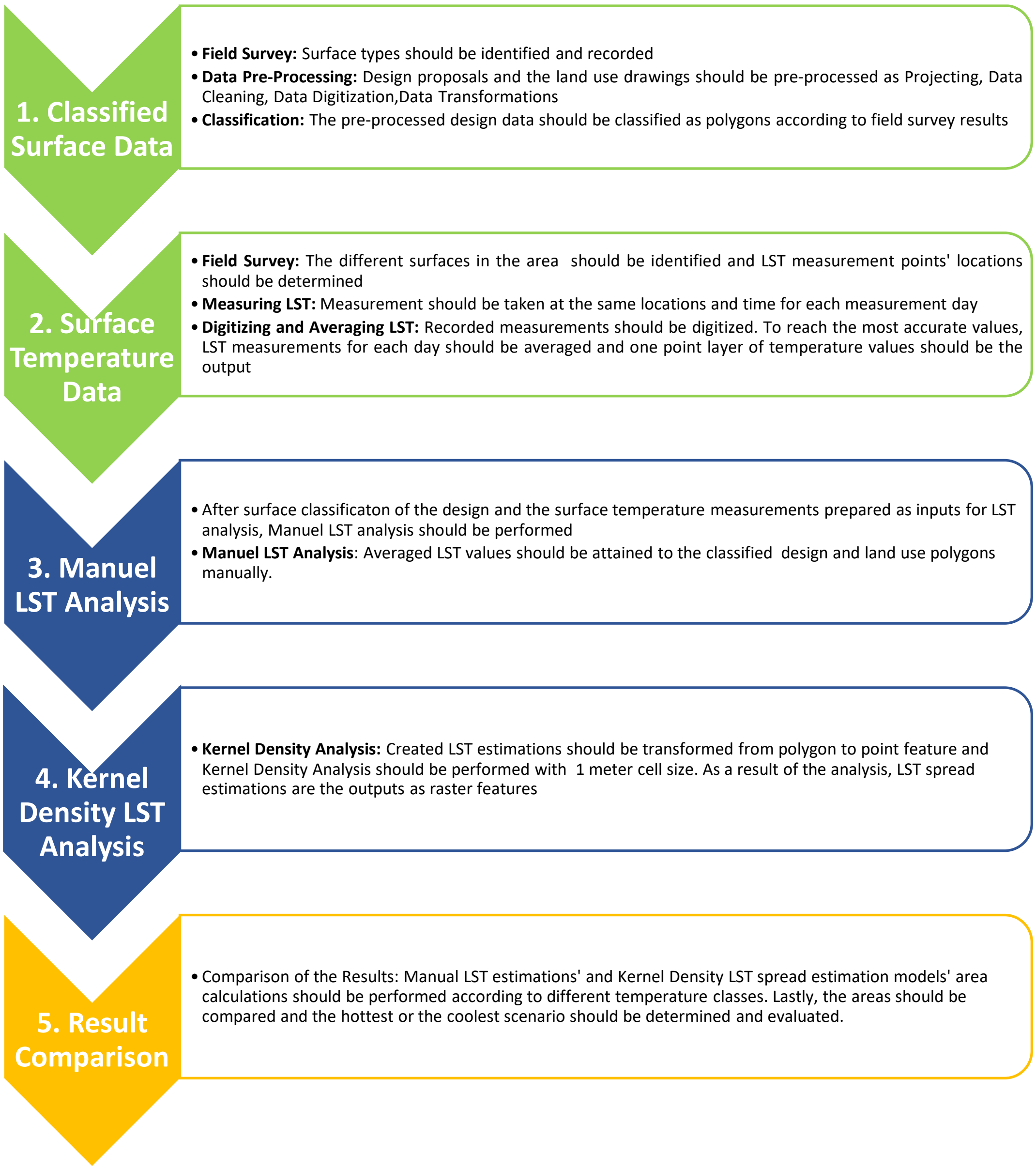


Figure 3.20 Procedure to implement LST Estimation Model in an urban design process

The procedure is given in Figure 3.20 can be used as a design control tool by adapting it to every urban design scenario in the world. However, this thesis study was carried out specifically for Taksim Square and the Urban Design Competition. In this case, the inputs and variables that are expected to be changed during the adaptation of the method applied in the study to other studies are listed;

- Impacts of climate: As mentioned before, the climatic conditions seen in the urban design area are important in strategy development in the preparation phase, as they will guide the whole study.
- Urban geometry: Urban geometry was transferred to 2D and evaluated shading. However, in cases where the design of the buildings can be changed, building shadows can also be added by reflecting the area shaded by the trees on the surface in the study. However, the effect of the wind variable on surface temperatures should be studied separately and added to the analysis.
- Urban furniture: Since it covers less than 1% of the area in this study, it was included in the study, but it was not reflected in the results and could not affect the results. Since the effects of urban furniture on surface temperature will also differ according to designs, it may need to be considered in future studies.

Concluding Remarks

This chapter provided background information about the study area. It discussed the surface temperature field measurements, data collection, and methods used for the LST analysis. LST models and estimations of Taksim, Project 15, and Project 19 were obtained as a result of the analyzes. One of the aims of the study is to compare these three results. In the next chapter, the the findings of the study presented.

CHAPTER 4

RESULTS

This study's main purpose is to emphasize the importance of LST in the urban design principle and integrate it as a design control mechanism to the urban design process. The major obstacle to achieving this goal is the absence of a commonly used LST analysis method at 1/1000 and 1/500 scales. In this context, developing a practical and low-cost LST modeling method in high-resolution LST analysis in the urban design process and by using the developed method, evaluating LST differences between two projects of Taksim Square Urban Design Competition and the land use of Taksim Square are the two main research objectives.

The effects of different surfaces on the LST and the details of the LST analysis method developed within the scope of the study are presented in Chapter 2 and Chapter 3, respectively. In this chapter, the surface temperature results of three plans obtained from the developed method are evaluated (one plan showing the existing situation and the other plans showing the proposed designs for the chosen areas). The results were evaluated by answering the following research questions asked within the scope of the study.

1. Which physical environmental attributes of the land use of Taksim Square affected the land surface temperature?
2. Compared to the land use, do the two projects, which made it to the finals in the design competition, positively affect the LST values in Taksim square?

In this chapter, firstly, the surface elements that impact the LST values of Taksim Square, Project 15, and Project 19 are defined, and their effects are evaluated. The results of the LST analysis were compared. It has been evaluated whether the LST values of the finalist two projects are advantageous to the land use of Taksim.

4.1 LST analysis of the land use of Taksim Square and two proposed design projects for this area: Project 15 and Project 19

According to selected methods and parameters, the LST models and estimations analyzed after the measurements made in Taksim Square are expressed in two ways. The first is created by assigning measured temperatures to polygons formed according to different surface materials, as shown in Figures 4.1, 4.2, and 4.3. The surface temperatures are specified in these maps as precise lines defined over the polygons. The surface temperatures increase as the color distribution goes from blue to red.

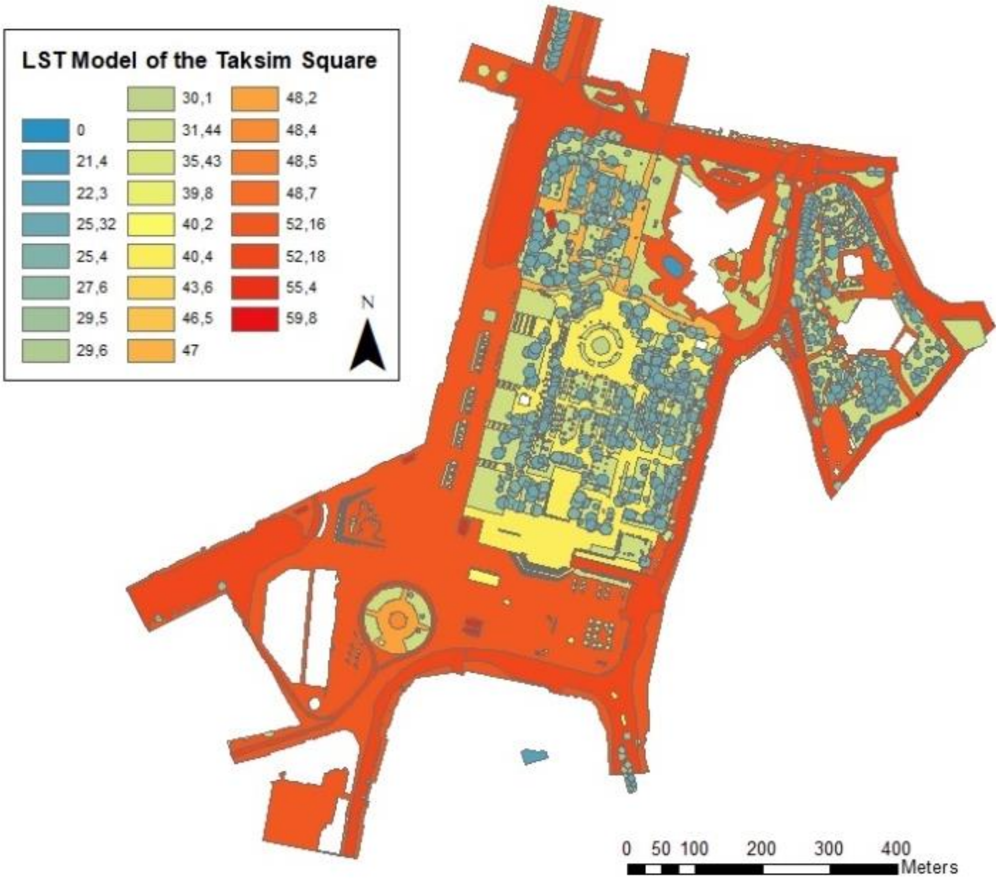


Figure 4.1 LST Model of Taksim Square

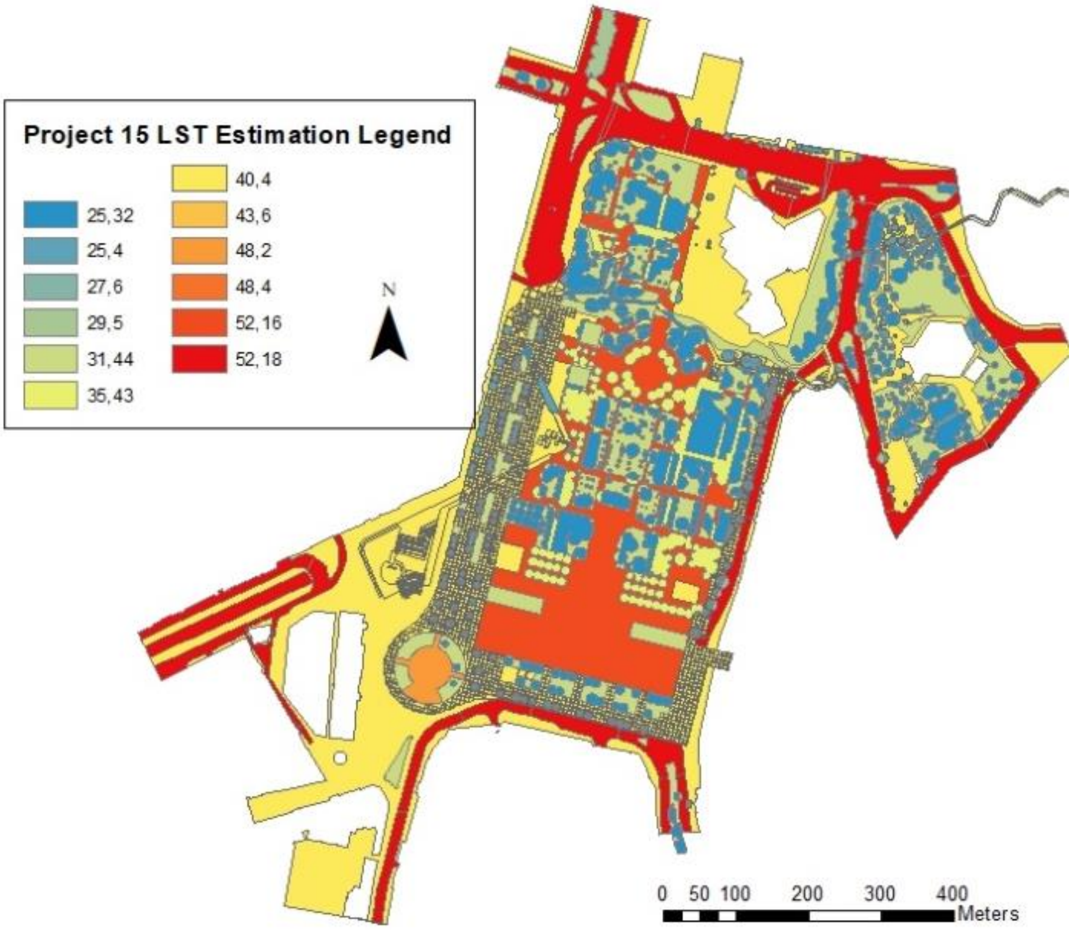


Figure 4.2 LST Estimation of Project 15

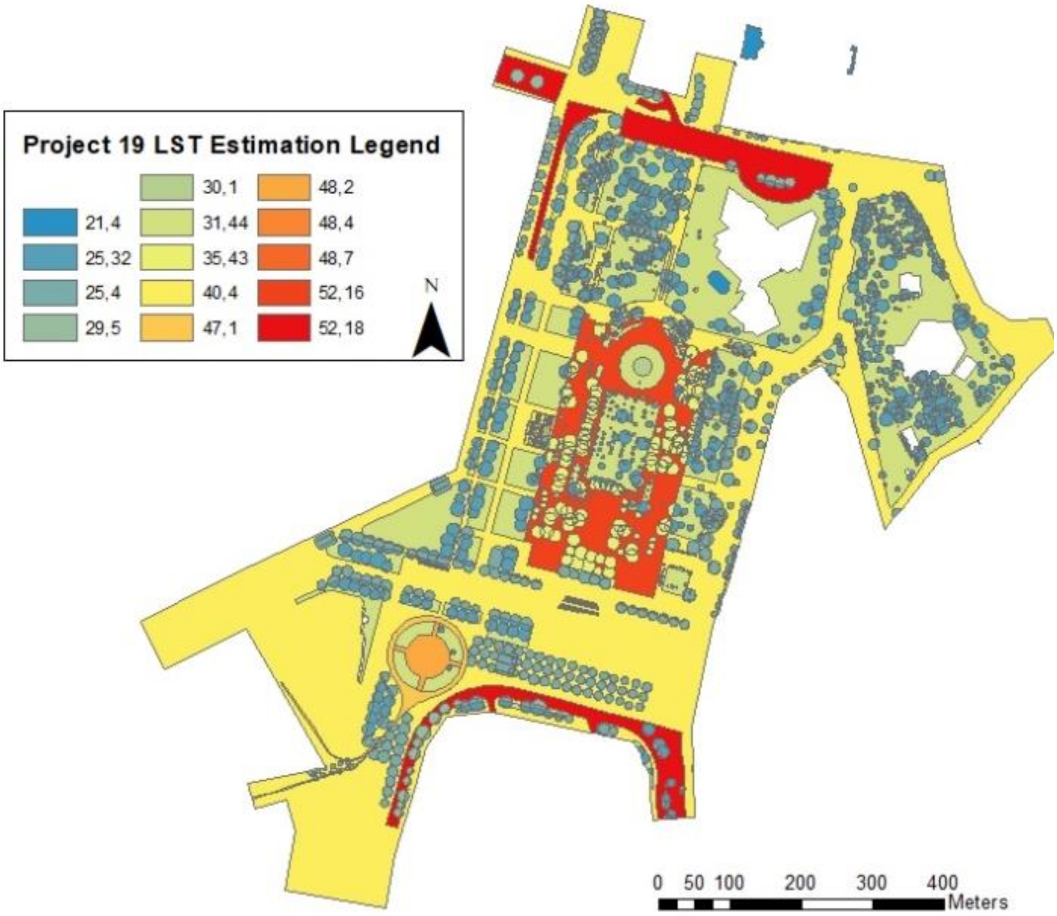


Figure 4.3 LST Estimation of Project 19

As observed from the red color distribution differences of the LST analyses, the plan with the highest LST is the land use of Taksim Square. The surface temperatures of Project 19 are lower than other plans. However, to make a numerical comparison, the area calculations of the models and estimations were made. The temperatures of the LST analyses, whose surface elements are defined as polygons, are divided into 4 groups and classified. These classes are 19-25 Degrees, 26- 32 Degrees, 33- 39 Degrees, and 40 - 55 Degrees. The area sizes of the polygons belonging to these 4 temperature classes were calculated for all three plans. The results are shown in pie charts (see Figure 4.4). As illustrated in the charts, the land use of the Taksim Square has the warmest surfaces (69% of the area is between 40°C and 55°C), and the Project 19 has the coolest surfaces (only 13% of the area is between 40°C and 55°C). Parallel to these findings, the surfaces between 19°C and 25°C are the largest in Project 19. Compared to the temperature range groups, most of the surfaces in Project 15 (which received the highest public vote count in the selection process of the winning project) are in the 30°C - 40°C temperature range. To sum up, with the preferred methods and variables in the developed model, the Project 15 design is cooler than the land use of the square but warmer than Project 19. As a result of the analysis made according to the polygons, it is seen that the most successful design in terms of LST parameters belongs to Project 19.

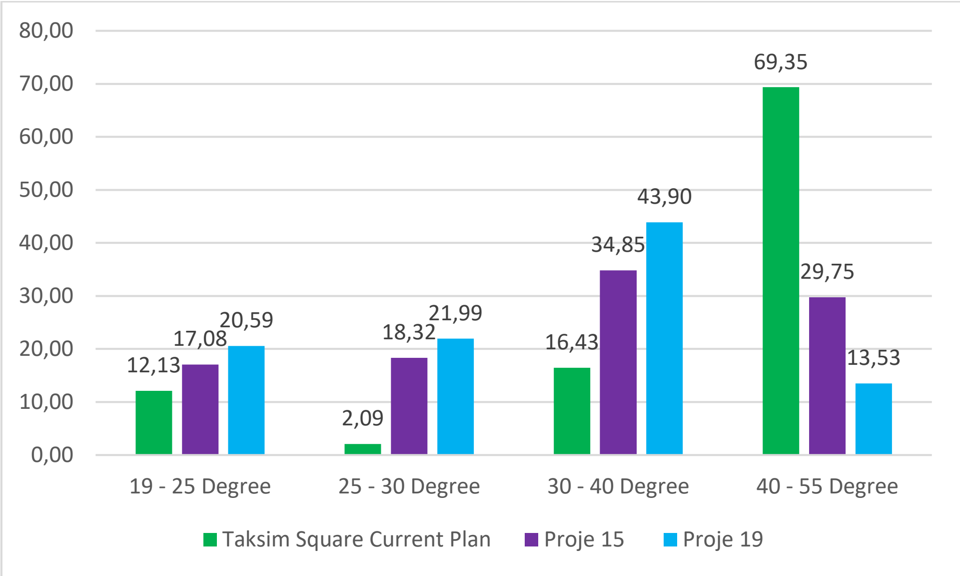


Figure 4.4 LST Area Analysis of Taksim Square plan, Project 15, Project 19

Kernel Density analysis was performed in addition to the polygon analysis, as the heat energy spreads from the higher to the lower temperature among the materials. Thanks to Kerner Density, the spread of surface temperatures with reference from the measurement points was also modeled and estimated (see Figures 4.5, 4.6, and 4.7). While analyzing and mapping, surface temperatures are divided into seven classes. According to the classification, the hottest surface is colored red, and the coldest surface is colored blue.

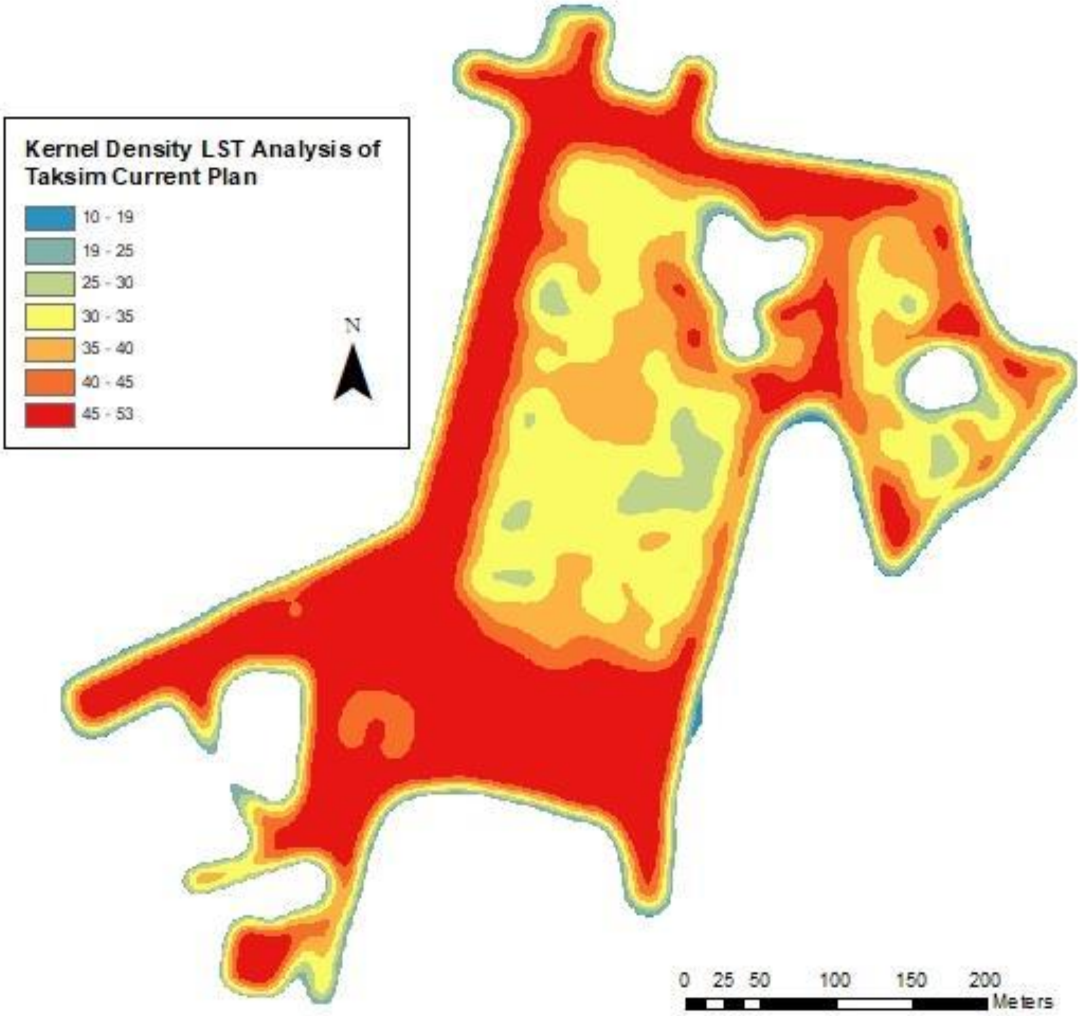


Figure 4.5 Taksim Square Kernel Density analysis of LST

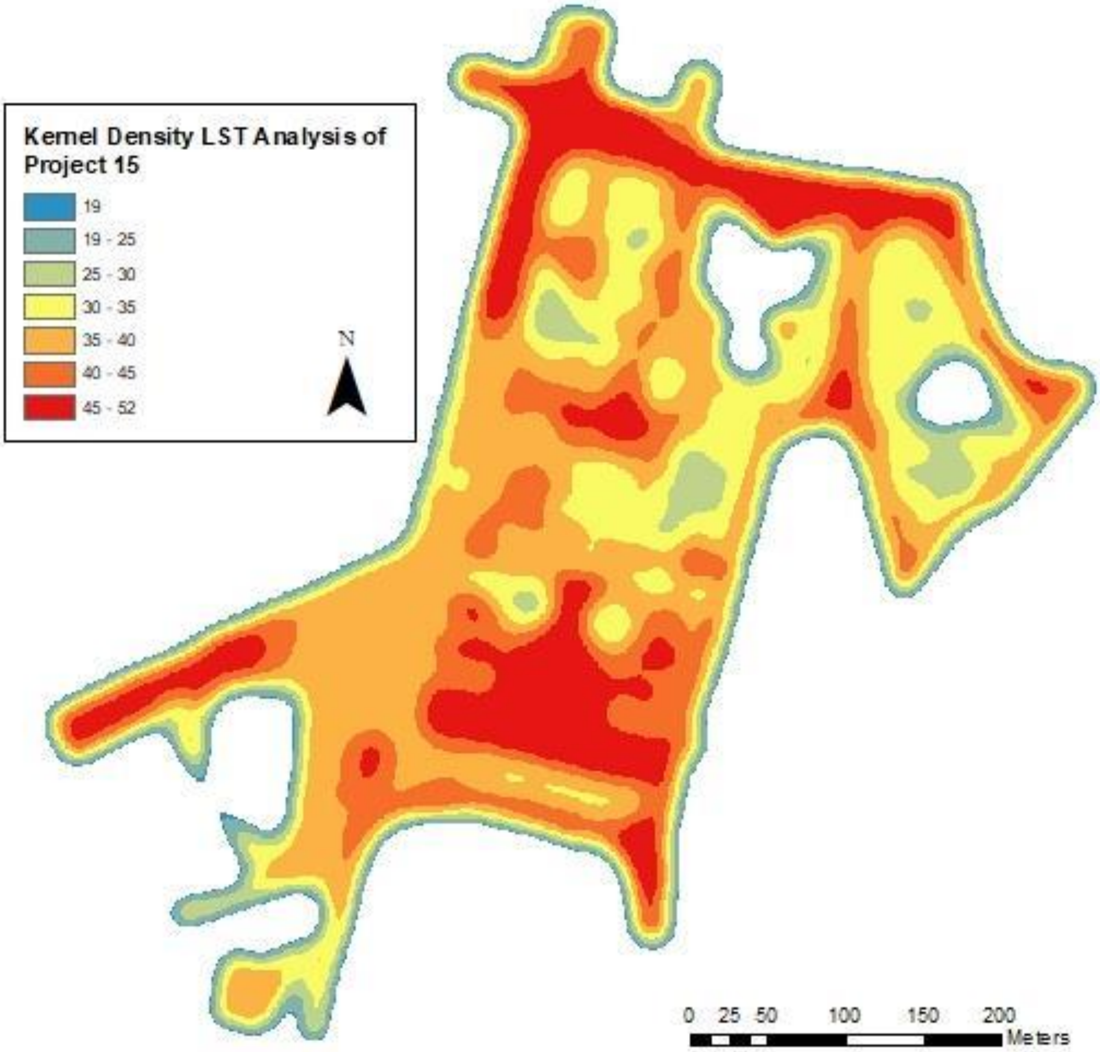


Figure 4.6 Project 15 Kernel Density analysis of LST

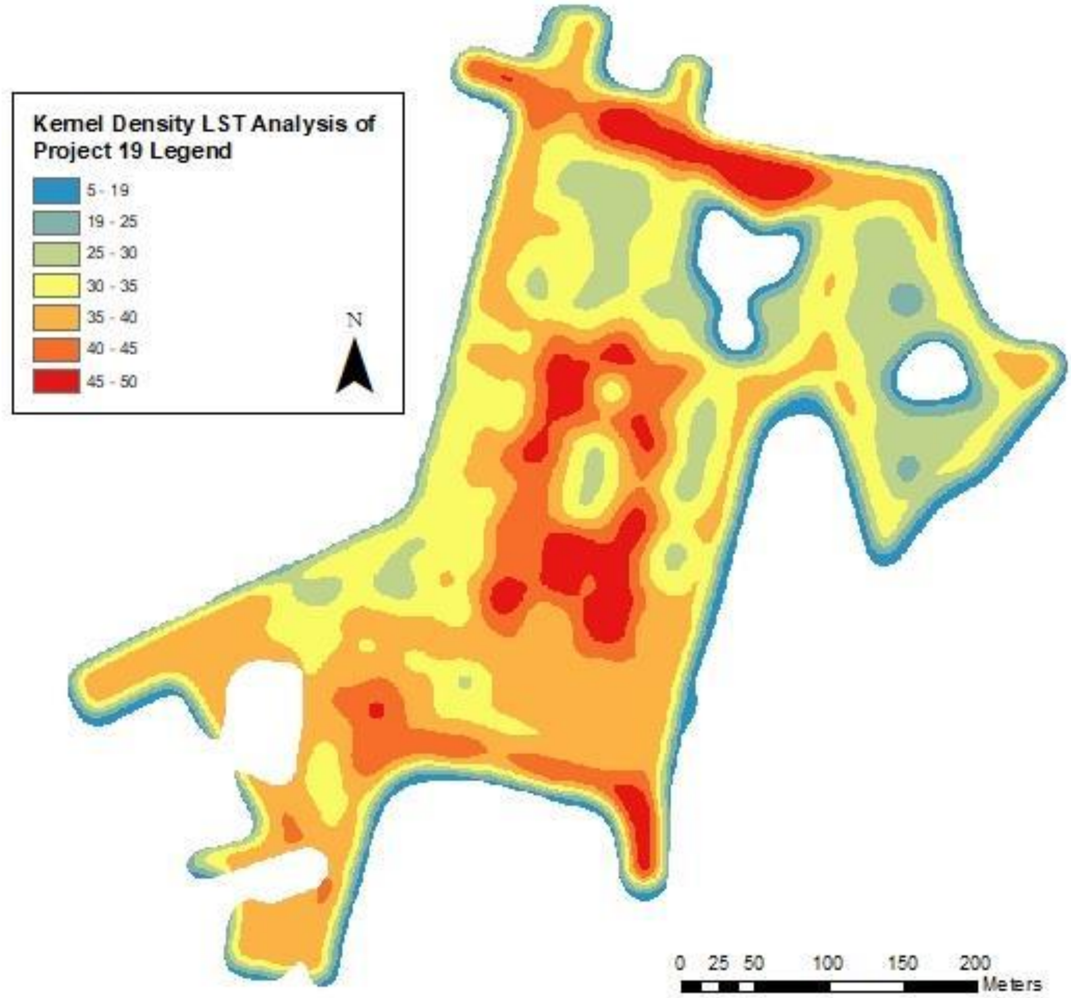


Figure 4.7 Project 19 Kernel Density analysis of LST

As the LST analysis defined over polygons, the results did not change in the LST models and estimates analyzed with the Kernel Density tool. The maps show that Project 19 is the coolest design, with the majority of the surface being yellow and green colors by 5 °C to 35 °C. However, the land use of Taksim Square has the hottest LST distribution, with the majority of the plan being in the red and orange coloring by 40°C to 50 °C.

These results, which can be deduced from the maps, are also supported numerically by the field analysis. The field analysis results are shown in Figure 4.8 with pie charts. According to the graphics, the plan with the hottest surface is the land use of

Taksim Square, with 49% of the total surface area having a temperature between 40℃ and 55℃. It is followed by Project 15, 39% of the surface area with temperatures between 40℃ and 55℃. The coolest surface was again in Project 19, with only 26% of the surface area having temperatures between 40℃ and 55℃.

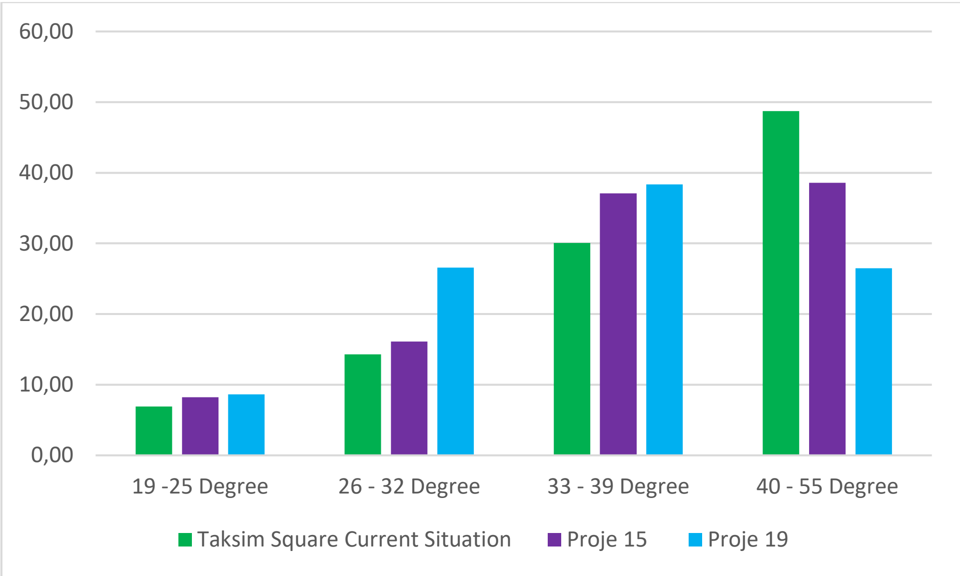


Figure 4.8 LST Kernel Density area analysis of Taksim Square land use, Project 15, Project 19

The LST values of Taksim Square's land use, the winner Project 15, and the runner-up Project 19 were analyzed. According to the common result of the analyses, the hottest surface belongs to the design of Taksim Square; Project 15 is the second warmest design, while Project 19 is the design having the coldest surfaces. These differences are based on the distribution of the surfaces and design elements used in the plans and the material selection. Therefore, it should be discussed how the surface elements evaluated in detail in Chapter 2 differ in these 3 different designs.

4.2 Surface elements' impacts on LST

As stated in Chapter 2, within the scope of the study, there are mainly four elements that affect the LST in the urban design resolution: vegetative surfaces, water elements, and hard surface materials. These surface areas, Taksim Square's land use, Project 15 and Project 19, LST analysis results were evaluated.

4.2.1 Surface elements of Taksim Square's impacts on LST

According to the LST analysis performed with certain parameters, Taksim Square has a higher surface temperature than the other two projects, and the surface analysis reveals the reasons for this. Percentage distributions of the surface elements of Taksim Square are given in Figure 4.9. When the graph is examined, it is seen that the surface that takes up the most area is hard surfaces, with a rate of 78%. The area with the second-highest percentage is vegetative surfaces with approximately 21%. The area occupied by the water element is approximately 1%. The effects of the surfaces on the square's current LST are examined in detail.

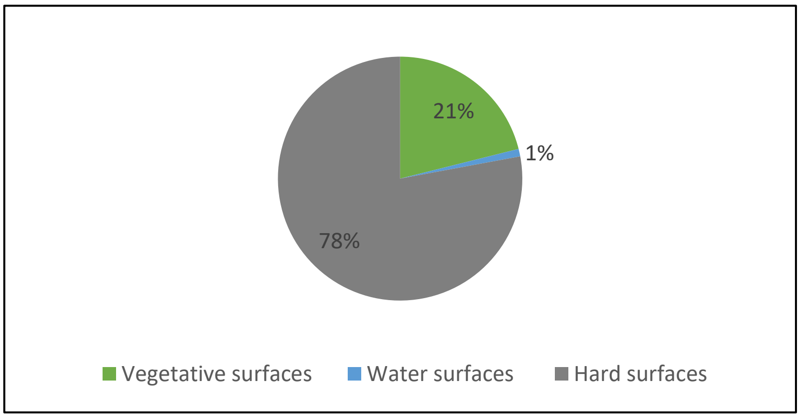


Figure 4.9 Distribution of the surface elements of Taksim Square

Vegetative Surfaces

The LST analysis, the grass surfaces of Taksim Square, and the plans showing the areas with trees were compared (see Figure 4.10). When examining the areas overlapping the vegetative surface on the map created with polygons, it was observed that the surface temperatures were minimum 21 degrees and maximum 35 degrees. Since vegetative surfaces show a cooling effect (ref), areas with temperatures in the range of 25-35 degrees expressed with yellow and green colors are vegetative surfaces, as seen even more clearly in the Kernel Density analysis. In addition, the temperature difference between the LST analysis created with polygons and the Kernel Density LST analysis is since Kernel Density analysis is a smoothening process. Thus, although there are differences between the temperature values, there is not much difference between the distribution.

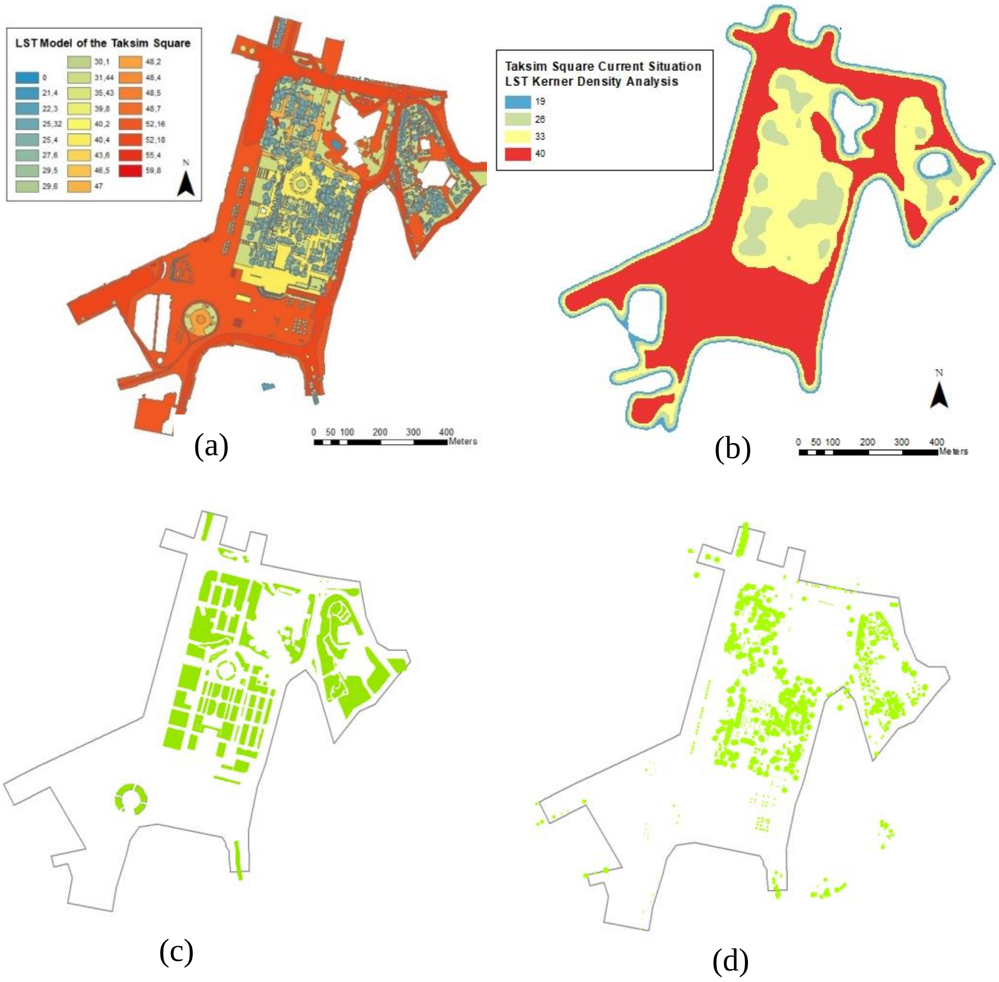


Figure 4.10 Taksim Square (a) LST analysis, (b) Kernel Density LST analysis, (c) grass surfaces, (d) trees

Water Surfaces

The water element is one of the design elements whose surface temperature is quite low in summer compared to other materials and has a cooling effect (Tominaga et al., 2015). However, the cooling effect is directly proportional to the volume of the water mass. The volume of the largest water body in Taksim Square is approximately 150 m^3. The cooling rate around the pool, which was about 1 meter high, was also very low (Bakar & Ariffin, 2012). For this reason, in the analysis of surface temperatures defined by polygons, although the surface temperatures are quite low where the water element is located, no effect was observed in the Kernel Density analysis where the water surface is located.

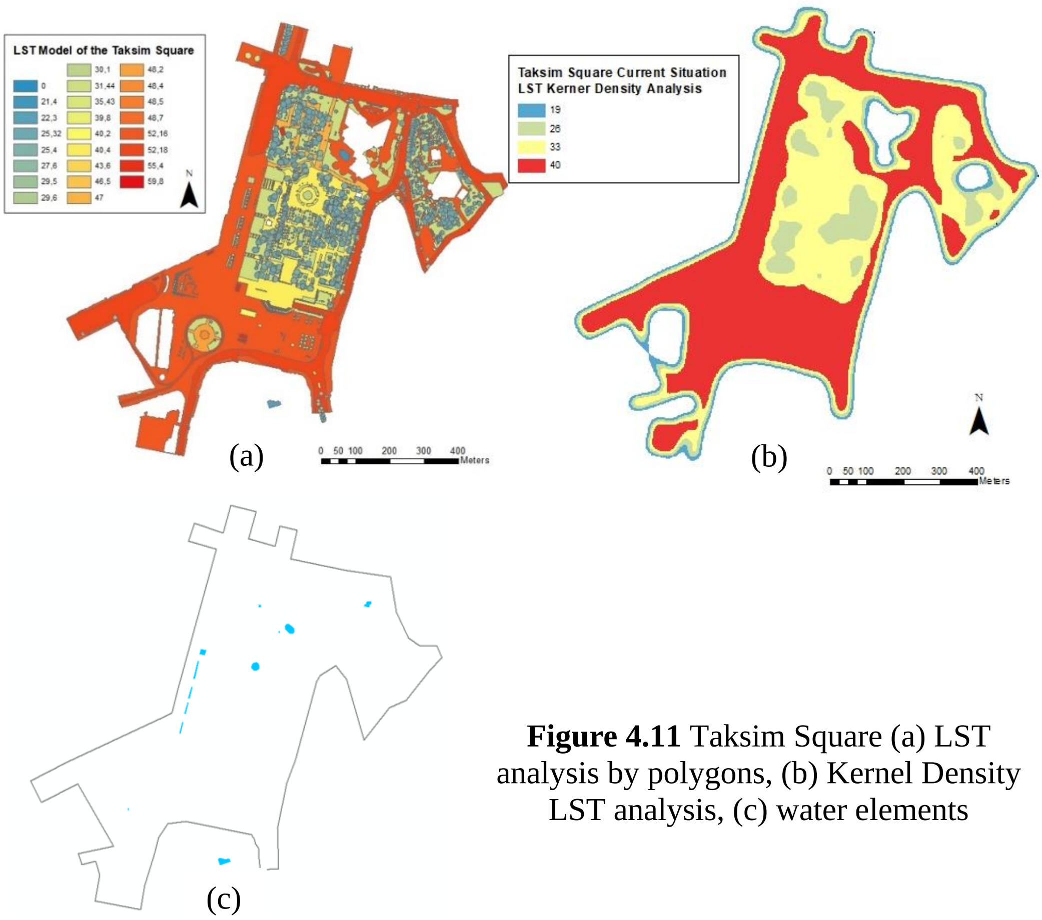


Figure 4.11 Taksim Square (a) LST analysis by polygons, (b) Kernel Density LST analysis, (c) water elements

Hard surfaces

The built surfaces in the design are divided into 3 classes according to their materials; asphalt, high albedo pavement, and low albedo pavement. However, in the land use of Taksim Square, in addition to these 3 hard surfaces, there is cobble, and it is included in the LST analysis.

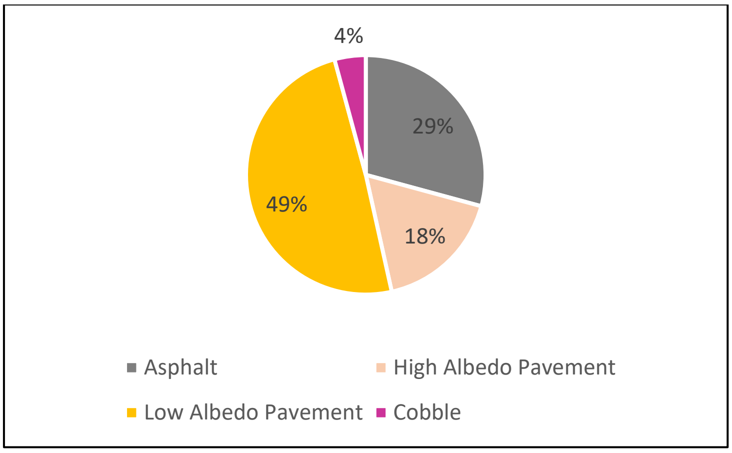


Figure 4.12 Taksim Square land use, hard surface types distribution

The utilization of low albedo pavement and asphalt is higher in the land use of the Taksim Square than in the other two competition projects. Due to this, the LST of the square's asphalt and low albedo pavement surfaces are between 40℃ and 53℃ (see Figure 4.12). The high albedo pavement and cobble have lower surface temperatures than the other hard surface types by 30℃ to 40℃.

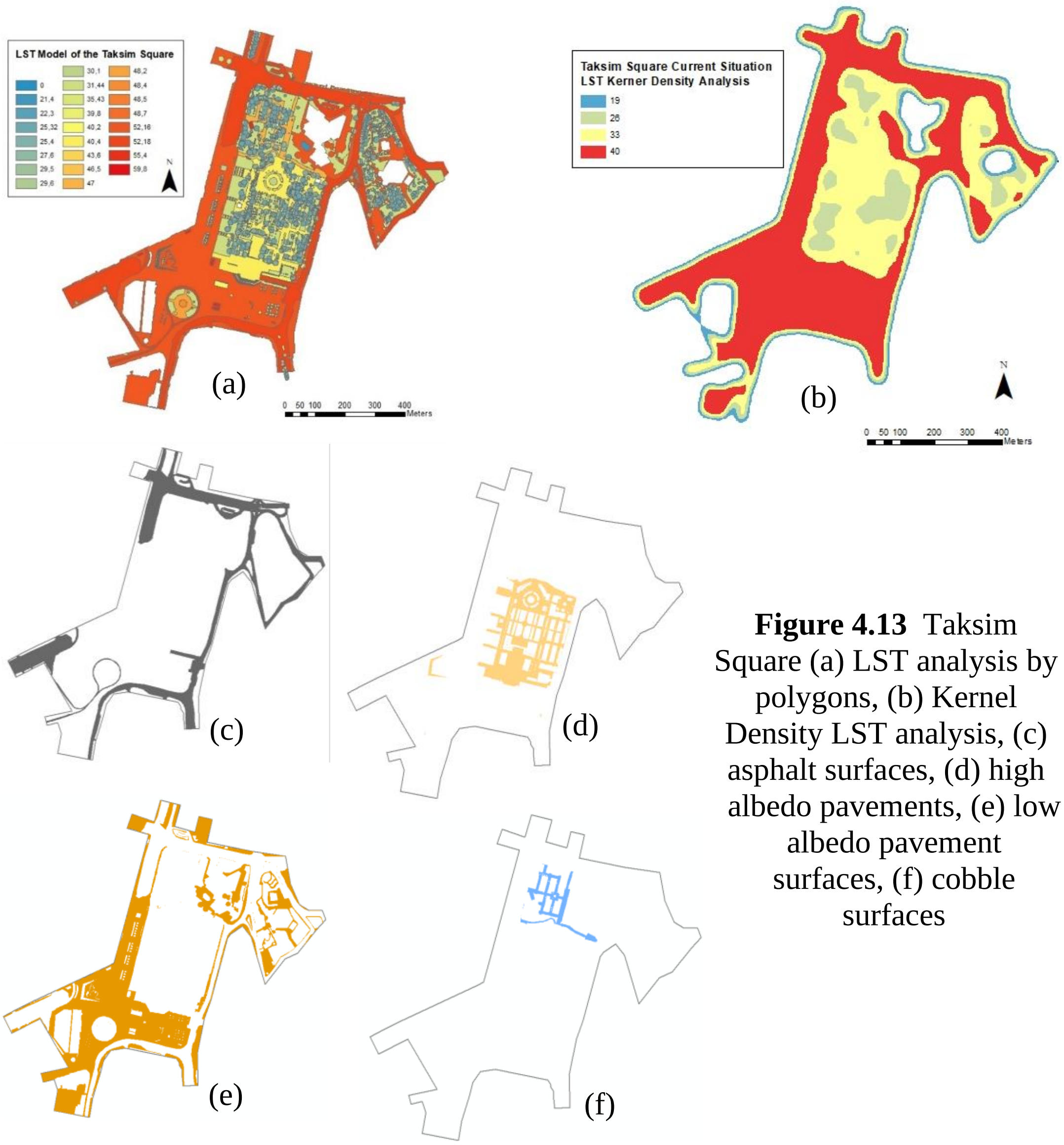


Figure 4.13 Taksim Square (a) LST analysis by polygons, (b) Kernel Density LST analysis, (c) asphalt surfaces, (d) high albedo pavements, (e) low albedo pavement surfaces, (f) cobble surfaces

4.2.2 Project 15 surface elements' impacts on LST

As a result of the LST analysis made with certain variables, comparisons made in Title 4.1, the LST of Project 15 is lower than the current surface temperatures of Taksim Square and higher than the surface temperatures of Project 19. This situation is caused by the distribution of the different surfaces and their areal sizes in designs. In this section, surface analyzes are evaluated through the vegetative, water, hard surfaces, and urban furniture that affect the LST in the square. However, since the water element is unavailable in Project 15, water surfaces could not be included in the surface analysis. The water element in Project 15 is the fountains placed for entertainment, aesthetics, and cooling purposes. However, it is difficult to measure the mass effect as these fountains and the water coming out of them do not form a field in the horizontal plane. The splashing of water sprayed in the vertical environment may have a cooling effect. However, there is no continuity of the water layer in the horizontal plane, and the cooling effect created cannot be measured. Thus, it is excluded from the equation in this analysis.

In the square design of Project 15, nearly 74% of the area is covered by hard surfaces, while approximately 26% of the square is green areas (see Figure 4.13). Unlike the other designs, an elevated pedestrian path has a shadow over the square. In addition to the tree canopy, the effect of this bridge was also included in the analysis. It was defined as an element that lowers the temperature with the shaded area it provides. This bridge provides shade for approximately 4% of the area, but since the analysis was 2D, it was not included in the surface analysis in Figure 4.13.

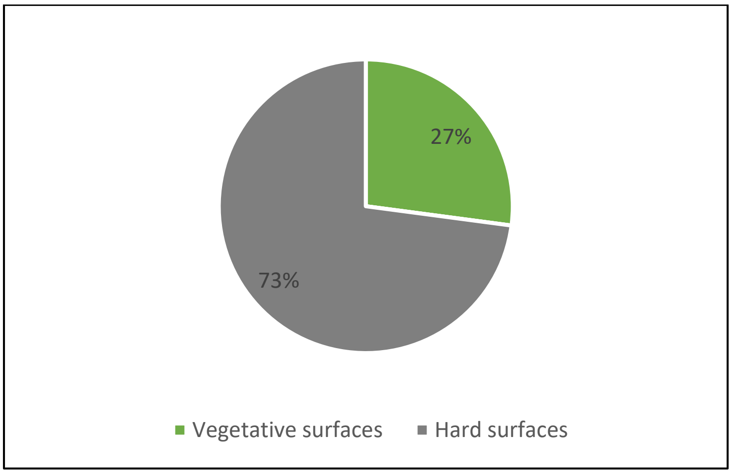


Figure 4.14 Distribution of the surface types of Project 15

Vegetative Surfaces

As can be seen from the color distributions in the LST analyses, the temperatures of the areas designated as grass areas with trees within the scope of Project 15 are between 25℃ and 35℃ in LST analysis by polygons. In the Kernel Density LST analysis, vegetative areas in Project 15 are between 25℃ and 40℃. As expected, areas designed as vegetative surfaces are the coolest surfaces represented by blue, green, yellow, and light orange colors on the map.

Figure 4.15 Project 15 (a) LST analysis, (b) Kernel Density LST analysis, (c) grass surfaces, (d) trees

Hard surfaces

The hard surfaces in the area are classified as asphalt, high albedo pavement, and low albedo pavement. The percentage of low albedo surface of all hard surfaces of the design is 52, the percentage of asphalt surfaces is 26, and the percentage of high albedo surfaces is 22 (see Figure 4.16).

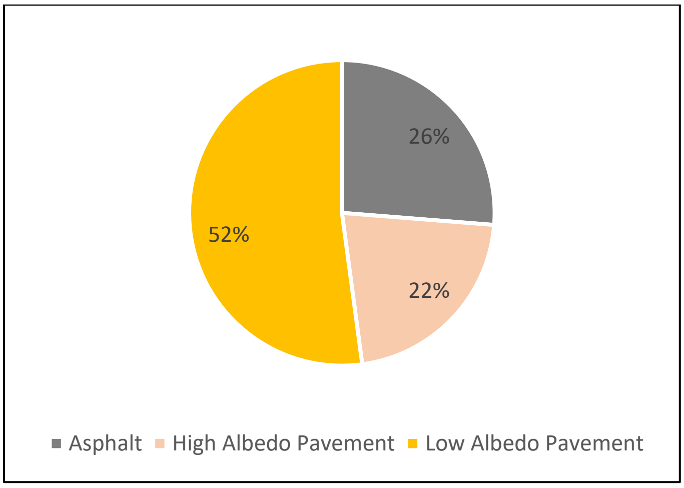


Figure 4.16 Distribution of hard surfaces in Project 15

Since the surface temperature of low albedo materials and asphalt is high (REF), the temperature of these areas varies between 48℃ and 50℃ in the LST analysis by polygons. In Kernel Density analysis, the temperatures vary between 40℃ and 52℃. The temperature of high albedo surfaces is between 35℃ and 40℃ in the LST analysis by polygons and the Kernel Density analysis (see Figure 4.17).

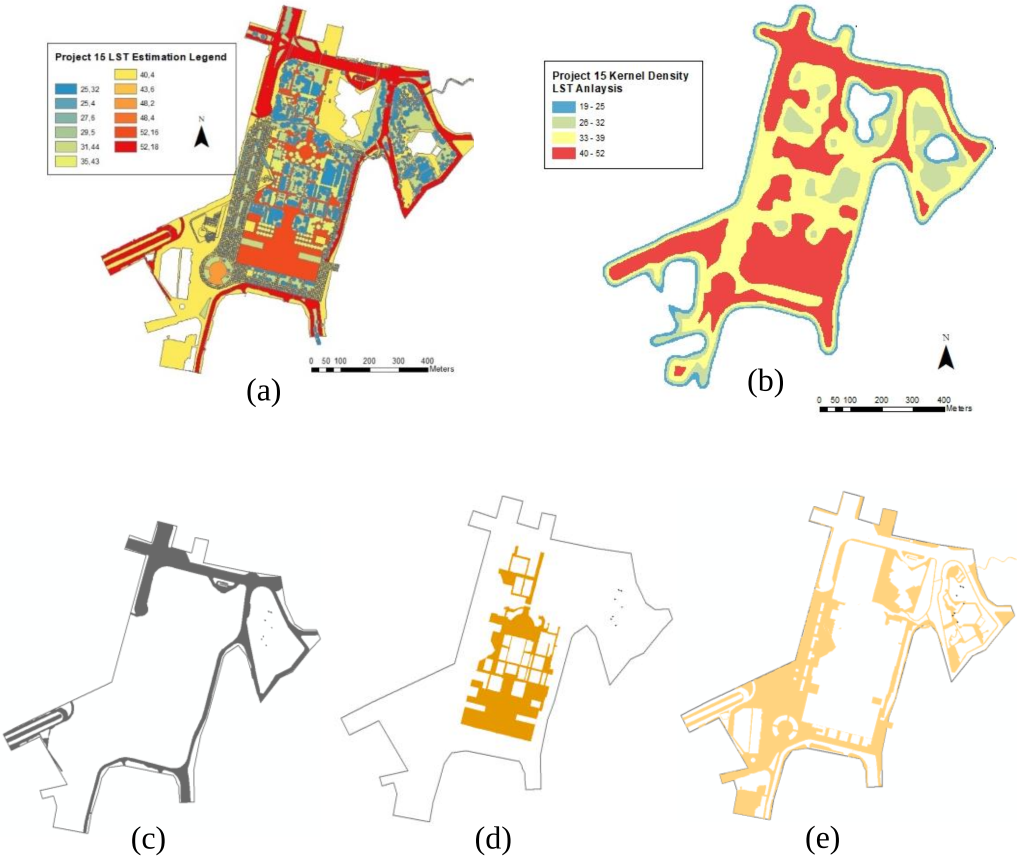


Figure 4.17 Project 15 (a) LST analysis by polygons, (b) Kernel Density LST analysis, (c) asphalt surfaces, (d) low albedo pavements, (e) high albedo pavement surfaces

4.2.3 Project 19 surface elements' impacts on LST

As a result of the LST analysis performed by utilizing certain methods, the surface temperature of Project 19 was lower than Project 15 and Taksim Square's land use. Therefore, Project 19 is the plan with the most successful design in terms of LST parameters. There are mainly two reasons behind these successful results. The first one is the nominal ratio of hard surfaces in the area with 64%. Furthermore, high albedo pavement surface usage is higher than low albedo pavement surface, which is examined in detail in the hard surface part. The second reason is that, parallel to this, the proportion of the vegetative surface is high with 35% (see Figure 4.18). In addition, although the effect of water is not observed in the Kernel Density analysis' results, low surface temperatures are also observed in the LST analyses defined by polygons in water surfaces (the range in the area is 1%). In summary, Project 19 is "greener" than the other two designs, so it has lower LST values on average.

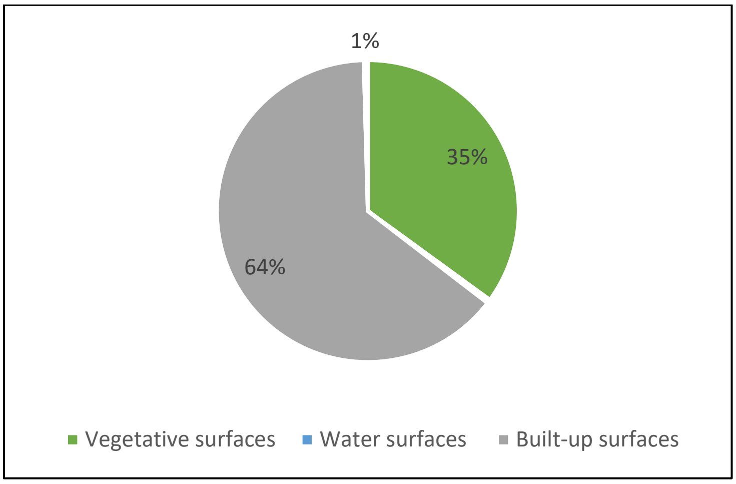


Figure 4.18 Distribution of different surfaces in Project 19

Vegetative surfaces

The proportion of green and wooded areas in Project 19 is 34%, higher than the other two designs, and therefore the design has the lowest LST values. As indicated in the LST analyses given in Figure 4.19, the temperature values of the vegetative surface in the design vary between 25℃ and 35℃. However, unlike other plans, apart from the green areas, the warming effect created by the hard surfaces has been reduced in some areas, thanks to the afforestation and their shadows designed on the hard surface.

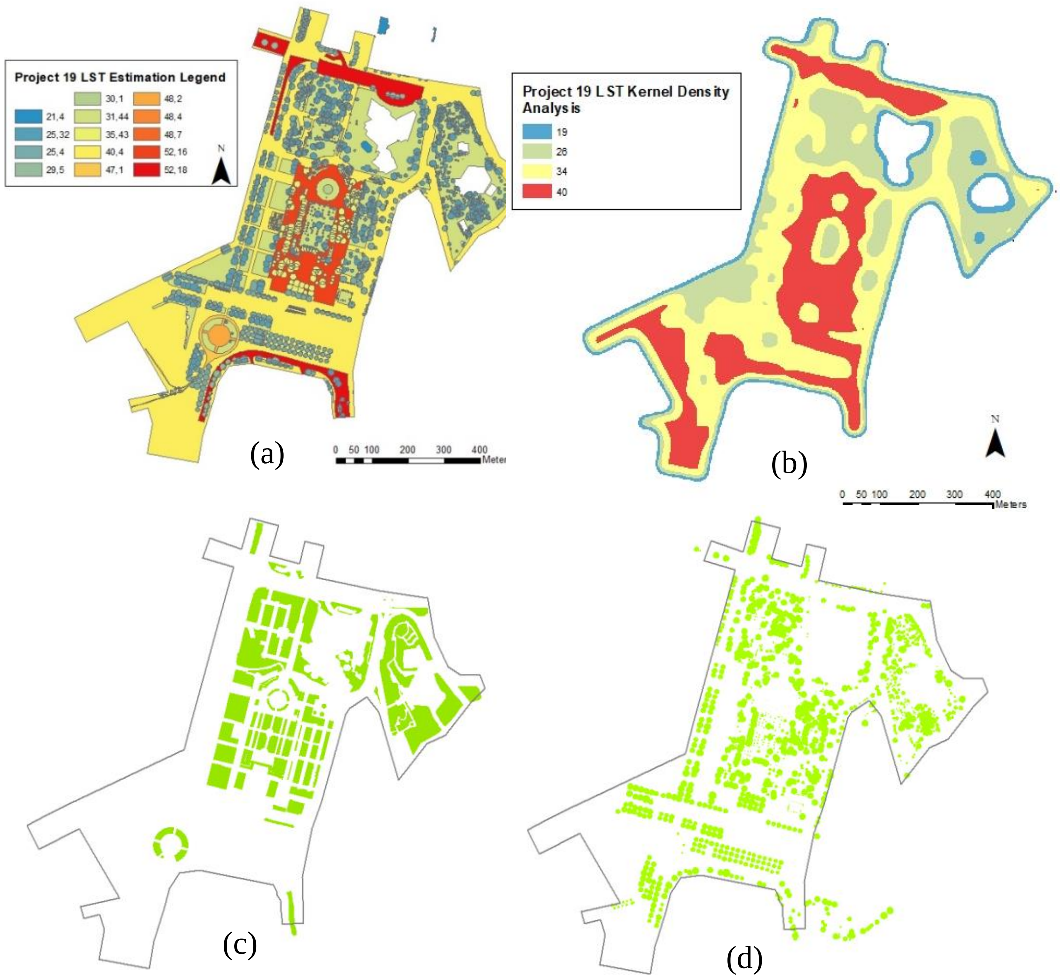
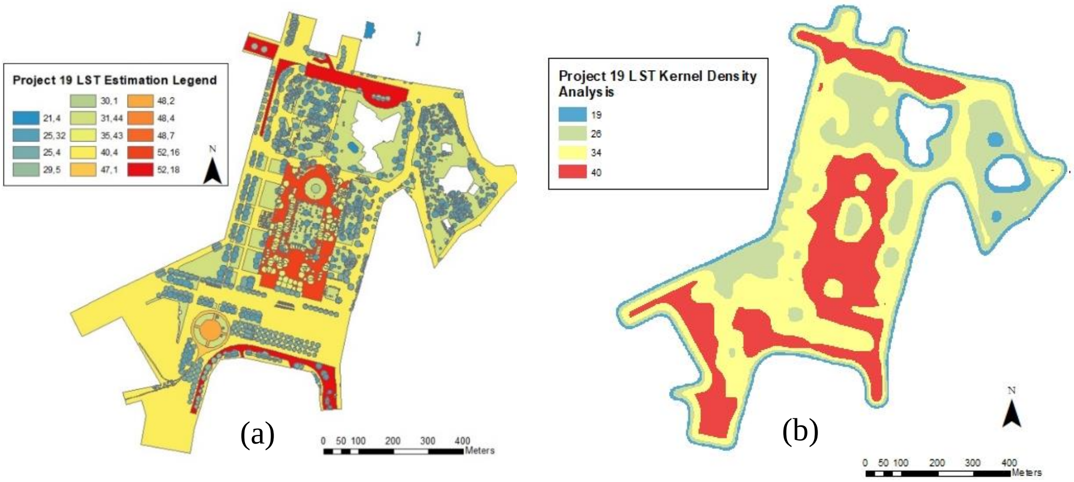


Figure 4.19 Project 19 (a) LST analysis, (b) Kernel Density LST analysis, (c) grass surfaces, (d) trees

Water surfaces

As in the land use of Taksim Square, the volume of the water elements and the surface area they cover are 21 degrees in the LST analysis, which is analyzed with reference only to polygons. No effect of the water elements in the design was observed in the Kernel Density analysis (see Figure 4.20).



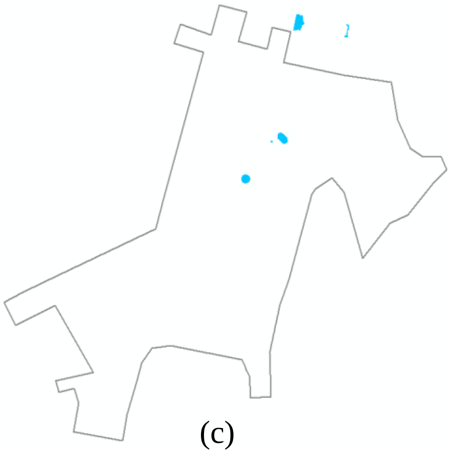


Figure 4.20 Project 19 (a) LST analysis by polygons, (b) Kernel Density LST analysis, (c) water elements

Hard surfaces

Unlike the other two designs, the floor material used extensively in Project 19 is high albedo pavement. Approximately 82% of the hard surface in the design is high albedo material, 9% is asphalt, and 9% is low albedo material (see Figure 4.21).

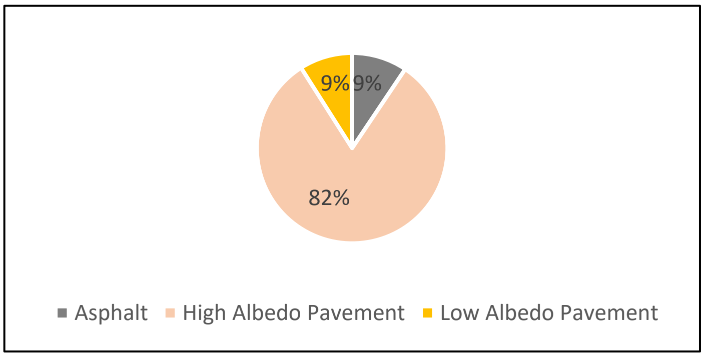


Figure 4.21 Distribution of hard surfaces in Project 19

Thus, the majority of high albedo hard surfaces in Project 19's LST analyzes are represented by yellow colors, and their temperatures range from 35℃ to 40℃. On the other hand, low albedo hard surfaces are expressed in orange and dark orange colors and are used in a very narrow area, as expressed in Figure 4.22 (d). In LST analysis based on polygons, the low albedo surfaces are nearly 47℃ and 48℃. However, the surface temperatures of these areas are distributed between 40℃ and 50℃ in Kernel Density LST analysis due to the cooling effect of vegetation surfaces.

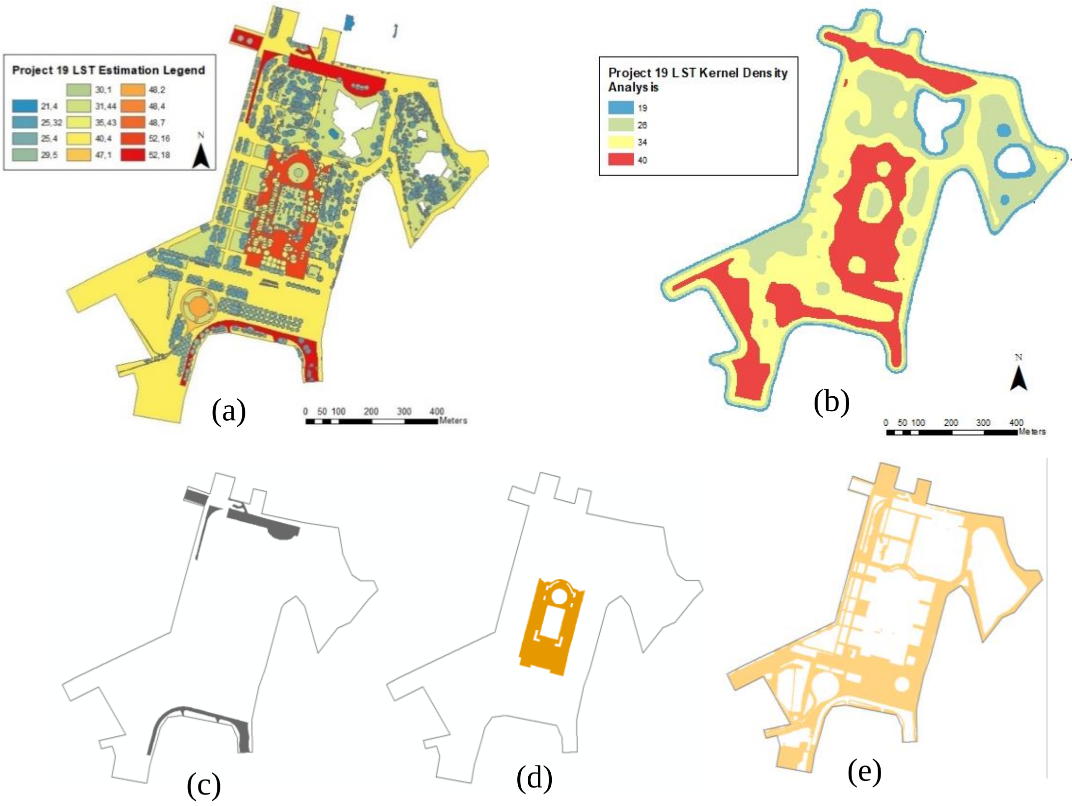


Figure 4.22 Project 19 (a) LST analysis by polygons, (b) Kernel Density LST analysis, (c) asphalt surfaces, (d) low albedo pavements, (e) high albedo pavement surfaces

4.3 Comparison of the surface spread of the land use of the Taksim Square, Project 15 and Project 19

The developed LST analyses model for different surface types was evaluated. Average LST analyses of Taksim Square, Project 15, and Project 19 were calculated. Average LST values analyzed manually by assigning the temperatures measured to defined surfaces by polygons is nearly are 41℃ in Taksim Square, 35℃ in Project 15, and 32℃ in Project 19, respectively. In this case, Project 19 is about 10 degrees warmer than the land use. According to Kernel Density analysis, the average LST value is approximately is 39℃ in Taksim Square, 37℃ in Project 15, and 35℃ in Project 19. In this case, Project 19 is about 4 degrees warmer than the land use of Taksim.

The differences in LST values of the three designs, one belonging to the land use of the square and the other two to the proposed projects, can be better understood when different types of surfaces within each design are analyzed in detail. As indicated in Figure 4.23, the hard surface is mostly preferred in Project 15, but the warmest LST is in Taksim Square due to the floor's albedo difference. On the other hand, the vegetative surface has the highest percentage in Project 19 with around 35%, and therefore, the coolest LST value belongs to this design.

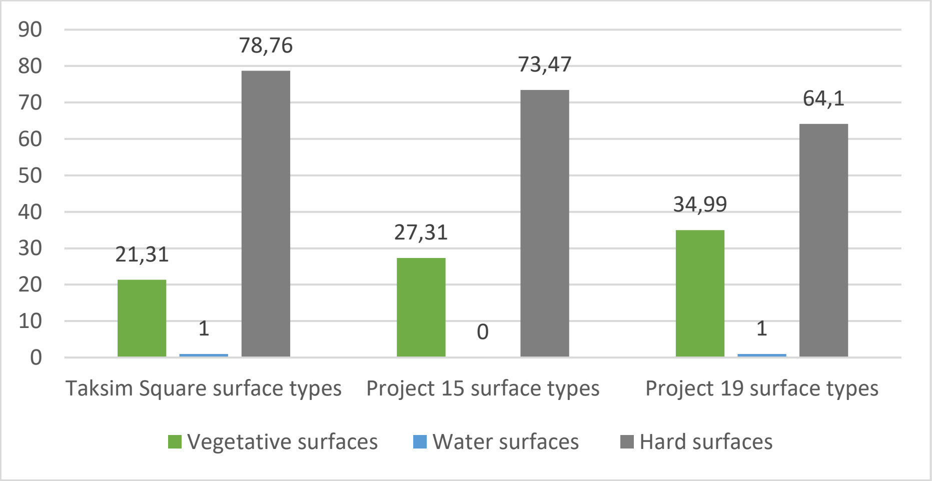


Figure 4.23 Taksim Square, Project 15 and Project 19 surface types (percentages, %)

CHAPTER 5

CONCLUSION

The temperature rise due to the climate crisis brings extreme weather conditions. The loss of life of people, animals, and living things due to great forest fires, floods, tsunamis, and similar disasters with these weather conditions is the most important and major problem of our day. Cities are most affected by this crisis and trigger these conditions. For this reason, controlling and reducing the temperature increase should be the most important agenda of decision-makers, planners, and urban designers who play an active role in the formation of urban areas. Moreover, urban areas are covered with surfaces that increase warming, and the discipline that is effective in defining these surfaces is urban design. However, land surface temperature (LST) control and mitigation at the scale of urban design has not been adopted as a crucial parameter, neither in Turkey nor globally. There are two reasons for this problem.

Firstly, LST analysis, control, and mitigation strategies were evaluated only in high-scale studies. One of the most important reasons for this is the Remote Sensing method in LST analysis. LST analyses obtained by the remote sensing method can guide experts in the city planning phase, but this is not possible at the urban design resolution. Due to the technical competence of the satellite images, the maximum resolution that the LST analysis performed with the remote sensing method can reach is 3 meters. In the urban design principle, 1/1000 or sometimes 1/500 scales are studied. For the LST analysis, which is expected to be carried out in designing temperature-sensitive cities, the 3-meter resolution is quite insufficient. In summary, no LST analysis method can serve the urban design resolution in the literature.

The second important reason is that the actors working in the field of urban design have a low level of awareness in the field of LST analysis, and this parameter is not evaluated in the design process. It is urgent to make a clear assessment of which design elements and how LST is affected, which is important, especially in the design of public spaces that cover approximately 80% of cities because public spaces are all surfaces in cities where people are directly affected by the increase in temperature and directly affect the microclimate of the city.

The main purpose of this study is to ensure that the surface temperatures are included as a variable in the urban design process and to design cities with low LST. To achieve the stated purpose, in line with the two main problems mentioned above, it is necessary to develop a design control method for LST analysis at the urban design resolution and raise awareness on the effects of LST. Two research questions were asked within the scope of the study: (1) Which physical environmental attributes of the land use of Taksim Square affected the land surface temperature? (2) Compared to the land use, do the two projects, which made it to the finals in the design competition, positively affect the LST values in Taksim square? In order to answer the stated research questions, firstly, the study investigated the importance of urban warming and LST parameter in public space design and the features affecting LST in these areas.

Secondly, Taksim Square Urban Design Competition (2020) has been selected as the case study to investigate the LST differences between designs. Selected projects are 1st (Project 15) and 2nd (Project 19) projects that made it to the finals in the competition. Designs, drawings, and land use were obtained from the project owners and the municipality for the LST analysis. For the worst-case surface temperature analysis, the hottest month and days of the year were preferred, and measurements took place on August 10th, 11th, 14th, 15th, and 17th. Laser infrared non-contact thermometer Benetech GM300 device was used for surface temperature measurements.

Within the scope of the study, a practical and low-cost GIS-based LST analysis and design control method was developed, which is aimed to be used by city planners, urban designers, and decision-makers to disseminate LST measurement at urban design resolution. Using the ArcGIS program, this method can perform an LST analysis of the design areas. The method consists of 3 basic steps; (1) data preprocessing, (2) LST analysis with manual surface type identification, (3) LST analysis with Kernel Density analysis, and (4) comparison of different LST analyses. Since the study aims to develop a low-cost and easy use method, consideration had been taken not to include complex formulas in the analysis.

In line with the literature reviewed (Cai et al., 2018; Hulley et al., 2019; Li et al., 2012; Mustafa et al., 2019), this study found that vegetative and water surfaces have a cooling effect on surface temperatures while hard surfaces and some urban street furniture has a warming impact. The study's LST analysis results supported the literature. According to the preferred parameters in LST analysis, the average LST of Taksim Square is 41℃ (hard surfaces cover 74%, and vegetative surfaces cover 26% of the area). The average surface temperature of Project 19 is 32℃ (hard surfaces cover 64%, and vegetative surfaces cover approximately 35% of the project area). Finally, the average surface temperature of Project 15 is 35℃ (hard surfaces cover 73%, and vegetative surfaces cover 23% of the area). Despite being the winner of the square design competition, the LST values of Project 15 are lower than the current surface temperatures of Taksim Square but higher than Project 19, the runner-up in the peninsula.

Consequently, regarding the second research question of this thesis (Compared to the land use of Taksim Square, do the two projects, which made it to the finals in the design competition, positively affect the LST values in Taksim square?), this study found that both of the proposed projects (Project 15 and 19) contributed to the LST values of the Taksim square. However, the local government preferred to choose not the most heat mitigating project as the winner project (in this study, this was Project number 19), but a less influential project concerning its contribution to LST values (which is Project number 15).

Soydan (2020) stated that average LST values of impervious hard surfaces are approximately 5 °C warmer than the green areas. However, based on the analysis of the LST values of the land use of the Taksim Square, this study showed that asphalt surfaces could be approximately 10°C - 20°C warmer than the green areas under the sunlight.

Similar to the study conducted by Gill et al. (2007) for grass areas, the results of this study emphasize that grass spaces with approximately 100 m^2 area are 24°C cooler than the concrete pavement.

As stated in Jamei and Tapper's (2018) study on the effects of water bodies on air and surface temperatures, cooling impact varies according to the size of water bodies. In support of this study, this thesis study showed that the water bodies in the square are smaller than 150 m^3 and only affect the surface temperatures within their borders. The cooling effect of water bodies in the square was not observed after the Kernel Density analysis due to the low effect. In the study, the average temperature of the water surfaces was measured as 27°C.

In line with the studies of Georgakis and Santamouris (2006) and Niachou et al. (2008), this study indicated that dark-colored (low albedo) pavements reached 65°C during hot summer days while grey stone (relatively high albedo) surface reached 48°C. Parallel to the studies, dark color stone is measured during shaded and non-shaded periods, and the results are nearly 30°C and 60°C, respectively. Moreover, as Santamouris (2013) indicated, a comparison of LST analysis of Taksim Square's land use and projects showed that pavements' maximum decrease in surface temperature due to the high albedo cover effect is 16°C.

5.1 Discussion

The method used in this study was developed to provide LST analysis at the urban design resolution, which is seen as a deficiency in the literature. If the remote sensing method were used with satellite images obtained from open sources, the frequently preferred method in LST analysis results with the desired resolution would not be achieved. Analyzing at 1/1000 scale with images obtained from satellites with a maximum resolution of 3 meters cannot be considered a method that will serve the requirements of the study.

Another option is to perform LST analysis using the drone remote sensing method. This method is technically sufficient, but it is costly. Since the study's main purpose is to disseminate LST analysis in the urban design process, this method will likely include costly and complex digital image analysis methods, which does not serve the study's objectives.

After evaluating these options, it was decided to develop a method within the scope of the study. One of the aims of the developed method is to construct the LST analysis as worst-case. İstanbul is located in a climatic region where the summers are quite hot. Therefore, the temperature increase due to the climate crisis is most intense in August, the hottest month of the year. The study evaluates the hottest days of the year. Thus, the objective is to evaluate the LST analysis of the designs to be implemented in the worst conditions.

The analysis results may be parallel or different from the literature due to the developed method. These studies were mentioned in the previous section. Significant differences were observed in comparing the average LST temperatures of asphalt and green areas obtained by the remote sensing method by Soman (2020). The article has been examined, and the reason for the difference may be due to the scale of the analysis, the width of the analyzed area, and the time intervals in which the measurements were made. This inference can be considered the main difference between this thesis study and other studies in the literature. In fact, this study is based on performing LST analysis on a scale considered a gap in the literature. Therefore, it is expected that the analysis results differ from the literature. However, this should not be ignored, and the results obtained in this study should be evaluated by considering the scale difference, measurement times, area sizes, and selected parameters.

LST should be an important parameter in the urban design process. Numerous designers participate in urban design competitions, both nationally and internationally. With this aspect, urban design competitions play an important role in raising awareness of the climate crisis and creating a design approach to this crisis. Therefore, in urban design competitions, the LST of the area's land use to be designed, and the LST analysis of the participants' designs should be performed. The different design scenarios should be evaluated according to the LST results. A clause requiring LST analysis can be added to the competition specifications to ensure each project owner carries out the LST analysis. The impact of each project on the LST can be revealed with the LST analysis method developed in the thesis study.

The measurement method and the steps followed for the LST analysis in the scope of this study can guide any public space design process. Thanks to the changes to be made in variables such as the time frame of measurement and analysis of the classification of the analyzed area's surface materials, this method is flexible, practical, and cost-free and can be applied in any public place. However, the average LST value obtained as a result of the study is specifically affected by the climate of İstanbul and the characteristics of Taksim Square. The results can guide in areas with similar climatic and spatial conditions. Nevertheless, climate and location are important and diverse for public space design. Accordingly, these conditions should be considered when applying the study.

5.2 Limitations of the study

Since the results of an urban design competition are compared in this study regarding their LST values, the surrounding buildings and thus the urban geometry is not varied due to the competition conditions. The reason behind this is the study makes calculations on the square design example. Even if urban geometry were added as a parameter in the LST analysis, there would be no difference between designs when compared. Therefore, urban geometry was excluded from the study. Since the orientations and heights of the buildings will be closely related to the shading factor in the new designs to be made, the urban geometry factor should be considered and evaluated in the design scenarios.

Throughout Project 15, the water element could not be included in the LST analysis included in the study. The areas, which are stated to have the purpose of periodically cooling the square with fountains, could not be considered fixed water bodies due to the unknown frequency and duration of use. For this reason, it was excluded from the analysis. However, if water were included in the analysis, it could create significant cooling effects on surface temperatures.

The study was carried out in 2D instead of 3D. Since the measurements were made at 12:00, the areas shaded by the buildings around the square are quite low. However, performing a 3D analysis study would make the study's results more valid, even though the measurement was taken at 12:00. On the same surface, measurements could be taken from sun-exposed and shaded surfaces, and the average LST value of the square could reflect the result more accurately. Especially for other time zones of the day, the 3D analysis would have a statistically more significant effect on these average values.

5.3 The implication of the study findings for practice and research

Urban design competitions affect the design understanding of the contestants participating in these competitions and serve as an example for decision-makers. Therefore, they are crucial organizations in raising awareness about the necessity of LST analysis at the scale of urban design. The method used in this study can be applied to compare the LST values of the designs during the evaluation process of each urban design competition. In addition, if no expert can do this analysis from the jury members in the competition, one of the conditions of the competition is that the competitors may be requested to compare the LST analysis of their designs with the LST analysis of the square’s land use. In other words, urban design competition jury members can evaluate projects using this design control mechanism.

In addition to the design competitions, the participants can create design scenarios during the urban design process and choose the one with the low LST value among these scenarios to apply. However, in this case, urban geometry and urban street furniture elements may need to be included in the analysis to obtain correct results. After the LST analysis, it is important to evaluate the preferred surface elements in the design. The study shows that the use of vegetation and water elements provides a decrease in LST values. In contrast, the excessive use of asphalt and dark-colored stone floors, which are hard surface elements, increases the LST values. When designing public spaces, surface elements must be preferred over high albedo, vegetative or permeable surfaces, considering other design purposes and functions.

As emphasized in the literature review, there are not enough studies on the effects of urban street furniture elements on LST. These elements, whose surface area is limited to a maximum of 1% in the square sample, may cover much larger surfaces in other studies. Studies included in the LST analysis will gain importance in such a case.

As mentioned in the Limitations of the study section, this study is based on the analysis of 2D plan images. Measurements in the field were taken at 12:00, and measurements on vertical surfaces, shadow effect of surrounding buildings, winter season values, and nighttime measurements were not taken into account. Conducting future studies in different seasons, understanding what kind of LST values in different surfaces have at different time intervals, conducting such studies in public open spaces with different physical environmental characteristics, and having information about surface types that are not covered in this study can guide urban designers more accurately. This study is important in terms of taking the first steps of this process and has made an important contribution to the literature in this sense.

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