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THE RELATIONSHIP BETWEEN PREFERENCE UTILIZING VR
AND SYNOPTIC THERMAL EVALUATION
THE CASE OF PUBLIC SQUARE OF AMIRKABIR, ARAK

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A Master's Thesis

by
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Ankara
December 2022



To the best companions, my parents

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The Graduate School of Economics and Social Sciences
of
Ihsan Dogramaci Bilkent University

By

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By Seyed Mahziar Taghavi Araghi

I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

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ABSTRACT

THE RELATIONSHIP BETWEEN PREFERENCE UTILIZING VR AND SYNOPTIC THERMAL EVALUATION THE CASE OF PUBLIC SQUARE OF AMIRKABIR, ARAK

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Public Open Spaces (POS) have been proven to have a positive effect on people's life and overall well-being. As also suggested by the existing literature, the success of a POS can be interrelated with the number of individuals using it. However, the occurrence of Urban Heat Island (UHIs) has increased in recent years as a consequence of climate change which can significantly affect the presence of people in POSs and their usage pattern. Urban green spaces on the other hand can provide shade that covers outdoor environments, attenuating the effects of UHIs. In addition, urban inhabitants can benefit from psycho-physiological advantages of urban green spaces. Meanwhile, Amirkabir square as the first environment with the main concentration on pedestrians rather than vehicles in the city of Arak, needs urgent improvements in both aesthetics and thermal condition. To accomplish this aim, alongside thermal sensitive decision making, the use of virtual reality (VR) as a participatory means can offer a unique opportunity to ensure the positive effects of local interventions. This method and the integrative mergence

between these two issues, and how they can frame an initial guidance for local design-oriented action, are interlinked contemporary factors that need to be addressed.

As a result, the study's primary objective is to provide interdisciplinary recommendations for architects and urban designers on how to effectively approach the alternation of POSs for enhanced greenery design to approach both thermal comfort and psychological expectations. Hence, this study investigated people's preferences in four greenery design scenarios using VR techniques, then compared them to thermal comfort situations to determine whether the preferred scenario chosen by Araki inhabitants is the same scenario in which people performed best or not. People's preferences were studied using VR technology and SPSS software for data interpretation. The quantitative thermal microclimatic conditions of Amirkabir urban square were obtained through the application and comparison of energy-based model thermal indices. These indices were the Physiologically Equivalent Temperature (PET) and the modified PET (mPET) through the use of biometeorological RayMan pro model. To facilitate the representation of the results, the Climate Tourism/transfer Information Scheme (CTIS) software was utilized. This innovative methodology revealed in the case of Arak, that the scenario preferred by people (Scenario D, $p < .05$), is different from the scenario with better thermal performance (Scenario A), and that people's preferences and thermal outcome on different design scenarios are not necessarily parallel, which draws on local design and planning orientated professionals that shape cities to work in an interdisciplinary manner whilst addressing such crucial aspects. Through such a perspective, the modification of the urban fabric can be made to better ensure the long-term triumph of urban projects.

Keywords: Outdoor thermal comfort; Virtual reality; Urban green spaces; PET; mPET

OZET

SANAL GERÇEKLIK (VR) VE SİNOPTİK TERMAL KONFOR ŞARTLARININ İLİŞKİSİ: AMIRKABİR, ARAK KAMU MEYDANI VAKA ÇALIŞMASI

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Kamusal Açık Alanların (KAA) insanların yaşamı ve genel refahı üzerinde olumlu bir etkisi olduğu kanıtlanmıştır. Mevcut literatürde de belirtildiği üzere, bir KAA'un başarısı, onu kullanan bireylerin sayısı ile ilişkilendirilebilir. Bununla birlikte, iklim değişikliğinin bir sonucu olarak son yıllarda Kentsel Isı Adası (KIA) oluşumu artmıştır ve bu da insanların KAA'lardaki varlığını ve kullanım şekillerini önemli ölçüde etkileyebilir. Öte yandan kentsel yeşil alanlar, dış ortamları örten gölge sağlayarak UHI'lerin etkilerini azaltabilir. Ayrıca, kent sakinleri kentsel yeşil alanların psiko-fizyolojik avantajlarından faydalanabilir. Bu arada, Arak kentindeki Amirkabir meydanının hem estetik hem de termal açıdan acilen iyileştirilmesi gerekmektedir. Bu amaca ulaşmak için, ısıya duyarlı karar verme sürecinin yanı sıra, sanal gerçekliğin (VR) katılımcı bir araç olarak kullanılması, yerel müdahalelerin olumlu etkilerini sağlamak için eşsiz bir fırsat sunabilir. Bu yöntem ve bu iki konu arasındaki bütünleştirici birleşme ve bunların yerel tasarım odaklı eylem için nasıl bir ilk rehberlik çerçevesi oluşturabileceği, ele alınması gereken birbiriyle bağlantılı güncel faktörlerdir.

Sonuç olarak, çalışmanın birincil amacı, hem termal konfora hem de psikolojik beklentilere yaklaşmak için gelişmiş yeşil alan tasarımı için KAA'ların değişimine nasıl etkili bir şekilde yaklaşılabileceği konusunda mimarlar ve kentsel tasarımcılar için disiplinler arası öneriler sunmaktır. Bu nedenle, bu çalışmada sanal gerçeklik teknikleri kullanılarak insanların dört yeşillik tasarım senaryosundaki tercihleri araştırılmış, ardından Araki sakinleri tarafından tercih edilen senaryonun insanların en iyi performans gösterdiği senaryo olup olmadığını belirlemek için termal konfor durumlarıyla karşılaştırılmıştır. İnsanların tercihleri VR teknolojisi ve verilerin yorumlanması için SPSS yazılımı kullanılarak incelenmiştir. Amirkabir kent meydanının kantitatif termal mikroklimatik koşulları, enerji tabanlı model termal indekslerin uygulanması ve karşılaştırılması yoluyla elde edilmiştir. Bu indeksler Fizyolojik Eşdeğer Sıcaklık (PET) ve biyometeorolojik RayMan pro modeli kullanılarak modifiye edilmiş PET (mPET) idi. Sonuçların gösterimini kolaylaştırmak için İklim Turizmi/transfer Bilgi Şeması (CTIS) yazılımı kullanılmıştır. Bu yenilikçi metodoloji, Arak örneğinde, insanlar tarafından tercih edilen senaryonun (Senaryo D, $p < 0.05$), daha iyi termal performansa sahip senaryodan (Senaryo A) farklı olduğunu ve farklı tasarım senaryolarında insanların tercihleri ile termal sonuçların her zaman paralel olmadığını ortaya koymuştur; bu da şehirleri şekillendiren yerel tasarım ve planlama odaklı profesyonellerin bu tür önemli hususları ele alırken disiplinler arası bir şekilde çalışmasını gerektirmektedir. Böyle bir bakış açısıyla, kentsel projelerin uzun vadeli başarısını daha iyi sağlamak için kentsel dokuda değişiklik yapılabilir.

Anahtar Kelimeler: Dış mekân termal konforu; Sanal gerçeklik; Kentsel yeşil alanlar; PET; mPET

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LIST OF ABBREVIATIONS

2D	2 dimensional
3D	3 dimensional
CTIS	Climate-Tourism/Transfer-Information-Scheme
CFD	Computational Fluid Dynamics
EXs	Existing Situation
HW	Heat Wave
IVEs	Immersive Virtual Environments
KG	Köppen-Geiger
MEMI	Munich energy-balance model for individuals
mPET	modified Physiologically Equivalent Temperature (°C)
octas	Cloud coverage
PBR	Pedestrian Based Response
PS	Physiological Stress
PET	Physiologically Equivalent Temperature (°C)
POI	Point of Interest
POS	Public open spaces
RP	Reference Point
RH	Relative Humidity (%)
ScA	Scenario A
ScB	Scenario B
ScC	Scenario C
ScD	Scenario D
SBS	Shadow Behavior Simulations
SVF	Sky-View-Factor

SAC	Surrounding And Center
Ta	air temperature (°C)
Tmrt	mean radiant temperature (°C)
UGS	Urban Green Spaces
UHI	Urban Heat Island
UTCI	Universal Thermal Climate Index
VR	Virtual Reality
WI	What If
WMO	World Meteorological Organization

CHAPTER 1

INTRODUCTION

People in urban environments, requiring leisure and recreation space, use Public Open Spaces (POS), such as parks, plazas and public squares for their activities. “Open public spaces are places where civic, cultural and social activities occur” (Djekic et al., 2018). They are stages of public life and a reflection of the interaction between physical, social, political and economic realities. Since the success of a POS can be assessed by the number of individuals using it (Keller et al., 2005), numerous studies have examined the number of individuals using specific spaces and how the different indices of the environment relate to the presence of people in POS (Carmona et al., 2008; Jan Gehl, 1987; J. Gehl & Svarre, 2013; Baruch. Givoni, 1976; Jacobs, 1961; Lin, 2009; W.H. Whyte, 1980).

In this between, walking in the city, beyond its transit function, benefits people's physical and mental health, as well as cities' environmental, social, and economic sustainability and seems to be an important factor for people's mental health (Frumkin et al., 2004; Shamsuddin et al., 2012) that can be considered as a free and widely accessible recreation activity. Walking fell in many countries over the last 40 to 50 years (Carmen Hass-Klau, 2015). The major reason for this fall is that the living circumstances have changed that the average travel lengths for all purposes have expanded to the point where many destinations are no longer comfortably walkable, necessitating the use of a car or public transportation in many circumstances (Carmen Hass-Klau, 2015). Hence, for many years,

walking was not considered a priority for urban planners and city authorities (Lee & Kim, 2019) but automobile requirements. However, in recent decades the necessity of urban walking areas is gaining back meritorious attention. By the late twentieth century, much-needed attention had been paid to the central public spaces of European towns, many of which had been converted into car parks throughout the 1960s and 1970s. Residents fought for them, and urban theorists argued that they are essential to a democratic system and urban lives (Ehrenfeucht & Loukaitou-Sideris, 2007). Cars were banned, new pavements were laid, street furniture was installed, and other major investments were undertaken to revitalize deteriorated POSs.

Arak, as one of the industrial cities in Iran, is not an exception. Arak is the capital of the Markazi province and one of Iran's eight most populous cities. This city is close to industrial activities such as power and petrochemical plants, combine and aluminum manufacturing, and other businesses. Furthermore, emissions from mobile sources like traffic have the potential to damage human health, just like pollution from industrial plants (Fard et al., 2021). In the last 50 years, this city has experienced massive structural and cultural changes and the general look of the city has been dramatically changed from a very green and organic city to a car-oriented, industrial city which puts vehicles the priority. This flawed strategy has been ongoing for decades but two years ago, the first pedestrian way was built to provide a peaceful environment for the citizens in the center of the city. Amirkabir is the name of the first walking pavement built in the center of the city exactly between the two most important parts of the city, the Meydan Shohada (martyrs square) and the great grand bazaar. These two areas are the key role players of the city which with this pavement, can be connected later. So, the importance of this area

is not only as a resting and recreation environment, but as a significant connector of the two parts of the city and it is predicted that with the implementation of the city master plan in the future, omitting cars from the city center, can also perform a more crucial role.

Furthermore, the production of Urban Heat Islands (UHI) which is referred to the phenomenon whereby urban areas experience higher atmospheric and surface temperatures than the nearby rural areas (Howard, 1835) has been increased. In general, UHI is formed primarily as a critical consequence of landscape changes caused by urban development, resulting in higher land surface temperature as the influence of reduced vegetation in urban areas (Estoque et al., 2017). Increased temperatures caused by the UHI effect may increase water and energy consumption in cities (Poumadère et al., 2005) and intensify the creation of ground-level ozone, which has adverse health consequences (Akbari et al., 2001). Mitigation of UHI effects through green space configuration and sustainable urban design has become a growing concern in the face of climate change (Maimaitiyiming et al., 2014). Green space can provide shades that cover outdoor environments, reducing direct heating from the sun's solar radiation, correspondently decrease the effect of urbanization on UHI not only by balancing the relative amounts of different land cover components such as trees, but also by optimizing their spatial configuration (Zhou et al., 2011). In order to create urban areas and cities with healthier and more comfortable environments, it is suggested that urban planners and policy makers optimize the spatial patterns of urban landscapes by clustering vegetation and dispersing built structures and paved surfaces (Estoque et al., 2017) so that people benefit from both aesthetic and health advantages of Urban Green Spaces (UGS). It is necessary to positively contribute to the city by using nature-oriented design criteria to improve the

quality of the space and increase citizen presence in POSs (Yilmaz et al., 2022). A diverse range of plant species with varying characteristics may have visual allure or fascination, attracting attention with little or no effort, and encouraging a viewer to remain in the setting (Kaplan, 1995).

On the other hand, Virtual Reality (VR) technology is a reliable tool for optimization of urban decisions through participatory design processes (T. L. J. Howard & Gaborit, 2007). The modern VR was introduced by Ivan Sutherland when he published his first paper “The Ultimate Display” (Sutherland, 1965) and since then different prediction has become attractive for the use of this technology in architecture (Slater et al., 2010). Scholars have formulated different definitions for VR (Cipresso et al., 2018), Bishop & Fuchs, 1992 defined VR as “real-time interactive graphics with 3D models, combined with a display technology that gives the user the immersion in the model world and direct manipulation”. Gigante, (1993) described VR as “The illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on a three-dimensional (3D), stereoscopic head-tracker displays, hand/body tracking and binaural sound. VR is an immersive, multi-sensory experience”.

Since the built environment is intrinsically correlated with 3D space, VR is a critical technology for the architecture, engineering, and construction sectors (Davila Delgado et al., 2020). The use of VR in the design process increases the level of simulation complicity while also enabling the designer to accumulate more information than using traditional media and to check design solutions more quickly (Jelena et al., 2002). Unlike the conventional consultation process, by using VR technology, the public can be better

consulted, enhancing the public's useful participation in the planning processes (T. L. J. Howard & Gaborit, 2007). The use of VR as a participatory tool alongside thermal and energy-based decisions can offer a unique opportunity for time and energy savings while ensuring the positive effects of any interventions when city authorities are deciding how to change the current situation. This interdisciplinary merge between these two issues, and how they can frame guidance for local design-oriented action, are two important issues that need to be addressed.

Two studies employing Köppen-Geiger (KG) climate classification system (Köppen, 1936) were used to identify Arak's climate classification. According to Peel et al. (2007), Arak has a hot semi-arid climate 'Bsh'. Summers in these climates are hot, sometimes extremely hot, and winters are warm to cool, with little to no precipitation. Whereas a more recent study by Beck et al. (2018) identifies the climate of the city as Mediterranean-influenced hot-summer humid continental climate 'Dsa'.

Table 1. MAT, mean annual temperature; Thot, temperature of the hottest month; Tcold, temperature of the coldest month; mean annual precipitation; Psdry, precipitation of the driest month in summer (Peel et al., 2007; Santos Nouri et al., 2021)

KG class	Colloquial name of sub-classification	General classification descriptors	Specific environmental thresholds			
			Precipitation descriptors		Temperature descriptors	
			General description	Climate specification	General description	Climate specification
'Dsa'	Snow/cold climate with dry hot summer	$T_{hot} \leq 21\text{ }^{\circ}\text{C}$ and $T_{cold} \leq 0$	Dry summer	$P_{sdry} < 40$ and $P_{sdry} < P_{wwet}/3$	Hot summer	$T_{hot} \geq 22\text{ }^{\circ}\text{C}$

In this classification, the coldest month averaged less than 0 °C (or 3 °C), the warmest month averaged more than 22 °C, and at least four months averaged more than 10 °C. The wettest month of winter receives at least three times as much precipitation as the driest month of summer, and the driest month of summer receives less than 30 mm. An important issue with KG to mention is that because it is a top-down classification and deals with temperature and aridity, other important variables such as short/longwave radiation fluxes are left out for a bottom-up understanding of local urban/microclimates.

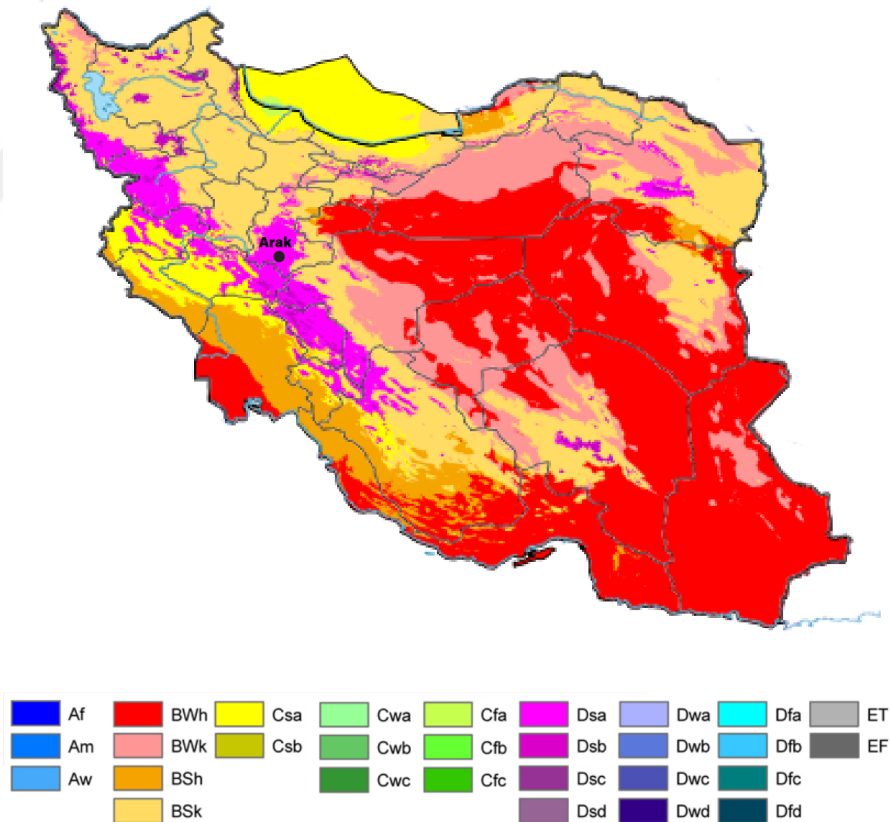


Figure 1. Iran and Arak climatic classifications, image from (Beck et al. 2018) edited by author

1.1. Problem Statement:

Climate change and global warming have become a universal concern in recent decades and scholars are searching for innovative short-term and long-term solutions to confront this issue. Implementation of UGS is one strategy to invite people to POS which can be aesthetically pleasant, provide better shading and thermal comfort (G. Givoni, 1991; A. S. Nouri, Costa, et al., 2018; Wong & Yu, 2005), improve outdoor air quality (Dimoudi & Nikolopoulou, 2003; Nemitz et al., 2020), and manipulate airflow (Sawka et al. 2013; Janhäll 2015) and a better respiratory health (Gallagher et al., 2015; Salmond et al., 2016; Zhang et al., 2021) and reduce the negative psycho-physiological effects of densely built environments on humans (Hartig & Staats, 2006), while the existing green coverage of Amirkabir public square cannot do any of them. Not being capable of providing enough shading nor the trees are in an ideal condition to be welcoming enough for the citizens for relaxing and recovering from mental fatigue (R. Wang et al., 2019). Although outdoor environments cannot be always comfortable as it is not technically possible (Velazquez et al., 1992), this situation raises the demand for the redesign of the pavement's greenery. However, any intervention in urban environments must be controlled and measured carefully not to aggregate the defects of the existing situation and maintain to assess the benefits to human health from lower temperatures (Bowler et al., 2010). Utilizing subjective wellbeing assessments, the greener an individual's local environment is the higher their levels of happiness and the lower their levels of stress (Navarrete-Hernandez and Laffan 2019; Laforzezza et al. 2009).

1.2. Aim of the study:

The study's primary objective is to provide interdisciplinary recommendations for architects and urban designers on how to effectively approach the alternation of POS for improved greenery design in order to meet both the thermal comfort and people's psychological expectations. The study by Li, Zheng, and Ma (2022) makes two key policy recommendations to enhance the benefits of UGS. To begin, in order to make the limited urban space more effective, urban planning must consider residents' environmental satisfaction and the design should be user-friendly for residents. Second, it must be taken into consideration that UGS should be provided in various ways depending on the studied city. Hence, this study aimed to explore the people's preferences and performance in four greenery design scenarios using VR techniques, then compared them with thermal comfort situation to recognize whether what was selected by people as the preferred scenario was the same that they had the best performance in or not. Then investigated the relationship between people's preference and performance with thermal analysis data to assure the increase of citizen's satisfaction of the Amirkabir pavement proposed designs. This study achieved this aim by utilizing four 360-degree animations videos and a head-mounted display with a structured questionnaire. Participants were completely immersed in the environment when 360-degree videos and VR presentations were combined, reducing their interaction with the outside world. As a result, it is anticipated that using this method, as opposed to using frequently used photographs, will consequence in more accurate evaluations of perceptions and affective appraisals of the examined environment (Mouratidis & Hassan, 2020). This study comparatively explored people's preference in four virtual pavement scenarios based on the Amirkabir pavement

existing geometry to increase people's satisfaction with an outdoor environment design and thermal comfort to encourage and invite individuals to use Amirkabir pavement more often and participate in outdoor activities which have undeniable effects on their health and overall wellbeing (Navarrete-Hernandez & Laffan, 2019). "By asking the right questions in sun and wind studies, by experimentation, we can find better ways to board the sun, to double its light, or to obscure it, or to cut down breezes in winter and induce them in summer. We can learn lessons in semi open niches and crannies that people often seek" (W.H. Whyte 1980, p2).

1.3. Structure of the thesis:

This study has been organized in several sections to reach its defined goals. Chapter 2: covers literature review on similar studies and efforts on the preference, perception and thermal comfort of different vegetation scenarios on the participants in different virtual environments using various virtual settings. These researches have investigated several factors like safety, density, happiness and general performance. Vegetation choice and tree type preference have also been discussed. literatures on the field of thermal comfort studies have also been reviewed. Chapter 3 defines the methodology of this study. Firstly, the research question is explained, secondly, the objectives are defined, and then, the sample and setting are described in detail followed by the experiment setup, process, instruments and data collecting methods. Subsequently, Chapter 4 addresses the quantitative data analysis methods and outcomes, compares the findings to other studies and finally highlights the study's limitations. Finally, Chapter 5 discourses the major points, wraps up the research and makes recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1. Public open spaces (POS):

Oxford dictionary defines public as "Carried out or made by or on behalf of the community as a whole; authorized by or representing the community; Open or available to, used or shared by, all members of a community; not restricted to private use". Most definitions of public space stress the importance of access, which might encompass both access to the location and access to the activities within it. As a result, public places and spaces are public because anybody has the right to be physically present in them (Madanipour, 2016). "Public spaces are the lifeblood of cities" (Németh & Hollander, 2010). They are the best places for people to spend their free time and participate in many possible outdoor activities. These spaces will allow citizens to experience their city and their people, in a better word, be present in their city. The importance of POS is highlighted not only because they serve as a stage for the representation of a multicultural society, but also because they put residents' relationships to the test (Amin, 2008; Wood & Gilbert, 2005).

POS are venues for relaxation, social interaction, entertainment, leisure, and simply having a good time (Banerjee, 2007). These venues help people preserve their social identity within society by exposing them to a variety of people and events, which improves the foundation for solidarity as well as learning to trust others. In public spaces, people interact with those outside their private circles (Ehrenfeucht & Loukaitou-Sideris,

2007). As a result, they serve as gathering areas for people to communicate and engage in various activities such as socio-cultural performances, festivals, and other outdoor activities (van Melik et al., 2007). These locations provide socio-psychological benefits that are important for the city's vibrancy and residents' health (Chiesura, 2004; Jabbar et al., 2021; Laforzezza et al., 2009).

Citizens' health and well-being are increasingly acknowledged as a challenge in times of increased urbanization leading to a significant amount of research on the relationship between urban settings and health or well-being (Krefis et al., 2018). Mental wellbeing is defined as a state of subjective well-being that encompasses both happiness and life satisfaction (Dong & Qin, 2017). Having a safe and exciting outdoor environment for citizens to spend their time is considered a great necessity in urban planning. In such spaces, people can connect with their environment, themselves, and one other in urban public places, all of which are vital components of maintaining wellbeing (G. Givoni, 1991; Navarrete-Hernandez & Laffan, 2019; Tuhkanen et al., 2022) .

It is also crucial to consider all age groups of the society when it comes to a public open space. Askari and his colleagues (2015), emphasized the importance of people's engagement with POS by all age groups. All groups of people, from teenagers to elderly people with physical disabilities, should have equal access to POS. A wide range of common POS can be thought to have a positive impact on both individual well-being and community life. Some people benefit from the opportunity to be alone that spaces provide, but for many others, it is their social value, their shared and collective use, that is important in reducing stress and maintaining health and well-being (Cattell et al., 2008).

Psychological wellbeing, also known as good mental health, is a condition of well-being in which people recognize their potential, are able to cope with everyday stressors, work efficiently, and contribute to their communities (Haver et al., 2015). According to the findings of the study by Tuhkanen et al. 2022, open spaces are important for socializing, relaxing, and exercising. This study suggests that POS can also provide health benefits many of which were commercial. When considering the benefits of public realm spaces, the research suggests taking a broader view. Greening existing urban spaces while also making them more convenient and accessible can improve societal well-being (Lafortezza et al., 2009).

2.2. POSs and greenery design

In this field, green areas are playing a vital role. It is proven by many scholars that UGS can be inviting and encouraging for citizens to spend their time more in POSs (Navarrete-Hernandez & Laffan, 2019; Sawka et al., 2013; *Urban Sprawl and Public Health*, 2002; van Dongen & Timmermans, 2019). Several studies have revealed a remarkable range of effects produced by the presence of plants in various contexts. Nature may improve social integration and engagement among neighbors by encouraging the usage of outdoor areas (Coley et al., 2016). The presence of trees and grass in POS may foster the formation of social relationships, helps individuals relax and regenerate, hence lowering violence (Kuo et al., 2016)

Growing empirical evidence means that the presence of natural assets (such as urban parks and forests, and green belts) and components (such as trees and water) in urban settings improves the quality of life in a variety of ways (Chiesura, 2004). The

Characteristics of urban green spaces are important for human well-being (Jabbar et al., 2021). Furthermore, urban parks' aesthetic, historical, and recreational aspects enhance the city's appeal and advertise it as a tourist destination, producing jobs and economy (Chiesura, 2004). According to Ronghua Wang's (2019) research on Hangzhou, the characteristics of UGS favorably influence human aesthetic values and stress recovery. The study looked into urban green spaces as a supply of enjoyment as well as a place to unwind and recuperate from mental fatigue. The study revealed that green places with a variety of trees, clean water, and vibrant flowers attract individuals and aid in the recovery of mental stress. As a result, studies on mental stress recovery and aesthetic preference advocate green spaces with trees and flowers (Parsons et al., 1998; Salmond et al., 2016; R. Wang et al., 2019).

Land-use planning has the potential to create built environments that are beneficial to residents' health and well-being (M.-J. Alcoforado & Matzarakis, 2010; Ambrey, 2016). In cities like Arak, most of the hard surfaces are seen, built, and used primarily as car traffic spaces rather than areas for people, social interchange, or ecological purposes, with the spare space accessible for other uses. Hence, intellectual interventions in POS design have been considered to improve the general quality of urban spaces. Aspects like "number of public green spaces per person," "public parks," and "recreation areas" are frequently stated as key variables in making a city livable, pleasant, and appealing to its residents (Chiesura, 2004).

A study by Hernandez and Laffan (2019) explored a novel new strategy for investigating the impact of green infrastructure investments on people's perceptions of urban areas at

the 20th Biennale of Architecture and Urbanism in Chile. The authors' main contribution was to combine subjective wellbeing metrics with photo simulation to evaluate the influence of small-scale street-level greening on the pleasure and stress individuals associate with photos of the areas in question. It was possible by capturing some pictures from the site and modifying them in Adobe Photoshop then comparing them using an organized questionnaire. The findings suggest that green initiatives at the street level have a favorable influence on people's sentiments of happiness and stress associated with urban environments and that the effects vary depending on the type of green intervention (Navarrete-Hernandez & Laffan, 2019; Zeng et al., 2018).



Figure 2. Photographic Simulations of Street Vegetation (Navarrete-Hernandez & Laffan, 2019)

Another study in Vienna is trying to find the best balance for hard lands dedicated to cars and the lands available for pedestrians with the main focus on the outdoor greenery design. The scientists were trying to investigate how to build streets to be more sustainable to meet a broader range of functions, including greenery in urban areas, and how to allocate available space. This may broaden the range of conceivable uses and activities within streets on the one hand, while also expanding on the subject of how streets may be designed to work as greenery carriers (Furchtlehner et al., 2022). They argued that the people's relationship and perception of streets as a result of established car-dependent routines and lifestyles in cities have to be shifted as a necessary stage in the transition from the street as a traffic area to a green living outdoor space. It was possible by implementing the 50 percent non-motorized use criteria serving as a carrier of green infrastructure including trees, vegetation, and permeable surfaces.

The other study conducted by Dongen and Timmermans (2019) also proved that virtual environments and pictures are appropriate for stated choice research. The goal of the research was to see how different small scale natural components in residential streets, as well as their possible arrangements, influence residents' preferences for stressful daily urban living to improve the design of the UGS so that citizens are more likely to encounter or choose urban green settings throughout their regular activities (van Dongen & Timmermans, 2019). They attempted to answer their research question that if the distinct effects of diverse greenscape features and configurations on preference are meaningfully distinguishable and quantifiable. A design was created based on what is usually seen in Dutch residential streets, three basic types of natural elements in residential streets for the UGS designs were chosen: trees, horizontal green, and vertical

green. Then the scenarios were asked using an online questionnaire of 5 different parts. Their findings suggest that trees, in particular, have a considerable influence on preference, implying that they deserve more attention and space in cities.

2.2. VR as a tool for human perception and evaluation of space

It can be said that the concept of virtual reality began with the idea of Sir Charles Wheatstone, who first introduced the concept of stereopsis to the world in 1832 which used two mirrors set at a 45° angle to reflect images set opposite each other, creating a spatial image, opening the way for more investigations in this field (Paszkievicz et al., 2021). The present study uses the concept of virtual reality proposed by Steuer (1992), who described it as a specific form of human experience activated by the feeling or sense of presence. Presence is the experience of being present in a given location after perceiving it – a result of senses' perception of external stimuli (Huang et al., 2021; Marr, 1982). Presence refers to the subjective feeling of being a part of an extensive, realistic experience, which contributes to the illusion that the virtual world is the valid and actual environment (Bowman & McMahan, 2007). The most important distinction between non-immersive and immersive VR is the level of presence (or immersion), which the immersive kind tries to improve through the use of stereoscopic visualization and other resources (Paes et al., 2017). Participants with a good sense of presence experience and behave as if they were in reality, resulting in high ecological validity and transferability of research findings (Roberts et al., 2019). VR not only offers an immersive interface that nearly parallels a real-world situation, but it also guarantees the standardization of experimental settings, which is impossible to do in real life (Huang et al., 2021).

There is substantial evidence that the built environment can influence human responses and performance in a variety of ways, as evidenced by the growth of the field of architecture (Coburn, Vartanian, & Chatterjee, 2017) where the use of approaches for visualizing VR is prevalent. What is meant here is that architects use virtual 3D building models to create rendered images or fly through videos they display to customers and other potential users (Adi & Roberts, 2014). In most cases, the application of VR or virtual environments in architecture relies more on construction approaches rather than design features (Patel et al., 2002).

The biggest drawbacks of this technique are that architects prefer to offer consumers what they expect them to see as designers, without allowing customers the freedom to navigate and appreciate the room on their own (Barrett & Stanley, 1999). It may also be argued that while most decisions have been made, the simulated versions presented to consumers and users appear to be in the final stages of production. Models put in simulated worlds such as Second Life, CAVE or OCTAVE aim to offer the customer (building users) a high degree of flexibility that enables them to explore and communicate with any aspect of the building (Patel et al., 2002).

The most positive aspect of VR is that it is possible to give people the experience of the golden rule in operation. The golden rule of reciprocity (“treat others as you would have them treat you”) can be found in most ethical traditions and religions and is considered a simple human moral obligation (Slater et al., 2020). For example, VR will put individuals in the bodies of others, allowing an "ingroup" member to briefly assume the body and location of an "outgroup" member: A individual with pale skin may have dark skin for a

brief period (Maister et al., 2013, 2015; Peck et al., 2013; Banakou et al., 2016) or vice versa, an adult can become a child (Banakou et al., 2013; Tajadura-Jiménez et al., 2017), and someone can experience a world where they are taller or shorter than their real height (Yee and Bailenson, 2007; Freeman et al., 2013).

Aside from transforming bodies, VR allows people to have a wide variety of first-person interactions. For example, a simulated image of a phobic agent (such as spiders) may be shown to a person, who is conscious that it is not actual but encounters it as if it were (Adi & Roberts, 2014). Thus, VR is being used for medicinal uses such as pain relief (Matamala-Gomez et al., 2019) and anxiety problems and phobias treatment (Freeman et al., 2017) as well as for assessing signs and neurocognitive deficiencies of individuals that are suffering or are at the risk of psychosis (Rus-Calafell et al., 2018). Moreover, its usage for preparation in several numbers including military, nursing, surgery, and disaster management is gaining momentum (Spiegel, 2018; Vehtari et al., 2019). All these advantages rely on the extent to which the experience is perceived as real. It is reasonable to imagine that more realism in these VR scenarios increases their effectiveness (Slater et al., 2020).

VR has shown its potential in numerous articles and studies to be used as a reliable tool for architectural and urban usage. When compared to traditional non-immersive systems, immersive VR systems would provide better support for the spatial perception of architectural models, i.e., the level of effectiveness of such systems in terms of facilitating improved spatial cognition (Paes et al., 2017). The study led by Paes et al. 2017 seeks to investigate and quantify the ability of a specific low-cost, projection-based

immersive environment to provide a better understanding of a three-dimensional virtual representation than a traditional VR system (non-immersive model).

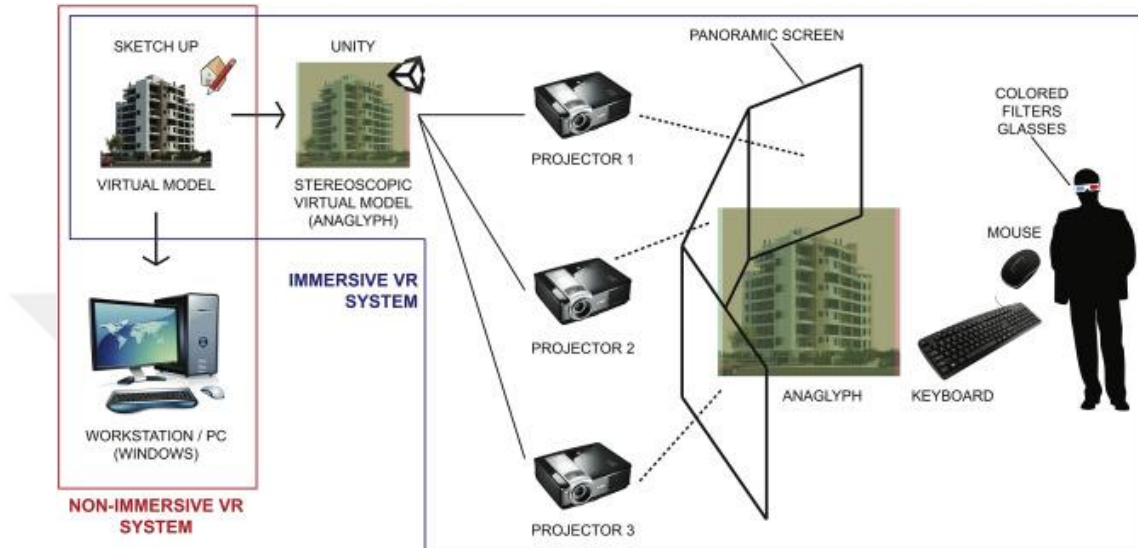


Figure 3. Setup and operating schema of the VR environments (Paes et al., 2017)

The IVR system was shown to improve the spatial perception of a very specific user profile, which may be one of its limitations. This user does not need prior knowledge or experience with 3D models to improve their spatial perception. However, a strong link between the level of education and perception of virtual space was certified, that participants with undergraduate or graduate degrees had better perceptions than high school students, suggesting that educational level may play a significant role in spatial cognition in immersive environments. Furthermore, architects and engineers had a greater grasp of the 3D model in the IVR system than architecture students and other professionals, showing that professional expertise may help with spatial awareness while using the immersive system. Overall, the major finding of this study was that immersive VR provided a superior spatial perception of the 3D model as opposed to traditional VR.

The research by Yuan et al. (2014) describes a VR experiment that looked at how people build mental maps, produce spatial memory, and respond when navigating an urban space. In this study, a virtual town was created with only its spatial signals retained to ensure that non-spatial cues such as traffic signs and crowd activities had no effect on explorers. Participants were asked for the study to explore the virtual street space wearing a 3D-glasses and use control devices to explore the virtual village. They were instructed to memorize the street network as best they can then complete questionnaires and redraw the street structure after the VR experience. By comparing the participants' behavior trajectory with the real town spatial structure, the interaction mechanism between urban evolution and human behavior was examined. Moreover, this study shed light on the potential usage of VR technology as an effective tool in cognitive urban research. As the experiment suggests, VR technology can be useful in studying spatial cognition, memory, and behavior in various environments.

2.3. Application of VR in POS, UGS and environmental design:

Several studies are using VR methods as a tool for investigating people's preferences and choices in outdoor environments. These are great backup and support for utilizing VR methods in research. The possibility and advantages of employing Immersive Virtual Environments (IVEs) to assess individual environmental preferences were discussed by Barenboim and his colleagues (2019) where participants were asked to rate and score their cycling experience after pedaling a few simulated routes with different environmental variables consisting of lanes, greenery and cyclist and pedestrian lines. It was shown that in the IVE, the presence level was significantly higher than in the still

image experiment. This finding backs up the theory that IVEs have a higher level of external validity due to their realism (Birenboim et al., 2019).



Figure 4. Still pictures that were taken from the IVE of the experiment (Birenboim et al., 2019)

Reviewing the literature shows that one of the main aims of employing VR techniques is to analyze the design before making any constructive decision and implementation in the real world. A democratic society requires public engagement in the decision-making processes that shapes cities all around the world (Christodoulou et al., 2018). Some scholars have named this process as participatory design. When compared to viewing designs on non-immersive displays, VR headsets provide more engagement and vivid recollections, this fact makes it a better choice for participatory design (van Leeuwen et al., 2018).

Research by Dutch scientists Van Leeuwen et al. 2018, Hague city municipality defines the project and invites researchers to help them in the re-design process of a local park.

The project was done in two phases. Some 3D modeling as the proposed designs were prepared in a virtual environment. Then the participants who were the residents of the neighborhood got exposed to different scenarios and then fill out the questionnaire. The findings were critical for the municipality in considering whether to invest in immersive VR technology to encourage citizen participation, as they showed that participants who used immersive VR had higher levels of engagement than those who used non-immersive VR when examining various park designs. The outcomes indicated that employing VR headsets with 3D rendering in such a procedure had various advantages. First, immersive VR generates more engagement than 2D presenting technologies, indicating a greater possibility of a better participatory design process (Mahmoudzadeh et al., 2021). Second, immersive VR produces more vivid memories of the watched information than computer monitors, which may be useful in making informed judgments. Third, the impact of human interaction should not be overlooked in decision-making processes that make use of engaging technology.

In the study of measuring spatial perception of planning phases of high-rise urban development's Lu et al. (2021) introduced virtual 3D gaze-tracking and spatial perception experiments to examine how participants react to virtual representations of the two periods of planning. It has resulted in a better knowledge of participants' spatial perceptions and preferences, highlighting regions of greater interest and complexity, which may affect planning and design practice. This shows that the general public can take a larger role in various phases of the planning and design process. Representations

with higher levels of complexity, which are often accessible later in the planning process, aid with landmark recall.

Green parks are also studied by Atwa et al. (2019) with the primary goal of providing a technique for the green park landscapes that will help stakeholders make decisions and emphasizing that obtaining users' and experts' opinions via VR techniques is critical to accurately predicting how a space will perform. To address the issue of showing users 2-dimensional (2D) images with reports, a 3D modeling procedure in static VR was used to convert the 2D designs into 360° panorama images that could be easily explored on headsets and devices. Five 360° panorama photos in 5 different points for each scenario were created for the questionnaire survey and evaluation of this study to let participants quickly visualize different possibilities.

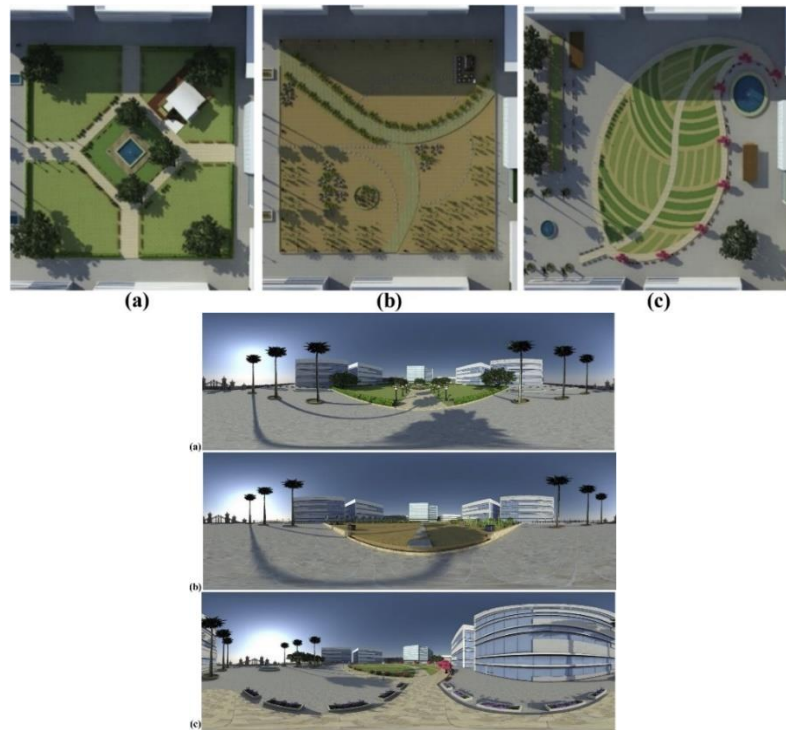


Figure 5. Top: The layout of the three alternative landscape designs, Bottom: 360° panoramic images of the three alternatives (Atwa et al., 2019)

The photographs were uploaded to a virtual tour website and transformed into static VR images that could be browsed on IOS and Android mobile devices, allowing the user to explore the landscape designs while wearing a VR headset. They then completed a questionnaire and chose the best option. The spent time for the users who completed the questionnaire without utilizing VR technology was significantly longer than those who utilized a VR headset and they were interested in employing this technology because it added realism to the design (Atwa et al., 2019). The study proved that 3D visualization on mobile devices has a strong potential to improve public participation and design scenarios involving employees, stakeholders, professionals, and businesses.

2.4. Greenery and thermal comfort

Thermal comfort is defined by ASHRAE as “the condition of mind in which satisfaction is expressed with the thermal environment”(ASHRAE, 1992). Urban inhabitants frequently experience summertime heat stress, which has serious negative health effects, especially in the context of climate change. (M. J. Alcoforado et al., 2009; Erell & Williamson, 2012; Fintikakis et al., 2011; A. N. Nouri, 2013; A. S. Nouri, Costa, et al., 2018; Zölch et al., 2019). There are numerous studies focusing on the role of greenery on POS and how they can alleviate the thermal condition for the users for a better participation and presence. The quality of life and physical health of people who live in metropolitan areas can be positively or negatively impacted by the environmental quality of those areas (Perini et al., 2018). So, these issues as the main natural hazards impacting densely populated cities need to be addressed in urban planning, with a focus on POS like public squares where people engaged in leisure and outdoor activities are exposed to heat

(M.-J. Alcoforado & Matzarakis, 2010; Oliveira & Andrade, 2007; Zölch et al., 2019). In this field studies are focusing on different aspects of the environments or the greenery elements.

Perini and her colleagues (2018) investigated the role of greenery in the streets, which they referred as green streets and their characteristics as foliage shape and dimension and seasonal cycle. Using Universal Thermal Climate Index (UTCI) thermal index values, an urban layout consisting of two urban canyons (NS and WE orientated) and a courtyard with and without vegetation was used. According to simulation results of the summer performances of trees planted along roads showed that roadside trees had larger effects on relative humidity and air temperatures and reduced wind speed. On the other hand, had a negative impact on outdoor comfort during the summer in courtyards, and in the midst of canyons. Trees reduced mean radiant temperature both during the day and at night, enhancing thermal comfort.

Another research undertaken by Nouri et al. (2018) examined the impact of *Tipuana tipu* species on thermal comfort levels of pedestrians during summer and winter in Lisbon, Portugal. The assessments were conducted using a new version of the SkyHelios model, locally derived Grad values calculated using the human-biometeorological model RayMan, all of which were based on a reference point (RP) system. To classify the findings and make their interpretation easier, the study used the climate tourism/transfer information scheme (CTIS). The study determined the *in-situ* thermo-physiological influences of *Tipuana tipu* during various seasons of the year, including (1) the summer, showed a significant PS reduction during an extremely hot day and (2) the winter, which

revealed the dangers of oversharing because the species retains its foliage during the winter with reductions in PS grades. They lately address 2 practices for public space design remarks (i) Specify the current thermal risk factors (ii) provide innovative ways to improve thermal conditions for pedestrians in an era prone to climate change.

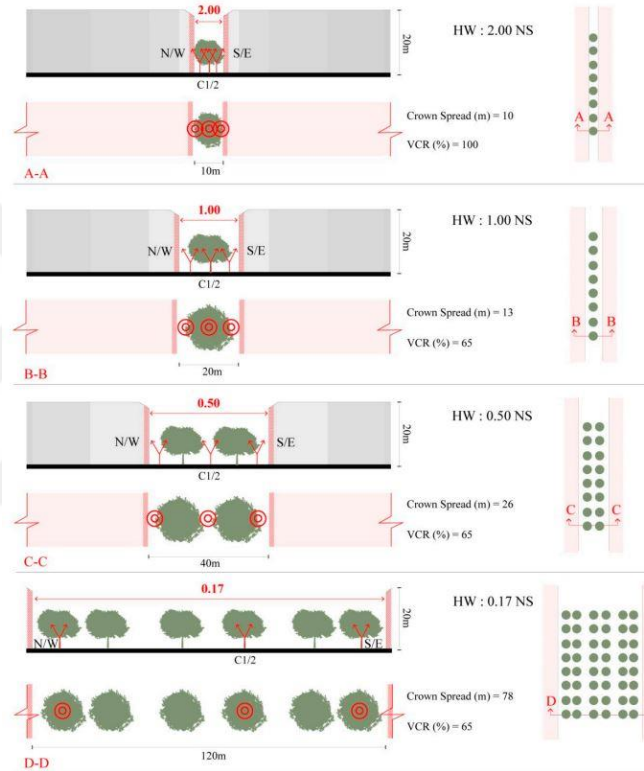


Figure 6. North-to-south orientation layout of the determined urban canyon cases and the central/lateral reference points with specified crown spreads and vegetative coverage ratios (A. S. Nouri, Fröhlich, et al., 2018)

Next study took place in Munich, where Zolch et al. (2019) evaluated the microclimatic effects of common greening designs for rectangular public squares on a hot summer day, both during daylight hours and at night and thermal comfort values were compared using a validated ENVI-met V4 model. To test the microclimatic effects of various green designs at public squares, nine scenarios were created by categorizing all 326 public squares in Munich according to their greening design and their aerial photographs that is,

the shape and structure of the vegetation on the square. The greening design for the most common square shape -rectangular- could be further divided into eight varieties, one of which is the current state of greening at rectangular Bordeauxplatz, and another that is non-greened and devoid of any vegetation. The case study was then given the 8 derived greening options plus one optimized green design solution as greening scenarios and each one was given a name based on the tree layouts. Based on the analysis it was understood that a climate-adapted design must use trees to increase the amount of shaded surface areas, while the main wind channel must be kept clear of trees but planted with grass to reduce heat storage. Thus, markers for creating climate-adapted public spaces can include the quantity and positioning of trees as well as the size and placement of grassy areas.

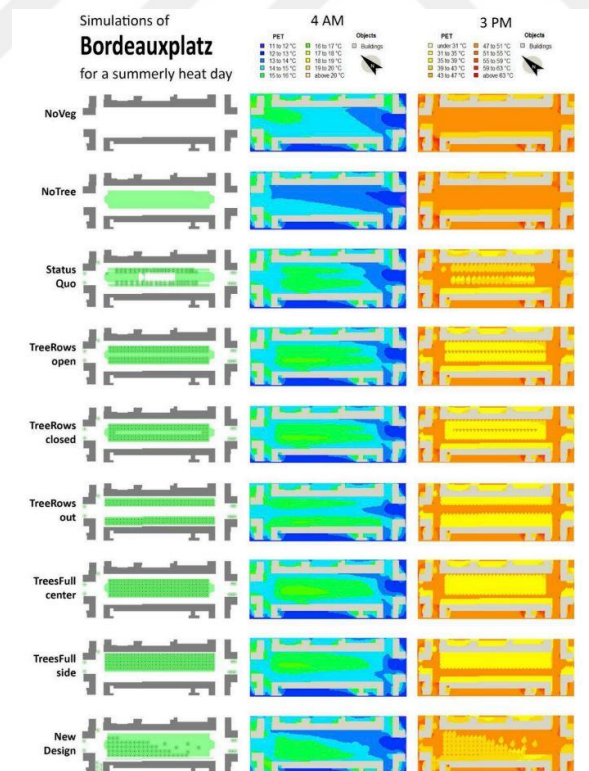


Figure 7. Spatial maps of PET distribution (at 1.4 m height) in the case area for 3 p.m. and 4 a.m. of a hot day (Zölch et al., 2019)

In the other study, the primary microclimatic risk elements in the Rossio square affecting pedestrian thermal comfort thresholds were analyzed in order to be used to create opportunities for public space design (A. S. Nouri & Costa, 2017). The findings of a bioclimatic investigation conducted at Rossio, one of the city's oldest public areas of Lisbon, were presented in this paper. The study concluded a series of public space design ideas that were built upon the square's microclimatic risk indicators using readily available meteorological equipment and user-friendly models and software for urban design and planning specialists.

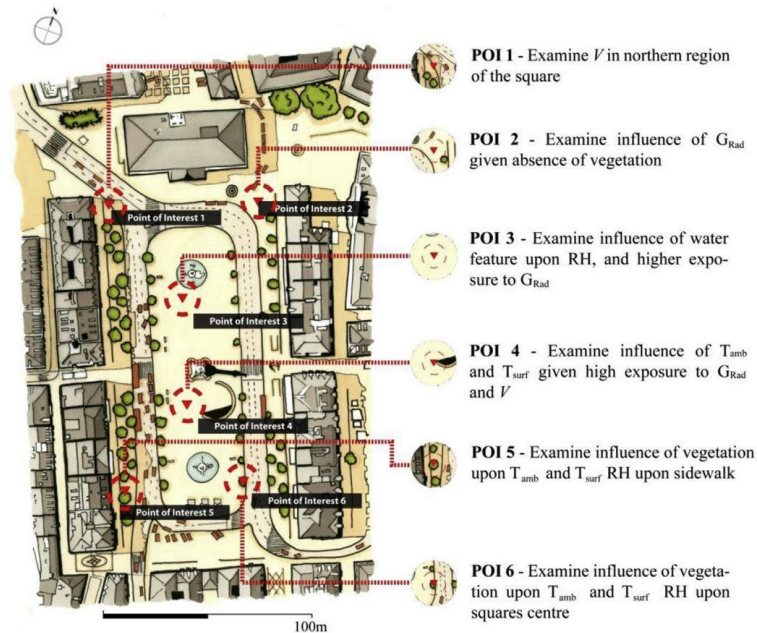


Figure 8. Developing particular POIs based on initial simulations around the square

The empirical goals of the study, conducted in the summer of 2015, were after identifying the microclimatic risk factors within various Rossio locations, offer conceptual intervention that can enhance pedestrian thermal comfort during times of increased yearly climatological stress. Six Points of Interest (POI) were established within the square using Computational Fluid Dynamics (CFD) and Shadow Behaviour Simulations (SBS)

simulations in order to build an early knowledge of thermal comfort conditions. Then, using on-site meteorological portable equipment, ambient temperature, surface temperature, relative humidity, wind speed, global radiation, and Sky-View-Factor (SVF) were measured. Pedestrian Based Response (PBR) interviews were also done to supplement these assessments. The study finally ends with some design guidelines like for vegetation for a better urban thermophysiological conditions.

2.5. Literature gap:

Thermal and environmental studies utilizing VR techniques reveals some gaps in the literature. The fact that POS have a significant impact on human's relationship with their surroundings and urban inhabitants is undeniable. Moreover, these spaces have a direct effect on people's overall well-being and mental health which is also the influence of the environment on minds. Furthermore, the types and patterns of greenery that exist in towns are dramatically influential on the frequency that an outdoor space is used. On the other hand, existing greenery have a direct relation to overall thermal comfort in POS. The average air temperature is expected to rise as a result of climate change, and UHI are expected to become more frequent, intense, and prolonged (Chapman et al., 2017) . Climate change's health consequences can have indirect psychological and social costs including the so-called secondary health effects of stress, anxiety, and depression (Matzarakis, 2022). Effective passive cooling and UHI mitigation strategies, along with the appropriate design of public areas, will considerably improve the local urban microclimate (Gaitani et al., 2011). Existing heat risk factors on human health, as well as the growing urgency as a result of climate change making management of POS

increasingly important, especially as the climate change adaptation agenda calls for thermally responsive POS. As a result, there is an increased demand for planners and architects to assess and quantify adaptation measures such as approaching particular urban morphological configurations and implementing various types of vegetation that can optimize the local urban climate (Matzarakis, 2021).

In addition to that, greenery can affect the individuals' general perception of outdoor spaces and judgements and also the preference of a POS that will again lead to the usage pattern of spaces. The understanding of how people perceive microclimate in outdoor areas may be a foundation for urban spatial planning (Gaitani et al., 2011). The spaces that are preferred by people will be used more often or if they do not like them, they will be discouraged. Although POS and VR applications are receiving more attention these days, the number of papers available is still very limited when compared to thermal studies. Nevertheless, these numbers serve as a solid foundation for the current research and comprehension of scientific applications of IVEs. There are different environmental studies about outdoor and indoor spaces using VR technology (E.g., Burns et al. 2011; Lu et al. 2021; Patel et al. 2002) but a common problem is that a great number of those studies that have used VR applications in indoor environments studies have asked the participants to do a task with some remotes or controllers (E.g., Yuan, Song, and Zhang 2014) or by reading something (E.g., Mahmoudzadeh et al. 2021) and by observing their performance some conclusions are made (Fukuda et al., 2019; C. Wang et al., 2021; D. Yeom et al., 2019).

Nevertheless, in POSs, it is mostly the perception and preference that the tasks are mostly passive. This also can be due to the size of POS maybe because the huge size of these spaces making it impossible to ask the participant to do many things. Possibly, the most engaging task experienced is walking in a virtual environment that also has some defects as walking in a virtual environment is not always being done comfortably and some participants feel unsafe or dizzy, requiring protection from another person. Or sometimes a small part of a bigger outdoor environment should be selected as the site of research (Lee & Kim, 2021). Many researchers also have been working on innovative methods and tools to facilitate and aid the immersive walking (Birenboim et al., 2021), Omnidirectional treadmills allow users to perform locomotive motion with 360-degree freedom while remaining stationary in the physical world (Hooks et al., 2020). However, the costs and availability of these equipment make such orientated studies more difficult to accomplish. Natural walking necessitates an open and unobstructed environment that allows users to travel freely without fear of falling over barriers while engrossed in a virtual world (Sousa et al., 2019). In these environments, the walking behavior itself is not yet natural enough to imitate the natural walking that people do every day and also treadmill walking mechanisms are still not perfect (Birenboim et al., 2021). There are significant differences between how people walk in VR and how they walk in the real world as studies have shown that in the virtual environment, gait parameters such as velocity and step length are significantly reduced (Janeh et al., 2019). The limitations of most natural walking strategies for navigating in virtual spaces can also make them challenging to employ in tight home environments (Sousa et al., 2019). Sometimes, participants devote their whole attention to keeping their control and balance while

virtual walking and are distracted from doing their main task. Therefore, so far walking by any method and material that is being done cannot be evaluated as a completely reliable realistic and engaging behavior.

Another important gap here is that in many studies the participants are selected among a special group of people. For example, they are architects, nurses, university students or elderly people or even children (Cervinka et al., 2014; Lee & Kim, 2021; Mahmoudzadeh et al., 2021; Maillot et al., 2017; Strickland et al., 1996). As was mentioned before, people with a special degree or literacy level have a better performance in virtual spaces. The younger generation may have more connection with technology and they know more about the latest technological advancements in comparison with older people. So, selecting the special groups of people to conduct a study in virtual environments for a case like ours cannot be an appropriate option. All groups of people regardless of their profession were included, university degree, gender or age. They must be over 18 and mentally healthy. The other problem is the environment of the study itself. Many studies have been conducted the study in a very controlled area and trying to immerse people in a room into a virtual environment. Inviting people from one place to another to come to a special area seat on a chair and be informed of the processes and then be immersed in the environment. Although it is necessary for many studies, for the current study it doesn't seem an appropriate method. Instead of inviting people to a particular place with different methods, similar to the study by van Leeuwen et al. (2018) that the municipality mailed a written ballot invitation to all 13,500 residents in the area, as well as advertising the election online or through a poster campaign, the experiment was taken to where people are spending their ordinary life.

So, it was impossible to invite people for example from Germany or another city to participate or even among a random group of Araki inhabitants. Those actual users of that environment spending time at least once a month in the environment were sought, being fully informed of that space's physical and cultural attributes. Furthermore, it can be pretty assured that they have experienced using that area in different seasons and different times of the day. Thereby, any intervention will also affect those people. They are actual users, not merely virtual participants. This is deeply missing in most of the studies and sometimes the actual users are neglected and the study is being done by another group that will never use or experience the space.

Thus, it was tried to develop a method that people can experienced the proposed project in a virtual environment by watching 4 scenarios of 360-degree videos. Innumerable studies have shown that using VR besides all the advantages have some drawbacks that are mostly related to the mind, including headaches, mental and eye fatigue, the present experiment is simulating walking in the virtual environment. Although they are not physically walking, but the camera is moving which is set at the eye level and moving slowly giving participants adequate time to explore and percept the environment well.

The other extremely considerable gap in the literature is that although many thermal studies have proposed scenarios for outdoor environment to improve thermal conditions like in Nouri (A. S. Nouri & Costa, 2017) proposing various design guidelines such as designing with vegetation, shelter canopies and with water/misting systems, each one capable of improving thermal conditions of a hot and dry Mediterranean public square, they have never investigated people's opinion or perception of those proposals. Getting

the above example, if in real world, a project is being done, how do the designers will approach toward such designing mission? Just proposing a design based on the thermal simulations data or some terms like participatory design find importance too? Will people like the design concentrating just upon the thermal analysis? Or people's attitude and impression will be respected? On the other hand, many studies studying people's psychological feedback toward urban design projects also lack in terms of thermal information. Assuming that scholars concluded that people have preferred a scenario psychologically in terms of aesthetics or pleasantness (van Leeuwen et al., 2018). If such project is being done, thermal necessary analysis will be missing. The huge gap here provokes the fundamental cooperation of scholars and designers from various fields and backgrounds for a more fruitful design approaches which accomplish both sides of thermal and psychological aspects. It is vital to trust people's ideas, attitudes, and points of view in site design to succeed in the design of POS (Rahnema et al., 2019). According to Montgomery (2013), a successful site is one that is more alive and dynamic and can foster an environment where people's satisfaction is prioritized. They argue that having a foundation for exchange and engagement is the key to success in POS design. Designing POS for thermal comfort solely on the basis of a physical model is insufficient and also a purely physiological approach to characterizing thermal comfort conditions (Nikolopoulou et al., 2001). Understanding the wide range of factors affecting thermal comfort in these spaces will help in designing areas that encourage public use throughout the year, making the physical environment a crucial factor in outdoor thermal comfort along with psychological adaptation (Nikolopoulou & Steemers, 2003). The intersection of climate change, urban design, and user-based adaptation approaches can lead to the

strengthening of POS design guidelines in light of local risk factors (A. S. Nouri & Costa, 2017). In the present thesis initial steps toward this vital collaboration are taken. The experiment design is described in detail in the following chapter.



CHAPTER 3

METHODOLOGY

3.1. Research question

As mentioned in the previous chapters, people's perceptions, attitudes, and behavior in relation to green space have lately gained scientific attention, moreover as cities become further prone to growing climatic aggravations. The ultimate purpose of this study is to improve the outdoor environment design at a level where people's preferences and performance are converging the most, and at the same time the thermal comfort condition of the design is verified too. Furthermore, emphasizes the application of VR as a truthful scientific tool in participatory design toward a more successful outdoor environment design and minimizing the costs and defects.

RQ: Is there any relation between local people's preference, performance and thermal conditions for alternative greenery designs in the Amirkabir pavement?

Sub-RQ1: Is the aesthetically preferred scenario the one in which people perform better and demonstrate the most spatial comprehension?

Sub-RQ2: Is there any correlation between people's psychological responses toward alternative greenery scenarios and the thermal evaluation of them?

Sub-RQ3: How different greenery scenarios with different types of trees can thermally perform in the Amirkabir urban square employing PET and mPET indexes?

3.2. Hypothesis

H1: People's preferred Amirkabir pavement greenery design scenario significantly differs from the scenario that they showed better performance and provide a better thermal comfort.

H2: There is a significant association between people's sense of safety, happiness, stress, refreshing, freedom and the greenery design layout.

H3: All four recommended scenarios provide a better thermophysiological conditions for pedestrians in comparison with the existing condition.

H4: The green area and pavement's perception can be highly affected by the green space design layout.

3.3. Location and study sample:

Participants are one of the most important aspects of this study. It was critical to conduct the research among the actual Amirkabir pavement users. Participants were excluded if they were using the pavement less than once a month. A total number of 40 people were recruited for this study (20 females and 20 males). The participants ranged in age from 18 to 75 years old. All participants were informed that participation in this study is voluntary, and the authors did not put any pressure to participate. All of the participants expressed they were in good health and had no mental health issues and also none of

them had any prior VR experience. This study tried to understand people's greenery design preference and performance in Amirkabir pavement so the Existing Situation (EXs) was asked if any intervention is essential and all participants agreed.

The chosen location can be considered the city's main thoroughfare. Being the first walkway or pavement built in the city solely for the benefit of pedestrians, as well as the first experience of people using the space without disturbance of cars or motorcycles to sit and enjoy the environment. How this area can be beneficial for people's health and recreation was discussed in the previous chapter but the justification that why this area is the most important part of the city can be discussed below.

Arak was established in 1812 A.D. under the order of Fathali shah of Qajar on the central plateau of Iran and near the Zagros Mountains. In the early years of the Qajar dynasty, there was always insecurity and local disputes, and this caused political and economic complication for the central government. Arak was built to connect Tehran to southern cities such as Isfahan, serving as a defender castle of Tehran in the occasion of a threat from the south. Thus, Arak was built purposefully as a symbol of pre-determined designed historical cities in Iran and was shaped around the great grand bazaar. The bazaar has long served as the city's heart. Early in the 18th century, the bazaar of Arak was built according to predetermined plans. Unlike other bazaars, its alleys are rectilinear and geometric, rather than free and organic. The main corridor of the bazaar and the numerous alleys which intersect it forms the backbone of the city's checkered plan. The Arak Bazaar is known as the newest grand bazaar among Iranian grand bazaars; it is a collection of centuries of experience in building this type of bazaar and is projecting the

most stylish and newest construction methods of bazaar construction based on a predesigned and ordered checked plan.

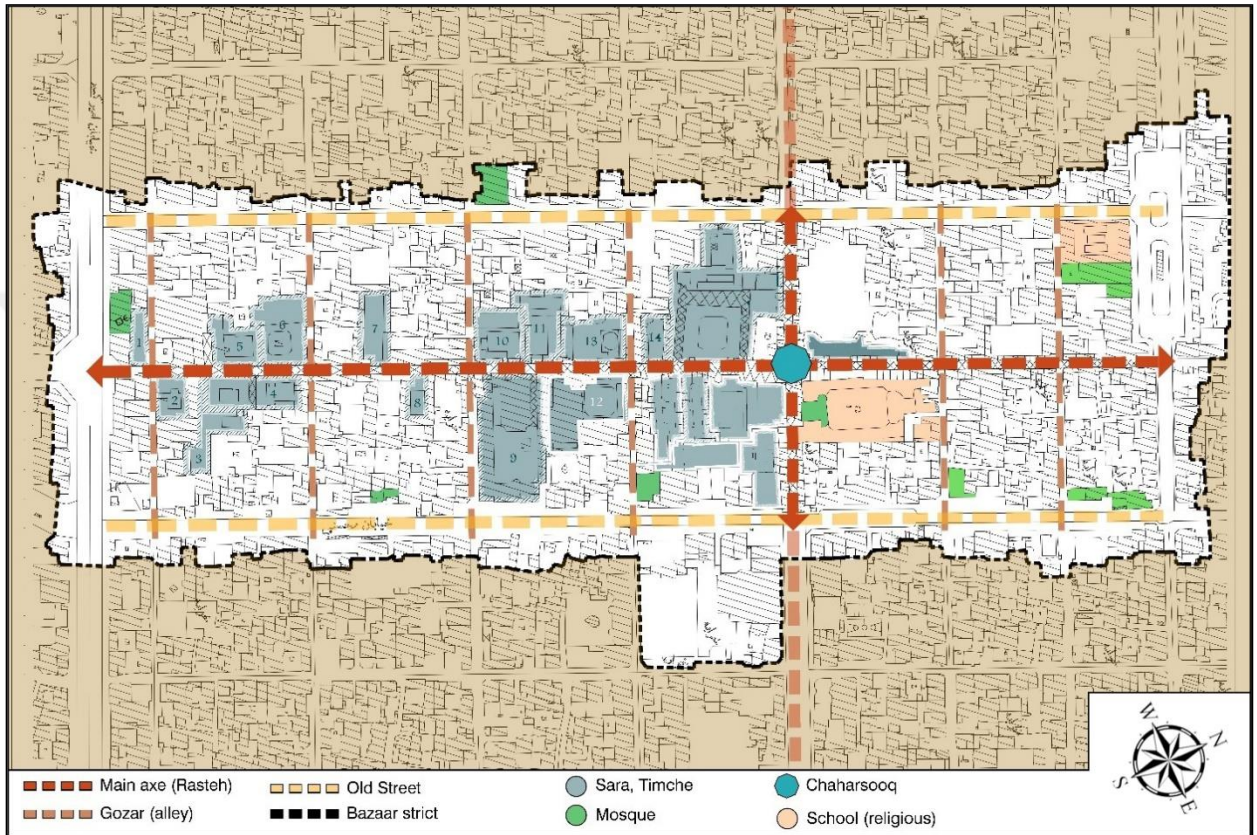


Figure 9. Grand Bazaar of Arak current condition map from (Pirbodaghi, 2015), analysis by author.

Many functions and activities are organized around the bazaar. Apart from their economic importance, they have served a variety of other purposes, such as social, cultural, educational, religious, political, and recreational functions (Kiumars Irandoost & Oramani Arman Bahmani, 2011). Eventually, the bazaar formed all of the people's activities and lives. The bazaar was divided into two main axes, one longer and one shorter. The longer axis began at The Baghmelli and ended at Ark Square. This axis was the most important axis of the city, shaping the geometry and physical attributes of the city. The shorter axis then cuts the longer, and the space formed by the intersection is

known as Chaharsooq, which means "Four-Direction". The main north-south corridor (Rasteh) is 880 meters long, and an east-west row is 600 meters long. These two main axes serve as the bazaar's skeleton, upon which other components are erected. Mosques, baths, schools, and residential buildings are all established in alleys that run parallel or perpendicular to these two axes.

Imam Street interrupts and cuts the direct connection between the Bazaar and the Baghmelli (means national garden), which is now known as Meydan Shohada (Martyrs' Square), resulting in a gap between the Bazaar and the city center. Despite the gap's small size, it significantly affects the city. Imam Street, which separates the city into two sections, is very congested and busy with many cars and motorcycles, making it difficult and dissuading those who are wandering and walking on the opposite side of the street from crossing it and going to the bazaar. If a person has nothing to do in the bazaar, due to the danger of crossing the street, will not visit it. Fortunately, the city's master plan predicts that in the future, the entire area will be paved and cars will be transferred to the underpass, reuniting the city's main heart. As a result, it is expected that this street and pavement will continue to play a pivotal role in determining how citizens and urban activities are shaped in the future.



Figure 10. Current condition (left), predicted condition based on the city's master plan (right)

3.4. Defining the Scenarios:

Four greenery scenarios were defined according to the planting layout, tree types and shop quantities. They were named as Scenario A (ScA), Scenario B (ScB), Scenario C (ScC) and Scenario D (ScD). In the following sections the scenarios' designing process is described.

3.4.1. Scenarios' planting layout:

To create the scenarios, it was necessary to research the current state of the city's pavements. However, because this is the first pavement built in the city with a primary focus on pedestrian needs, it has attempted to adhere some initial design standards while also being welcoming to citizens as their first experience with such an environment. Instead, 96 different green environments in Arak were studied and analyzed and their planting and path patterns were specified. It was understood that about 60.42% of the

urban parks are following different Persian garden 4-Bagh patterns, whereas 7.29 % are the pattern in which there is a Surrounding And Center (SAC) green area. Moreover, 3.13% are linear types and 29.17% are not following any specific pattern, and some are organic.

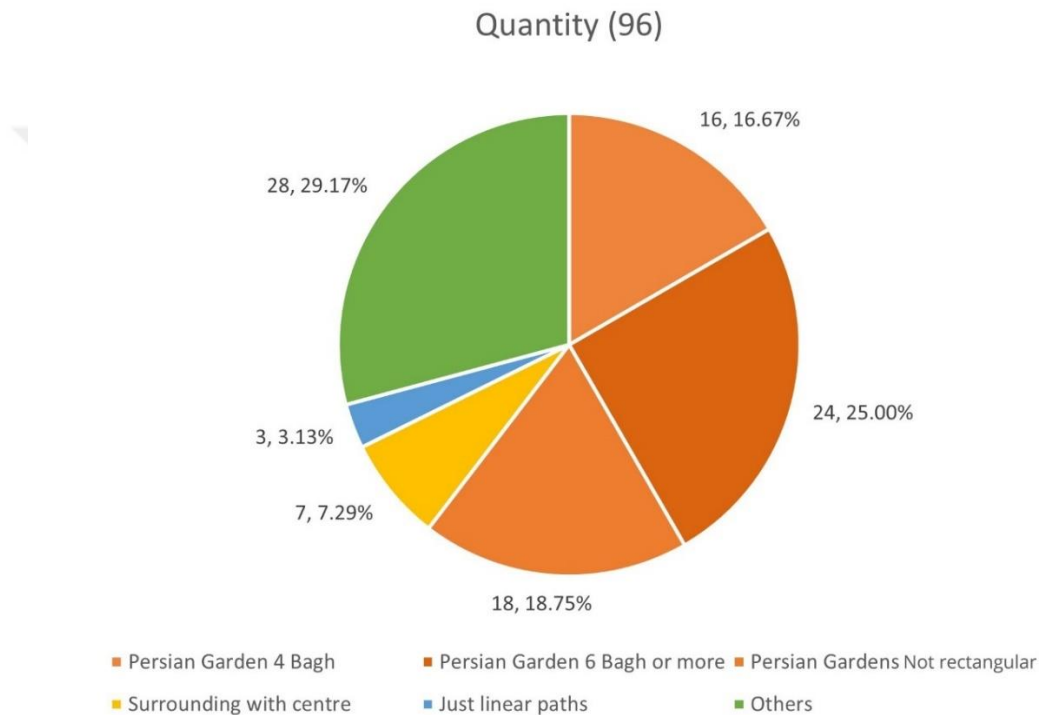


Figure 11. Variety of greenery plan typologies in greenspaces of Arak

3.4.1.1. Application of Persian garden and Chahar-bagh (4 garden) concept:

Persian garden is the term used to describe Iranian gardens around the country. The Persian gardens of Iran have been designated as UNESCO World Heritage Sites. “They exemplify the diversity of Persian garden designs that adapted to different climate conditions while retaining principles that have their roots in the times of Cyrus the Great in the 6th century BC” (Wilber, 1962). When Cyrus the Great established the royal city of Pasargadae during the Achaemenid dynasty, he introduced the concept of the fourfold

garden, or Chahar-Bagh (Asif et al., 2015). “This quadripartite order of Pasargadae gardens has been transferred to Timurid gardens in Samarkand, gardens that were created and shaped in India during Mongol empire and Andalusian gardens in Spain” (Asif et al., 2015). Traces of Persian gardens back to the Achaemenid and Sasanian periods, demonstrating how the early Islamic world's integration of Mesopotamia and Iran resulted in the Persian garden concept being extended to Syria, Egypt, and North Africa (Wilber, 1977). A Persian garden's most prominent feature is its geometry (Ojaghrou & Khakzand, 2019).

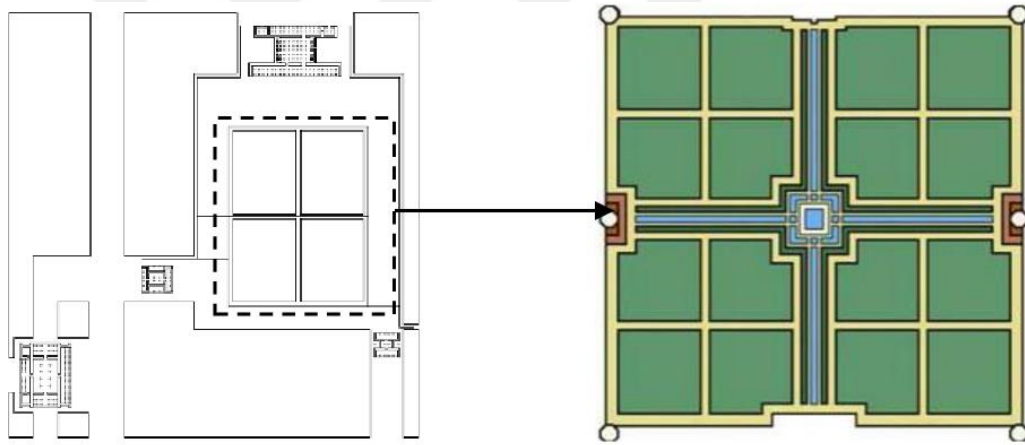


Figure 12. For centuries, the plan of the Royal City of Pasargadae 6th century BCE (Khosravi, 2014) (left) has become the basic pattern of Persian gardens (Halsted, 2014) (right). Comparison by (Latiff et al., 2017).

The quadripartite plan is the main concept for designing and forming the spaces in these gardens, and Persian gardens follow a unique pattern in their component placement from this perspective. Chahar Bagh is the name given to these patterns (the four gardens) (Ojaghrou & Khakzand, 2019). The Persian Garden is a metaphor for paradise and the heavenly world, streams of water split the garden into four sections, signifying the four rivers of heaven or the four directions of the universe (Barati, 2004), as well as a

marvelous area that promises a life of peace, tranquility, comfort, moderation virtue, and freedom from evil oppression and darkness (Barati et al., 2018) (Khosravi, 2014). Persian Gardens are the most prevalent type of greenery design in Iran, and can be found in almost all cities. Apart from the profound meaning and philosophy behind it, it is also the simplest and least time-consuming way for urban designers to design any UGS. It has been widely experienced and accepted by the Iranian people, and the straightforward implementation of the design has made this concept a secure strategy. Persian garden should not necessarily be consisted of four equal squares or rectangles despite the quadripartite concept. Four rectangles may not be exactly the same size and form, or they may not be rectangles at all and can be divided into six, eight, or even more portions, depending on the purposes or requirements of the project. However, the basic concept is the same, as seen in many Iranian greenery designs. Looking at some greenery spaces in Arak, there are shapes that are not regular geometries but have been designed by the same strategy.



Figure 13. Samples of Persian garden layout, Pardis Park; rectangular regular design (left). Mellat park; irregular pattern following Persian garden concept (right)

To sum up, according to APPENDIX B and figure11, an examination of greenery designs in Arak reveals that the city has three distinct types of greenery designs. The traditional Persian garden typology is presented first, followed by SAC typology which the area is

surrounded by a row of trees, which is supported by a second green area in the center and this design strategy is used in seven of the 96 spaces. The linear typology, which consists of long or short rows of trees with pavers in between, was also observed when examining greenery designs. This category contains three samples in Arak. The remaining 28 parks do not conform to any specific typology and are designed freely or haphazardly based on the shape of the site.

3.4.2. Tree type selection:

Different aspects of vegetation that affect people's thermal comfort in public spaces in a review study by Nouri et al. (2018) were presented. Correct plant selection can assist urban designers and architects to create resilient urban streets to improve the thermal comfort of the environment in cities that experience high levels of discomfort during the cold winter and hot summer months (Yilmaz et al., 2021). To select the appropriate types of trees for the experiments, papers about the Persian gardens had to be reviewed to acquire the principles of vegetation in those areas. At the same time, it is important to identify what is the local tree in Arak. Vegetation in Persian gardens includes a range of trees and other plants of diverse types and functions, with or without flowers and lawns (Latiff et al., 2017). Trees were planted for medicinal, food, aesthetic, and other purposes (Farrar & Carroll, 2003), and were primarily of three types: evergreens like cypress, deciduous like plane, and fruit trees (Latiff et al., 2017). Soil lands have traditionally been planted with aspen, Tabrizi, and rowan (Alidoost et al., 2013). According to (Seifloo, 2013) shade trees formed a major feature in the Iranian garden, and large numbers of sycamore and plane were planted to cast their shadow over water, against walls and over paths, which were therefore narrow to make the environment pleasant and

protect it from the intense sunlight. Other trees frequently found were the poplar, used for building since it grew quickly, and the cypress, appreciated by poets as a symbol of eternity and death, since it did not rejuvenate after being cut. Trees were regularly planted in rows, one particular species at a time being used to border an avenue or define or fill a distinct section. Fruit trees were valued not only for what they produced, but also for their aesthetic appeal (Wiber, 1963).

Unfortunately, there are not enough reliable resources to know exactly what the local trees in Arak are, but by looking at the local streets, especially those historical streets around the great grand bazaar, it is clear that plane and poplar are the most widely used and planted trees. In addition to what has been debated so far, in the study “An Introduction on Greenway Planning Criteria in the Suburban Mountainous Regions in the West of Iran”, Rastandeh (2009) investigates basic principles for greenway planning in the mountainous regions of western Iran, to propose a unique reorganization pattern for the outskirts, suburbs, and natural areas of neighboring urban populations based on the local context. A list of the trees in suburban areas in the mountainous region of the West of Iran, where Arak is also located close to the investigated region, is presented with the feature of different local trees. By matching the list provided by Rastandeh and the trees mentioned before, three commonalities were concluded. *Populus nigra 'Italica'* which is the binomial nomenclature for poplar trees, *Platanus orientalis* which are known as plane trees in English too, and *Cupressus sempervirens* which is a family tree with cypress. As Arak has extremely freezing winters and, in such regions, using a deciduous tree typology is needed to avoid excessive solar shading in winter (Teshnehdel et al., 2020), cypress was excluded as an evergreen tree and the main focus of this study will be on

Populus nigra 'Italica' and *Platanus orientalis*. Attributes of *Populus nigra 'Italica'* are explained as “covering unpleasant landscapes, controlling air pollution and creating pleasant sound with its leaves” (Rastandeh, 2009, p. 14). He defines the main functions of *Platanus orientalis* as “defending against cold winds and providing pleasant shade” following with this interesting claim: “The second respected tree among Iranians” (Rastandeh, 2009, p. 14).

3.4.3. Selection of Commercial functions:

The current different commercial categories of Amirkabir pavement were surveyed and the results are illustrated in the table below.

Table 2. The list of different shop usages in Amirkabir pavement

Functions	Numbers
Grocery shops (Café, Fast-food, Ice cream, Restaurant, bakeries)	15
Shoe shops	8
Watch shops	6
Home appliances and electric shop	7
Jewelry shops	8
Cloth shops	2
Other functions or closed	14
Total	60

As seen in the table, the two most common business kinds are grocery stores and shoe stores. On the other side, a well-known ice cream shop for residents is located there. The ice cream shop was chosen as a basis for the grocery stores because this street is well-known for its ice cream shops. As the experiment's second function, shoe stores were considered; although some jewelry stores have lately opened, they are not yet well-known. Four distinct shop layouts with varying shop counts were compared in this experiment (Table 3). All of them were represented in each scenario by distinguishable

logos and their names in Farsi; people could quickly read different functions by the signs or by their names. In general, these logos do not refer to any specific shop on the environment and are not used in any location throughout the city, but are simply some familiar references for those shops that are understandable to all people. However, no interior decoration was designed for these two categories because virtual environment should be as simple and light as possible in order to be more perceptible to the participants.

Table 3. Number of shops in each scenario

	ScA	ScB	ScC	ScD
Icecream shops	8	6	6	8
Shoe shops	6	6	8	8

3.4.4. VR Modeling, rendering and instrument:

The city plan was obtained from the municipality, then the AutoCAD file was imported into SketchUp. After the preferred experiment site was determined, the modeling process got underway. The intention was to keep it as straightforward as possible to make it easier for the software to process and later render, and for the viewers to comprehend. The shops and vegetation were later added after the walls were constructed using a simplistic brick that is typical in the area. The total area of the pavement is about 3272 m² and the vegetation area in all four scenarios has the same total area of 1695 m². It is about 52% of the total area in general. There are two types of plans as mentioned before, the first one is the Persian garden typology and the second one is SAC. The first one has one main path with a width of 5m and the next one, has two separate paths that are each

2.5m wide. For the number of trees, the aim was to cover 30% of the total vegetation area. According to Rastandeh (2009), each type of tree has almost a 3m radius of the crown so to cover 30% of the total vegetation area, and that the more trees, the higher greenery preference (R. Wang et al., 2019), the equal number of 74 trees were implemented in all scenarios with *Populus nigra* 'Italica' which the coverage of the *Platanus orientalis* is naturally more than Populus. However, the crown volume is the same for a higher similarity in the thermal analysis. For VR study, the model was then taken to the Lumion software which has capability of rendering 360-degree animations.

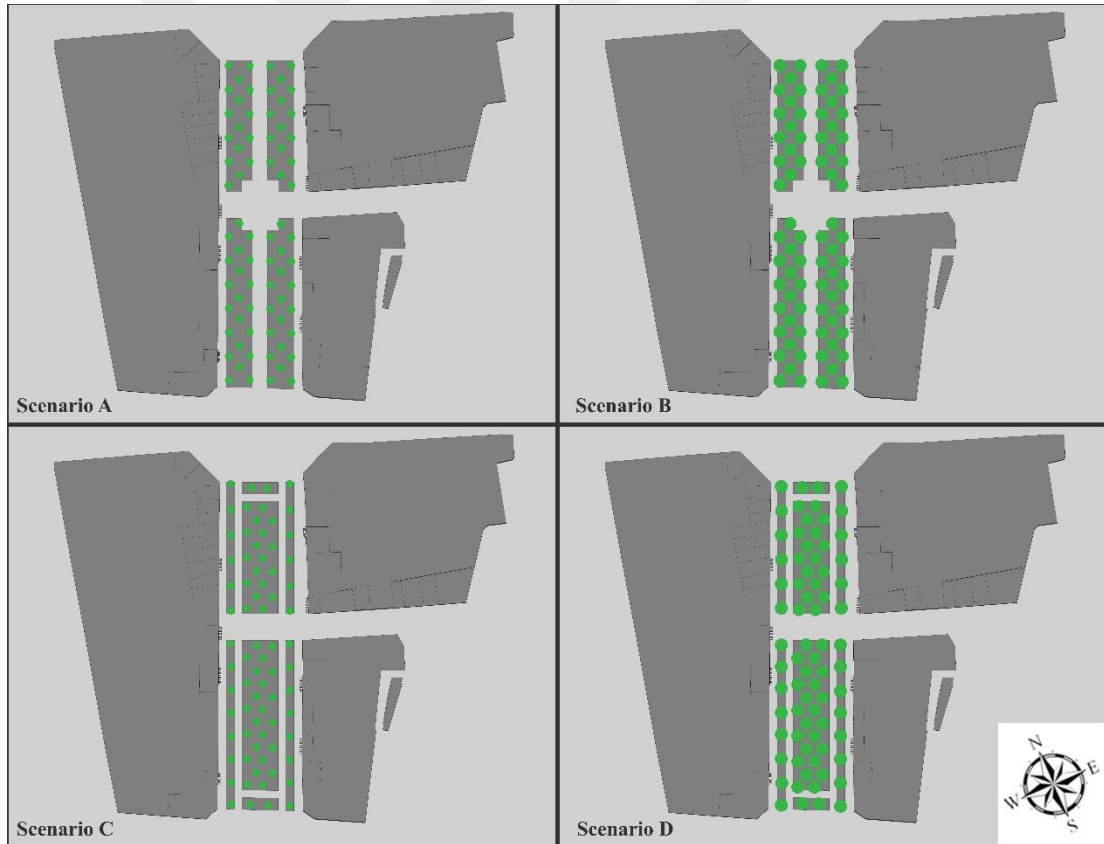


Figure 14. ScA: Persian garden with *Populus nigra* 'Italica', ScB: Persian garden with *Platanus orientalis*. ScC: SAC with *Populus nigra* 'Italica', ScD: SAC with *Platanus orientalis*

A head-mounted display device called the VR-Box was used in this study to show the 360-degree videos to the participants. This gadget, which was a box to set the phone in front of the lenses to assist watching 360-degree films, required neither a direct connection to the computer nor any external power sources thus provided the possibility of free head moving for the participants without any concern of connection or energy problem from the computer. Participants would enter a virtual world after putting their phones in the pull-out chamber on the front of the VR case virtual glasses. The VR media Player android app was used to play 360-degree videos on the Xiaomi Redmi note 8 pro smartphone (Appendix F).

In all scenarios, the animation starting point was from the great grand bazaar, then going to Shohada Square. After getting there it returned to the Grand Bazaar. For all 4 scenarios, the eye level was set at 1.8m and each direction took 1.5 minutes, so each animation was 3 minutes. Considering human average walking speed as 1.20 meter per second (Bohannon & Williams Andrews, 2011), and that the length of the pavement which was about 110m, the video's length was tried to be as the human walking speed. In total, participants would watch about 12 minutes of 360-degree animation. For the Persian garden scenarios, as there was one main path, the camera moved and returned from the middle of the path but for the other scenarios as there were two paths, going and returning were done in two separate paths.



Figure 15. First frame of the scenarios' 360-degree animation, top left ScA, bottom left ScB, top right ScC, bottom right Sc

3.5. Questionnaire

The questionnaire was designed in three main sections. Section A covered some demographic and general questions to present a panoramic picture of the participants. Section B, which is the main part of the questionnaire, was generated after a thorough review of numerous literatures on people's perceptions, performance, and psychological feedback in the real world (Cervinka et al., 2014; Imamoglu, 2000; Micek & Staszewska, 2019; Nasution & Zahrah, 2014; Rahnema et al., 2019) or using VR techniques and IVEs (Birenboim et al., 2019; Gómez-Tone et al., 2021; Mahmoudzadeh et al., 2021; S. Yeom et al., 2020) and also 360-degree videos (Mouratidis & Hassan, 2020). In the aforementioned articles many psychological subjects of environments are explored such as functionality, pleasantness, freedom, practicality, durability, safety, aesthetics, legibility, sensitivity, happiness, durability, roughness, stress, beauty, flexibility, familiarity, tension, complexity, depression and confusion.

In the present study, some of the items mentioned above should have been selected in order to (i) have a concise questionnaire; because the participants were exposed to four different scenarios with 3 minutes length each and they were to be asked some similar questions for each scenario, it could not be a long questionnaire unlike some of the studies which are only focusing on psychological aspects, (ii) to have a straightforward items understandable for all groups of people from different age groups and education as the majority of the participants were below bachelor and, (iii) to be efficiently and accurately translatable to Farsi. Thus, 5 items of safety, happiness, stress, freedom and refreshing were selected each with a Likert scale (1 = lowest score, 5 = highest score).

Moreover, a task of counting the shops and guessing the number of trees was given to the participants to do while watching the 360-degree animations. This was to assess the interpretation of the people using the VR in terms of quantitative counting of recurrent commercial features in the site. As mentioned before, the number of each shop differs from 6 to 8 and participants had the options from 5 to 10. For the tree as the accurate counting is not possible, some ranges of more than 30 (<30) to more than 90 (<90) were proposed, the number of trees in all scenarios is 74. Moving to section C and the last part of the questionnaire, after watching all VR scenarios, the participants were asked some comparative questions.

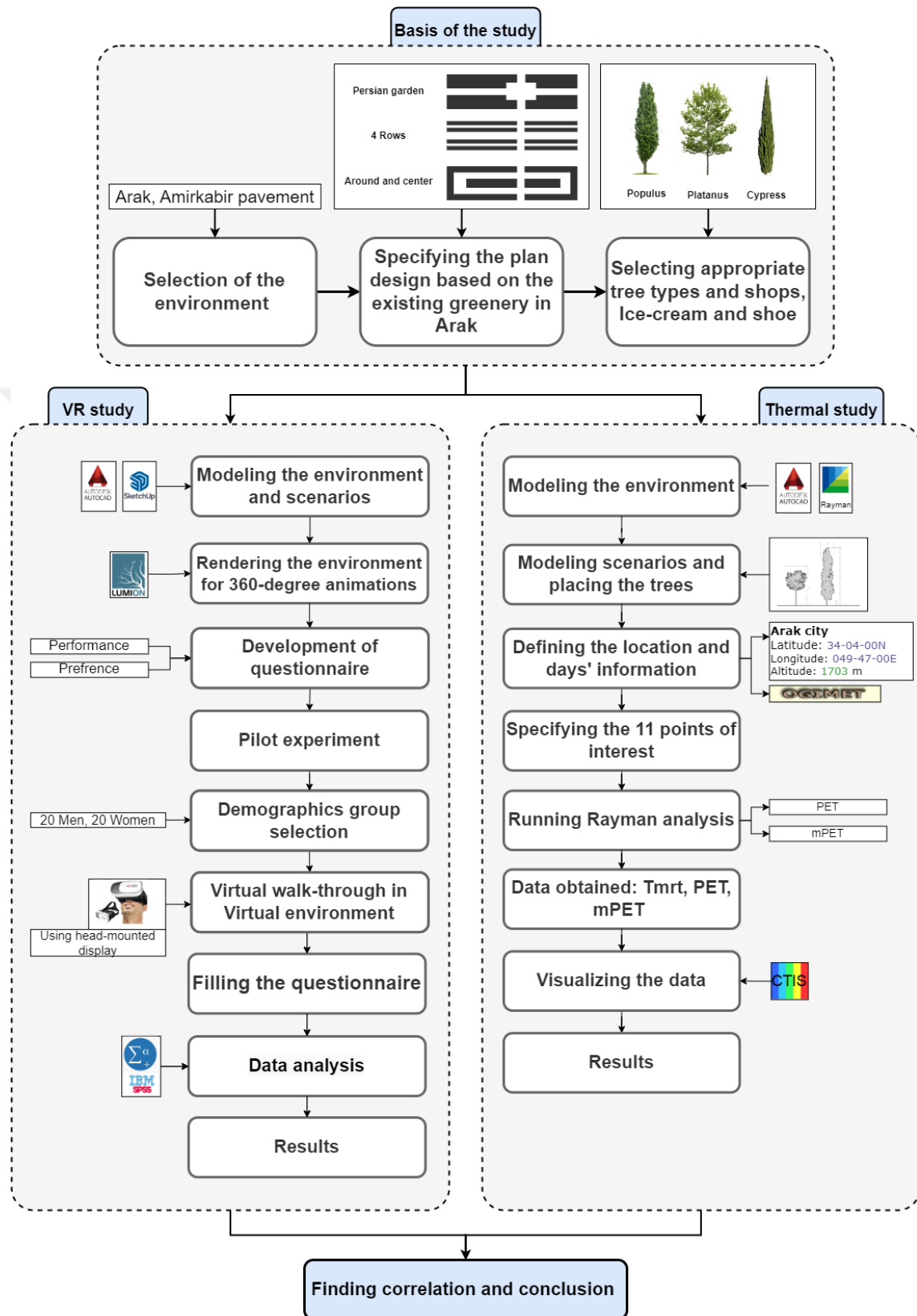


Figure 16. Flow chart of the experiment process

3.6. VR experiment:

As previously stated, one of the benefits of the current experiment design was that no one needed to be taken or invited to anywhere. The experiment was conducted in places where people spend their everyday lives, so, unlike many other studies, people were approached and asked if they had about 20 minutes for an experiment. They were informed that their participation in this experiment was entirely voluntary and that no pressure was applied to them to do so. Section A of the questionnaire asked for general demographic information, and participants were told that all information was confidential and would not be widely published. They were also given the researcher's information, which included his name, age, email, and the email of his advisor. This experiment was approved by the Bilkent University's ethics committee and that they could ask any questions or contact the authors at any time. Each participant was then given a brief explanation of the experiment. It was stated that the experiment was about greenery design and that no special abilities or literacy were required.

3.6.1. VR experiment process:

The participants were asked to watch various scenarios, form opinions, and respond to questions. None of the participants had any VR experiments or wore any kind of head-mounted display. A very short preparation video was prepared, similar to a practice session, for the participants to watch before watching the final videos, to see what the experiment was about and what they were asked to do. It was a one-minute video that participants could watch as many times as they needed in order to be prepared for the experiment. They were also instructed on how to use a virtual environment, the

distinction between immersive and non-immersive environments, and why the experiment is being conducted in a virtual environment. Then, they were taught how to put on and adjust a head-mounted display.

Participants were asked if they preferred the current vegetation condition before viewing the experiment's final section videos. None of them had a favorable opinion of the current state of affairs because many of the trees were old and, regrettably, have not been pruned and maintained well in recent years. On the other hand, one of the main problems, as noted previously, is that Arak has extremely hot summers, making that area unusable in hot weather without the right vegetation coverage. Even though the experiment was carried out in the spring, the temperature was still hot, and there were complaints from bystanders about the lack of adequate shade. None of them liked the existing vegetation, and some of them stated that more vegetation was desperately needed. In addition, all participants were asked if they had any mental health issues, headaches, or migraines. Some participants were excluded after receiving positive responses. They were also told that if they felt any discomfort, headache, or anything else, they could withdraw the experiment at any time with no issue or consequence.



Figure 17. Pictures of the *in-situ* experiment

After ensuring their health, the experiments began with the previously rendered scenarios. The order of the videos was randomly chosen for each person in order to minimize the learning effect in virtual studies, which is a very influential and acting factor. They were instructed to carefully examine and observe the shops, remember the numbers, guess the number of trees, and target any details they could find. Throughout the process, it was observed that all of them were performing very well; however, some participants, particularly the older ones, appeared to have a slight fear of moving their heads during the process; however, during their training session, this issue was resolved. Therefore, they were encouraged to look around since this is the advantage of this experiment and 360-degree videos. After watching each scenario, they were asked section B questions related to that video. For each video, they had to answer how many trees they saw, how many ice-cream and shoe stores did they see. Giving them some

minutes to relax and an opportunity to rest their eyes, and advising them to look at the sky to relieve any eye or mental fatigue. Because they were a comparison of various scenarios with one another and their general opinion about the virtual environments, section B was therefore asked after each video but section C was only asked after all of the videos had been viewed.

3.7. Thermal analysis process:

Arak is located in the center of Iran, with latitude of 34°06'N and longitude of 49°42'E, and an elevation of 1708 meters above sea level and represents the country's warm and dry climatic zone (Asghari et al., 2019). The main software for this study was the latest version of the meteorological model, RayMan Pro (Matzarakis et al., 2007, 2010). The model enables the calculation of the Mean Radiant Temperature (T_{mrt}) and various thermal indices for different climates and regions to quantify thermal conditions such as thermal comfort, cold stress, and heat stress (Matzarakis et al., 2010). For computing Physiologically Equivalent Temperature (PET) index (Mayer & Höppe, 1987) and also modified PET (mPET) index (Y. C. Chen & Matzarakis, 2018). These indices are based on the Munich Energy-balance model for Individuals (MEMI) - that both of these items according to (Freitas & Grigorieva, 2015, 2017) are energy-based models. To function with this program, the environment and trees must be created with the same software. This program works with coordination for building placement and measurements, as well as tree placements across the area. The environment was created using an AutoCad file received from the municipality, and the properties of the trees utilized in this scenario were depicted in the accompanying image. To obtain the best thermal data, all crown

volumes of *Populus nigra* 'Italica' and *Platanus orientalis* are the same, but the width and height differ. The tree placement and selection were done to define the scenarios from A to D, and the existing situation was also modeled for a better comparison between the proposed scenarios and the current thermal situation. To measure the thermal condition, some initial daily data were needed to be defined for the software including air temperature (T_a), cloud coverage (octas), wind velocity and relative humidity (RH) of the aimed days. In addition to these climatological aspects, the RayMan model's calibration was built on the default standardized man,' i.e., a height of 1.75 m, weight of 75 kg, age 35, with 0.9 clothing and an internal heat production of 80w (Mayer & Höppe, 1987).

Table 4. Thermal index physiologically equivalent temperature (PET) ranges for different levels of physiological stress (PS) on humans. Internal heat production: 80W, heat transfer resistance of the clothing: 0.9. According to Matzarakis & Mayer, (1997).

PET	PS
<4 °C	Extreme Cold Stress
4-8	Strong Cold Stress
8-13	Moderate Cold Stress
13-18	Slight Cold Stress
18-23	No Thermal Stress
23-29	Slight Heat Stress
29-35	Moderate Heat Stress
35-41	Strong Heat Stress
>41	Extreme Heat Stress

As the VR experiment took place from 10th of May to the 14th, the three-hourly synoptic dataset derived from World Meteorological Organization (WMO) station 40769 (representing Arak-Iran), at 34°04' N and 49°47' E. The temporal frame of the synoptic analysis was undertaken during the diurnal period, between the hours of 09:00 and 18:00, with a measurement resolution of 3 hours. Based upon a 'What if?' (WI) approach as

launched in studies such as (A. S. Nouri, Charalampopoulos, et al., 2018; A. S. Nouri et al., 2017), the same days in July were analyzed. These days were selected given the identified genre of a heatwave typology occurrence for the same temporal window, thus permitting the exploration of local thermal conditions during a local summer heatwave event. Wind speed was reduced to pedestrian height, 1.1 m, which is the human body's center of gravity for standing subjects (Kuttler, 2004). The data were entered in RayMan and after that the simulation was run and the data obtained for each day was presented in a row of table then taking them into CTIS software (Matzarakis, 2014) for visual interpretation. As climatic data can be very hard to understand for non-climatic experts, finding methods to more effectively present such data based on color thresholds associated with PS levels allowed for a more interdisciplinary representation of results. When sharing scientific data, it is critical to enable communication and appropriate results presentations while taking into account the audience's typology and reflecting this in the adequate language, with easily understandable examples that reflect solutions that are technically and economically viable (Matzarakis, 2021).

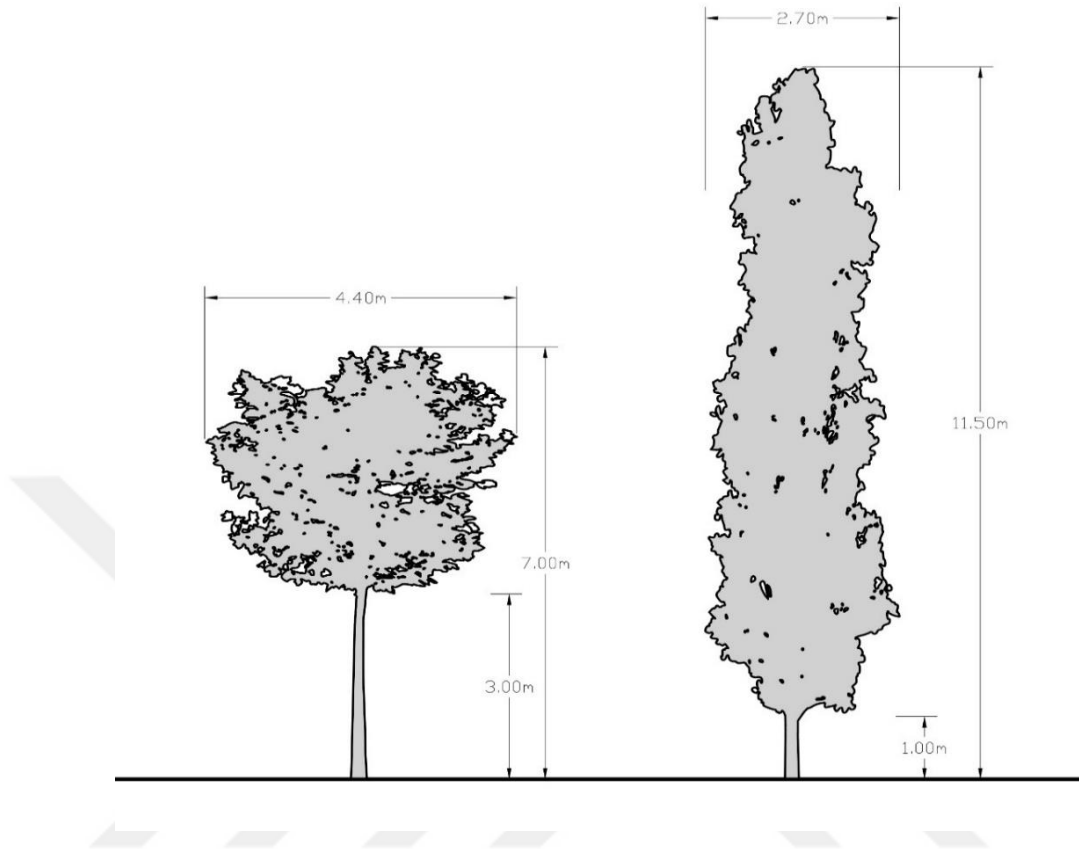


Figure 18. Tree dimensions used in tree simulation of RayMan software. *Platanus orientalis* (plane) left, *Populus nigra* 'Italica' right. Equal crown volumes.

3.7.1. Locating Point of interests (POIs):

RayMan only has one spatial dimension (all the calculations are performed for one point) which, as undertaken in adjacent methodical studies, was required to undertake the desired synoptic analysis of local thermophysiological conditions (E.g., in Lin et al. 2012; Nouri et al. 2017; Rodríguez-Algeciras et al. 2021). For this study one of the main tasks that needed a lot of attention was determining and placing the point of interests identical for all 4 scenarios plus the EXs which gives the opportunity to compare the data obtained from those points of interest (POI). Nine different points of interest were located all over the environment within the vertical and horizontal paths. The coordination of these points

is shown in the table below. Each POI, in each scenario had their own SVF value based upon the calculations run in the RayMan obstacle plugin.

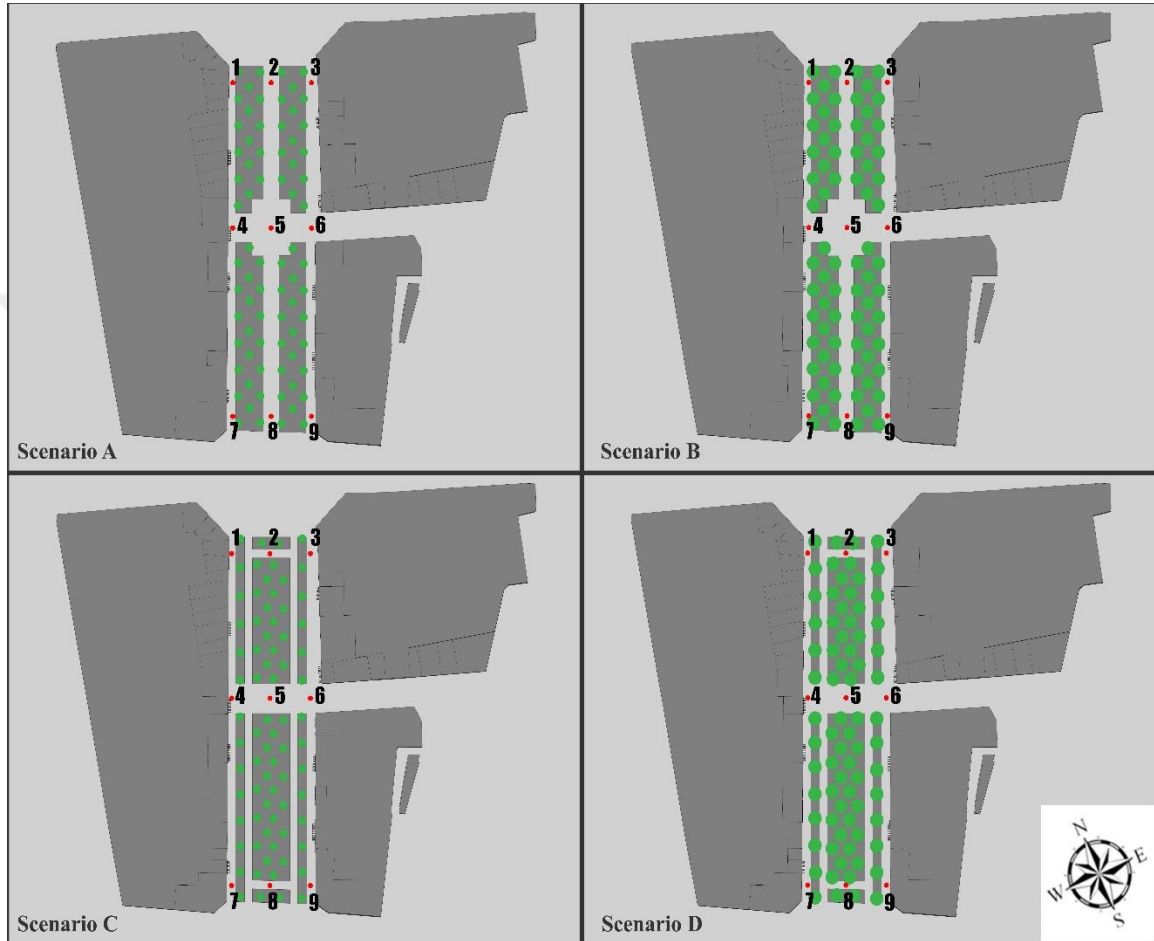


Figure 19. Location of POIs, POI1,4 and 7 left lateral points within the left path of the pavement, POI2,5 and 8 central points in the center of the canyon, POI3,6 and 9 right lateral points within the right path of the pavement.

3.7.1. Obtaining the SVF of the POIs:

Another important item for the present study was the calculation of SVF for each POI, so that when comparing one of them with each other the solstice diagram provides adequate information for the sun's position and movement. The SVF is a parameter that is widely used in a variety of research fields, including applied research and planning and it is

critical in terms of a particular location's energy budget (Hämmerle et al., 2011). The determination of SVF is one of RayMan's key features. This can be done using Fish-eye photos, free horizon sketching, a topography raster, or an obstacle dataset (Matzarakis et al., 2007). RayMan obstacle files are a sort of spatial vector file that is based on semicolon delimited text files that may be manually constructed using the RayMan obstacles editor (Matzarakis et al., 2010). A binary Fish-eye graph is generated for each of the input possibilities. SVF is defined as the fraction of the visible sky observed from a specific place (Oke, 1987, p. 353). It is dimensionless and ranges from 0 to 1, with 0 representing a completely covered sky and 1 indicating a free sky (Matzarakis et al., 2018).

Table 5. Coordination of POIs, Considering POI5 as the center of the environment

POI	x	y
1	-25.25	43
2	0	43
3	25.25	43
4	-25.25	0
5	0	0
6	25.25	0
7	-25.25	-55
8	0	-55
9	25.25	-55

CHAPTER 4

RESULTS

4.1. VR experiment:

To reduce the gender gap in the study, an equal number of female and male participants were considered. As a result, each gender was represented by a total of 20 people. As shown in the chart below, the majority of the participants were between the ages of 18 and 50, with 7 participants over the age of fifty. 35% of the participants held a bachelor's degree, 2.5% a master's degree, and the remaining 62.5% were below bachelor. In terms of occupation, 42.5% were employees, 27.5% were students, 20% were housewives, 5% were retired, and 5% were teachers.

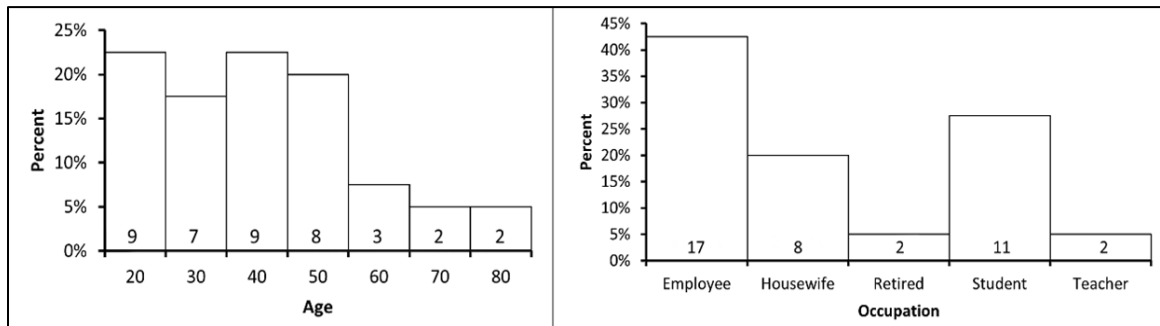


Figure 20. Age group of participants (left), count of occupations (right)

As previously stated, to ensure the appropriate participants' involvement, rather than inviting random people to participate in the experiment, the experiment was moved to the location that was intended for it, so the participants have experienced and visited the site at least once. To gain a better and more reliable understanding of the site's participants,

they were asked how many times per week they visited the Amirkabir pavement. All of the participants stated that this was not their first visit, which ensures their familiarity with the environment; however, many of them visit the area less than once a week. As depicted in the chart below, 35% of the participants visit the site less than once in a week, then 20% once a week, 17.5% twice a week, 15% everyday, 7.5% 3 times a week and 5% 4 times a week.

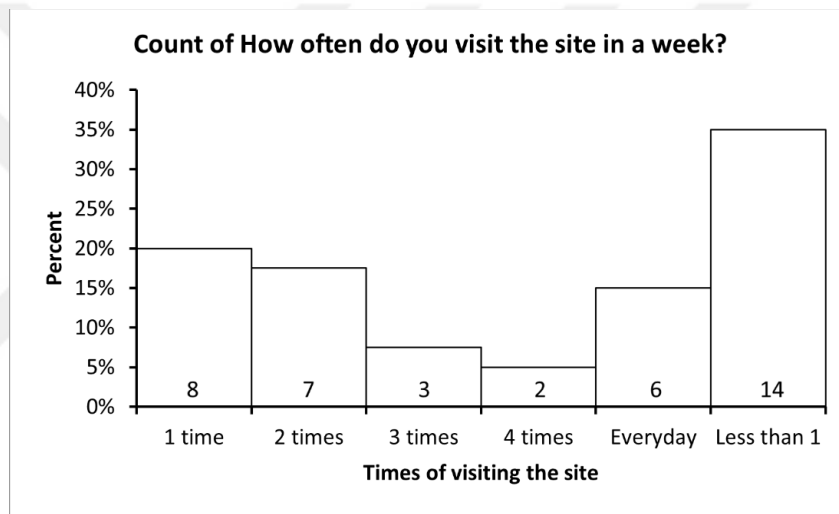


Figure 21. Counts of visiting the experiment's site per week

Moving to the second section, starting with this question. Which one was aesthetically more pleasant for you? Based on the analysis by SPSS software's chi-square test, it is concluded that people's choice on which scenario was more pleasant is statistically significant ($p < .05$) for ScD.

Table 6. Which one was aesthetically more pleasant for you?

Scenarios	Observed N	Expected N	Residual
A	8	10.0	-2.0
B	6	10.0	-4.0
C	8	10.0	-2.0

D	18	10.0	8.0
Total	40		

Table 7. Test Statistics for the question which one was aesthetically more pleasant for you?

Which one was aesthetically more pleasant for you?	
Chi-Square	8.800 ^a
Df	3
Asymp. Sig.	.032

Note. a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0.

On the question “In which one you had a better view to different parts of the pavement “, it was understood by SPSS chi-square analysis that there was a significant ($p < 0.05$) difference for ScB as the scenario with the least frequency and design ScD got the highest frequency close to ScA and ScC.

Table 8. In which one you had a better view to different parts of the pavement?

Scenarios	Observed N	Expected N	Residual
A	13	10.0	3.0
B	2	10.0	-8.0
C	11	10.0	1.0
D	14	10.0	4.0
Total	40		

Table 9. Test Statistics in which one you had a better view to different parts of the pavement?

In which one you had a better view to different parts of the pavement?	
Chi-Square	9.000 ^a
Df	3
Asymp. Sig.	.029

Note. a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 10.0.

For next two questions, no significant result was obtained, however for the question “Which one had more total pedestrians’ area?” ScA had the highest frequency.

Table 10. Which one had more total pedestrians’ area?

	Observed N	Expected N	Residual
A	12	8.0	4.0
B	8	8.0	.0
C	7	8.0	-1.0
D	7	8.0	-1.0
Equal	6	8.0	-2.0
Total	40		

Table 11. Test Statistics for the question which one had more total pedestrians’ area?

Which one had more total pedestrians’ area?	
Chi-Square	2.750 ^a
Df	4
Asymp. Sig.	.600

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 8.0.

For the question “Which one had more total vegetation area?” ScD had the highest frequency.

Table 12. Which one had more total vegetation area?

	Observed N	Expected N	Residual
A	9	8.0	1.0
B	6	8.0	-2.0
C	7	8.0	-1.0
D	11	8.0	3.0
Equal	7	8.0	-1.0
Total	40		

Table 13. Test Statistics for the question which one had more total vegetation area?

Which one had more total vegetation area?	
Chi-Square	2.000 ^a
Df	4
Asymp. Sig.	.736

Note. a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 8.0.

For the question, “How many ice-cream shops could you see?”, there were different correct answers for each scenario. ScA and ScD had 8, ScB and ScC had 6 ice-cream shops. According to the mean and mean difference for each scenario using one sample t-test of the SPSS software, people have a better performance of counting the ice-cream shops on first ScB (M= 6.58, SD = 1.46) then ScA (M= 7.10, SD = 1.41) then ScC (M= 7.20, SD = 1.68) and ScD (M= 6.68, SD = 1.18).

Table 14. One-Sample Test for the question “How many ice-cream shops could you see?”

Test Value = 8	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScA	-4.035	39	.000	-.900	-1.35	-.45

Test Value = 6	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScB	2.481	39	.018	.575	.11	1.04

Test Value = 6	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScC	4.511	39	.000	1.200	.66	1.74

Test Value = 8	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScD	-7.071	39	.000	-1.325	-1.70	-.95

For the question, “How shoe shops could you see?”, there were different correct answers for each scenario. ScA and ScB have 6, ScC and ScD have 8 shoe shops. According to the mean and mean difference for each scenario using one sample T test of the SPSS software, people have a better performance of counting the shoe shops on ScB (M= 6.05, SD = 1.41) then ScC (M= 7.80, SD = 1.93) then ScA (M= 6.40, SD = 1.42) and ScD (M= 7.45, SD = 1.58).

Table 15. One-Sample Test for the question “How many shoe shops could you see?”

	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScA	1.771	39	.084	.400	-.06	.86

Test Value = 6	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScB	.224	39	.824	.050	-.40	.50

Test Value = 8	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
In ScC	-.653	39	.518	-.200	-.82	.42

Test Value = 8	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	

					Lower	Upper
	-					
In ScD	2.19	39	.034	-.550	-1.06	-.04
	6					

“How many trees could you see?” was the other query relating their performance. The proper response to this question was <70, and in order to determine which scenario the participants performed best, it is necessary to look at the answers that <70 and closer to 70. One sample t-test was employed to do that. The findings are shown in the table below.

Table 16. One-Sample Test for the question “how many trees could you see?”

	Test Value = 70					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
ScA,	-4.539	39	.000	-11.000	-15.90	-6.10
ScB	-5.146	39	.000	-13.750	-19.15	-8.35
ScC	-4.310	39	.000	-11.000	-16.16	-5.84
ScD	-5.341	39	.000	-13.750	-18.96	-8.54

As demonstrated on the table, the mean difference for 70 in ScA and ScC is -11, while in scenarios B and D, it is 13.75. Vote histograms were acquired in the following stage to have a better understanding of the vote distributions. The participants' best performance was in ScA, while ScC came in second, according to the mean differences and the most votes for <70 between ScA and ScC in the histograms with the lower mean difference.

With 10 votes, ScD received the most votes for <70 out of all the scenarios, placing D in third place and B in last.

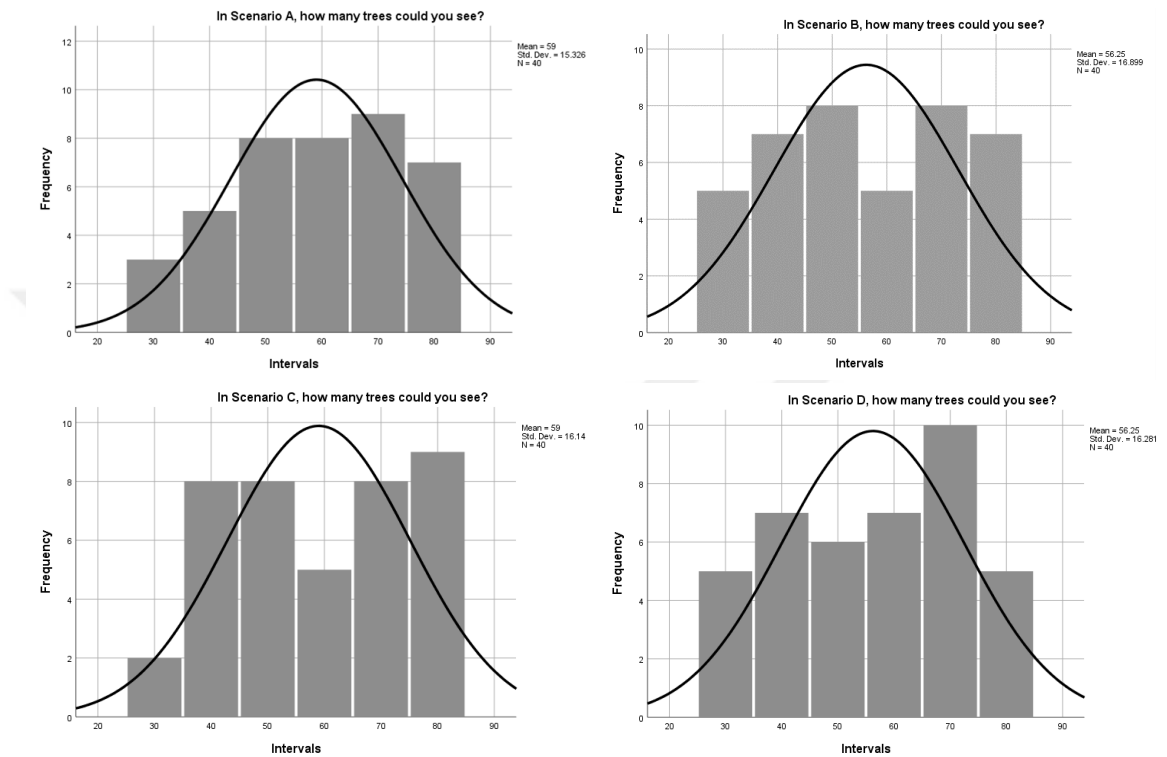


Figure 22. Responses histograms for the question how many trees could you see?

And for their preference, 5 different questions were ranked from 1: low to 5: a lot. The results can be seen below.

Table 17. Safety One-Sample Statistics

		Bootstrap ^a				
		Statistic	Bias	Std. Error	95% Confidence Interval	
					Lower	Upper
ScA	N	40				
	Mean	3.38	.00	.19	3.03	3.73
	Std. Deviation	1.192	-.017	.098	.982	1.362
	Std. Error					
	Mean	.188				

ScB	N	40				
	Mean	3.85	.00	.18	3.50	4.20
	Std. Deviation	1.167	-.017	.106	.933	1.357
	Std. Error					
	Mean	.184				
ScC	N	40				
	Mean	3.68	-.01	.20	3.28	4.05
	Std. Deviation	1.347	-.019	.110	1.091	1.522
	Std. Error					
	Mean	.213				
ScD	N	40				
	Mean	4.35	.00	.12	4.10	4.58
	Std. Deviation	.802	-.015	.095	.599	.971
	Std. Error					
	Mean	.127				

Note. a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

By comparing the mean score for each scenario, it is understood that ScD has the highest satisfaction in the safety followed by ScB, ScC and ScA respectively.

Table 18. Happiness One-Sample Statistics

		Statistic	Bootstrap ^a			
			Bias	Std. Error	95% Confidence Interval	
					Lower	Upper
ScA	N	40				
	Mean	3.58	.01	.21	3.15	3.97
	Std. Deviation	1.357	-.017	.109	1.125	1.539
	Std. Error	.214				
	Mean					
ScB	N	40				
	Mean	3.93	.01	.17	3.60	4.25
	Std. Deviation	1.071	-.019	.092	.859	1.223
	Std. Error	.169				
	Mean					
ScC	N	40				
	Mean	4.28	-.01	.14	4.00	4.53

	Std. Deviation	.877	-.015	.080	.705	1.010
	Std. Error					
	Mean	.139				
	N	40				
	Mean	4.30	.01	.13	4.05	4.55
ScD	Std. Deviation	.823	-.018	.091	.636	.992
	Std. Error					
	Mean	.130				

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

On the feeling of happiness, ScD has got the highest mean rank of 4.3, then ScC, ScB and ScA respectively.

Table 19. Stress One-Sample Statistics

		Statistic	Bootstrap ^a			
			Bias	Std. Error	95% Confidence Interval	
					Lower	Upper
ScA	N	40				
	Mean	2.05	-.01	.19	1.70	2.40
	Std. Deviation	1.218	-.020	.087	1.013	1.344
	Std. Error	.193				
	Mean					
ScB	N	40				
	Mean	1.55	.00	.12	1.33	1.80
	Std. Deviation	.783	-.019	.105	.552	.960
	Std. Error	.124				
	Mean					
ScC	N	40				
	Mean	1.70	.00	.15	1.40	2.00
	Std. Deviation	.992	-.021	.127	.680	1.202
	Std. Error	.157				
	Mean					
ScD	N	40				
	Mean	1.55	.00	.13	1.30	1.83
	Std. Deviation	.876	-.030	.168	.545	1.165
	Std. Error	.138				
	Mean					

Note. a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

For stress, ScD and ScB has got the lowest mean rate of 1.55, followed by ScC and ScA.

Table 20. Freedom One-Sample Statistics

	Statistic	Bootstrap ^a			
		Bias	Std. Error	95% Confidence Interval	
				Lower	Upper
ScA	N	40			
	Mean	3.08	-.01	.24	3.53
	Std. Deviation	1.421	-.018	.091	1.217
	Std. Error Mean	.225			
ScB	N	40			
	Mean	3.48	.00	.15	3.18
	Std. Deviation	.960	-.012	.104	.740
	Std. Error Mean	.152			
ScC	N	40			
	Mean	3.60	.00	.20	3.20
	Std. Deviation	1.236	-.022	.106	1.000
	Std. Error Mean	.195			
ScD	N	40			
	Mean	3.88	.00	.15	3.58
	Std. Deviation	.992	-.022	.082	.800
	Std. Error Mean	.157			

Note. a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

In freedom category, it was seen that ScD with the mean of 3.88 had the highest score, where ScC, ScB and ScA were on the next levels respectively.

Table 21. Freshness One-Sample Statistics

		Statistic	Bootstrap ^a			
			Bias	Std. Error	95% Confidence Interval	
					Lower	Upper
ScA	N	40				
	Mean	3.45	.00	.23	3.00	3.90
	Std. Deviation	1.484	-.025	.112	1.215	1.652
	Std. Error Mean	.235				
ScB	N	40				
	Mean	3.83	.00	.20	3.40	4.20
	Std. Deviation	1.279	-.025	.116	1.023	1.467
	Std. Error Mean	.202				
ScC	N	40				
	Mean	4.10	.00	.16	3.80	4.40
	Std. Deviation	1.008	-.027	.140	.687	1.250
	Std. Error Mean	.159				
ScD	N	40				
	Mean	4.15	-.01	.14	3.85	4.43
	Std. Deviation	.921	-.014	.088	.730	1.067
	Std. Error Mean	.146				

Note. a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

For freshness, ScD with the mean of 4.15 held the highest rank, ScC, ScB and ScA were in the next rank.

4.2. Thermal analysis:

The outputs obtained from the RayMan simulations and visualized in CTIS software were presented in the following pictures. As mentioned before for May and July five days from the 10th to the 14th were considered. These pictures will be explained with the focus on; (i) between POIs in terms of their PET and mPET differences; (ii) between POIs in terms of their mean radiant temperature (T_{mrt}); and (iii) the distinction between various

scenarios in terms of the impact of each greenery design and the ExS. It is crucial to stress that since the tree crown volumes were approximately equal in m³, the thermal results of the various scenarios were remarkably similar, making even little variances significant and worthy of discussion.

During May, the PET and mPET values were mostly within the comfort zone. PET index ranges from very cold (<4°C) to very hot (>41°C). Moreover, similar to the study by A. S. Nouri et al., (2022), this paper proposed an extension to the original grades for heat stress levels above the 'Extreme Heat Stress' threshold. The approach used to assess human biometeorological implications under extreme environmental conditions with two new grades established beyond the original threshold of > 41 C. In this study PET varies from 6°C degrees to 54°C degrees so the legend range has been extended to 50°C as the highest PET. The first step was determining the general bioclimatic conditions (PET and mPET values) obtained from the Arak weather station enabling us to determine how physiological stress (PS) grades vary throughout the year.

The general PS analysis image of these two months demonstrated a considerable diurnal heat stress difference. The data of the (40769) station on May revealed a 'slight cold stress' at 18:00 on all the days and a 'strong cold stress' at 18:00 of 13th which was mostly due to high RH at that time. Except 14th of May which a 'Moderate heat stress' is seen at 15:00, on 10th, 11th and 13th the 'Moderate heat stress' happened at 12:00 and the other times of the days the PS grades was mostly within 'No thermal stress' and 'Slight heat stress'. The PET and mPET analysis for May displays that the PS values were between 'Moderate cold stress' and 'Moderate heat stress', no extreme cold or heat stress

could be seen during this month. However, in comparison with the ExS, it was clear that the greenery scenarios could get the situation more closely to the comfort zone and lowering hourly PS fluctuations in the environment. On the other hand, POI5 and POI6 which were the center of the square and got the least tree-crown coverage in all scenarios had the highest PS value so the highest PET and mPET thresholds. Moreover, on 10th of May, ScC and ScD were successful to provide a more uniform pattern of the thermal situation with less hourly fluctuations of POIs all over the environment. On the other hand, for the 12th and 11th of May, at 9:00, ScA and specially ScB were providing a more thermally comfortable condition in comparison with ScC and ScD. It was also true for ScA at 15:00 of 11th, 12th and 14th of May. No heat wave (HW) was seen during the 5 aimed days in May.

Moving to July, it was clear that the PS thresholds oscillations were different from those seen throughout May. First of all, the PS values of the station made it evident that without any obstacles or natural shadings, July was the month in Arak with extreme heat stress that frequently remains well above 'no thermal stress' thresholds. Moreover, the PS range of the station at 18:00 is within the 'Moderate heat stress' range except on the 12th of July when a 'Strong heat stress' could be observed. Although none of the POIs in the ExS and all other scenarios were in the comfort zone, it was evident that all the scenarios were successful in ameliorating the PS, and PET and mPET fluctuation all over the environment and were showing a more even and convergence thermal pattern in that

month however, the CTIS image of the scenarios proved a more similar POIs' thermal pattern of EXc and ScC and ScD.

The 12th of July was experiencing an extreme HW type event where the PS value was mostly within the 'Extreme heat stress' range and the 14th of July was the day with more moderate hourly HW that PS grades were between 'Slight heat stress' and 'Strong heat stress'. Comparing scenarios with each other, it could be concluded that ScA and ScB with Persian garden planting typology could perform slightly better than scenarios C and D with SAC typology, especially on the 10th of July at 15:00, 11th of July at 15:00, 12th of July at 18:00 and on 13th of July at 18:00. Considering the PET and mPET values of the POIs, ScA and ScB apparently could also perform better in lowering PS on POI1, POI2, POI7 and POI8. On the other hand, POI5 and POI6 had the highest thermophysiological stress in all scenarios regardless of the planting layout or tree types. Concordant with the results of May, in July also the planting layout showed a more noticeable influence on PS grades than the tree type where ScA and ScB were following a proportionate PS pattern and also ScC and ScD presented an analogous PS occurrence.



Figure 23. mPET and PET analysis results for May



Figure 24. mPET and PET analysis results for July

4.3. Mean radiant temperature (Tmrt) analysis:

The mean radiant temperature (Tmrt) is the most significant meteorological input variable for the human energy balance in summertime. Therefore, Tmrt has a significant impact on important thermophysiological indexes like PET (Matzarakis et al., 2007). Analyzing the station Tmrt indicates the occurrence of a mean radiant temperature of around 40 degrees that sometimes can even go high up to 50°C degrees in the most hours of the studied days of May. In most of the days of ExS, the Tmrt is above 40°C, however at 18:00 of 10th and 14th of May, the temperature is about 20°C. Nevertheless the proposed scenarios had again a considerable achievement in the reduction of radiation fluxes and unifying the diurnal Tmrt pattern of the environment. On the 10th of May, proposed scenarios could reduce the Tmrt in all POIs specially at 9:00 where ScA and ScB could perform more noticeably. For the 11th, ScB could lower the radiation more than the other scenarios, nonetheless, ScD was the least successful scenario which is also true for the 12th of May. On the 13th of May, ScA and ScB could decrease the temperature from about 40°C at 9:00 to about 30°C in most of the POIs whereas ScC and ScD could do it for 3 and 2 POIs respectively. On 14th, scenarios C and D had a very similar Tmrt occurrence pattern but ScA and ScB could lessen the radiation more than them. ScA had the best Tmrt reduction effect on that day. Comparing the scenarios in May, harmonious to PET and mPET grades, unveils a synonymous Tmrt variation of ScA with ScB employing Persian garden and ScC with ScD employing SAC, emphasizing the planting layout impact on shading cast rather than tree types on the Tmrt occurrence.

When comparing Tmrt deviations during July, some significant outcomes were discovered. First, the station data demonstrated remarkably high Tmrt values which showed an 'Extreme heat stress' during July in the station concordant with PET and mPET analysis data. Tmrt value could sometimes increase to around 60 degrees which made the situation unbearable for human beings. Hopefully, the justifications of the physical canyon, Tmrt deviations can be reduced. Tmrt of the ExS shows a cluttered fluctuation of mean radiant temperature which is reduced and consolidated with the proposed scenarios. At 18:00 of all scenarios, the radiation was reduced to 30-35 °C in all POIs except POI5 and POI6 which were more directly exposed to sun radiation. On the 10th, at 18:00 and 9:00, on 11th at 9 and on 12th at 9ScA and ScB performed considerably better in controlling the gained radiation. This is also true on 13th at 15 and 9 and on 14th at 15 and 9. Homogenous to May, information for ScA with ScB were illustrating an identical Tmrt deflection and ScC with ScD as well.



Figure 25. Tmrt analysis result for months of May and July

4.4. POI 10 and 11:

After analyzing the nine initial different POI's, the concentration of this section was then passed upon defining two other points in each scenario which were under tree crowns during specific hours of 18, 15, 12, and 9 that were covered by the tree crown in relationship to summer solstice. It was possible to find such points using the SVF to ensure that in those hours no radiation is gained under the tree crown. It was tried to locate these specific points identical to each other however the points for ScA and ScB were in the same position and the points in ScC and ScD were in different location. Different planting layouts made it impossible to find two points that in all the scenarios were completely in shading casts. The aim of this section was to analyze the scenarios' PS grades in such points that were totally in shadow. It provided the situation or opportunity to understand how the trees and greenery planting layout were affecting those totally shaded areas, and which ones could provide a further thermally comfortable condition for pedestrians. While it was not assumed that pedestrian would stop in these areas in the defined pathways of the space, similar to the previous WI for July, these POIs were designed to further explore local variations between vegetative shading and the encompassing summer solstice. These points were presented as in Figure.26.

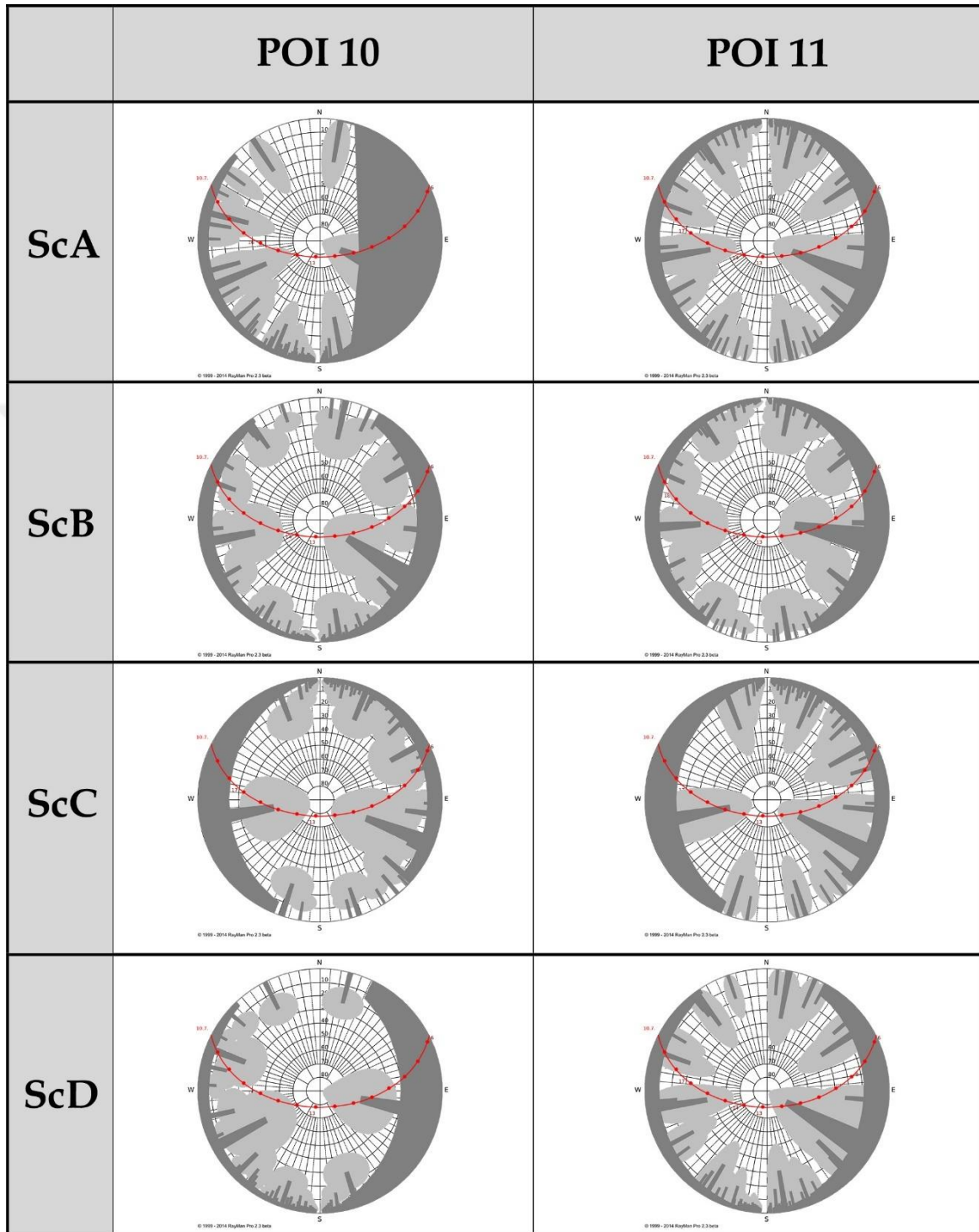


Figure 26. SVF of POI10 and POI11

By looking at the PET and mPET analyses for POI 10 in May, it is clear that the scenarios were successful in providing a thermally acceptable and satisfactory

environment for pedestrians during the majority of the hours. They were practically supplying the same condition between the 10th and 14th of May. However, ScA could demonstrate a more moderate PET value at 9:00 of 14th of May where ScB in POI10 is close to ‘extreme cold stress’ and two other scenarios employing SAC typology were meeting that in both POIs. When POI 10 was analyzed in terms of mean radiant temperature, almost all the scenarios were performing close to each other whereas in POI10 on the 10th of May at 12:00 and 14th of May at 12:00, ScD was slightly warmer than the other scenarios. ScD was not particularly effective at improving thermal conditions. Also, in POI11 of the 10th day of May at 9:00, ScA and ScC were within 30°C which was also true for ScA in POI10.

Table 22. PET, mPET and Tmrt mean values for POI10 and POI11 for May and July

May	POI 10				POI 11			
	ScA	ScB	ScC	ScD	ScA	ScB	ScC	ScD
$\bar{x}$ PET	20.88	20.46	20.5	20.64	21.05	21.05	20.65	20.66
$\bar{x}$ mPET	20.85	20.46	20.48	20.59	20.98	20.98	20.58	20.59
$\bar{x}$ Tmrt	33.76	32.54	32.59	32.92	34.19	34.19	32.95	32.95
July	POI 10				POI 11			
	ScA	ScB	ScC	ScD	ScA	ScB	ScC	ScD
$\bar{x}$ PET	37.63	37.53	37.58	37.42	37.53	37.53	37.51	37.51
$\bar{x}$ mPET	34.32	34.24	34.26	34.1	34.25	34.24	34.23	34.22
$\bar{x}$ Tmrt	45.83	45.61	45.7	45.34	45.63	45.61	45.6	45.59

Considering July, PET and mPET values for the POI 10 and POI11 indicated quite even PS grades for all scenarios. The same similarity was correct with very slight differences within Tmrt thresholds. It was evident that when the POIs were totally covered by tree crowns of the sun radiation, they could provide a significantly warmer situation.

Considering mPET result, no POI in the scenarios was with the ‘Strong heat stress’ and in many of them, PS grades could be decreased to the ‘No thermal stress’ range. This reduction of PS grades was also seen in Tmrt thresholds where tree shade casts could apparently lower Tmrt in all POIs. Table 22 clearly demonstrates that at POI10 and POI11, the mean PET and mPET thresholds on May were within 20°C and for July PET grades within 37.5°C and mPET 34.2°C. In addition, Tmrt values in May were around 33 °C at POI10 and POI11 and in July the Tmrt grades were mostly within 45°C. Approximately 14°C difference of mPET and almost 12°C Tmrt difference could be experienced within 2 months in Arak.

CHAPTER 5

DISCUSSION

This study is possibly one of the first architectural investigations concerning thermal comfort in the city of Arak, as well as using 360-degree videos. It is worth noting that this is the first project in which several scenarios of 360 animation were used and actual local participants' comments were monitored in the IVEs. For those interested in discussing thermal comfort and VR techniques, it can serve as a very useful context of study. The purpose of this study was to examine the psychological responses of local residents to various greenery design scenarios in virtual reality while comparing them to the thermophysical properties of those scenarios in the Amirkabir public square. This was done to determine whether the scenario that was chosen as the most preferred by the participants also offered the most comfortable thermal environment or not. The importance of designing outdoor environments and the effects of climate change on thermal comfort and quality of life have been discussed in the introduction and literature review of the current study. However, there is a demand for interdisciplinary approaches using innovative facilities to not only bring together divergent disciplines on the subject of minimizing the negative effects of climate change on humans (A. S. Nouri & Matzarakis, 2019) but also ensuring the functionality of different design scenarios both thermally and psychologically specially for the cities like Arak. The city which has been experiencing more heat stresses in recent years (Roshan et al., 2018).

This section of the discussion deals with the three parts of (i) the obtained psychological data of VR; (ii) the analysis of the climatic comfort data and finally (iii) combines the results from the first and second parts to determine the overall outcome of these studies.

5.1. Analyzing peoples' psychological responses on VR:

The findings of this study, which are consistent with the findings of many other studies, revealed that urban configuration (Kwon, 2007; Yuan et al., 2014), urban greenery (Birenboim et al., 2019; Kendal et al., 2008; Smardon, 1988) and in particular trees (Gerstenberg & Hofmann, 2016a; Todorova et al., 2004; van Dongen & Timmermans, 2019; J. Zhao et al., 2017) have a strong influence on preference, indicating that they deserve more attention and space in cities. The data analysis for the outdoor greenery design scenarios revealed that ScD was the people's first choice among all the scenarios in terms of aesthetic values. Regarding the comprehension of the environment, it was stated that ScD had a better view of the various parts of the environment, which is similar to the previous question. It demonstrated that ScD could capture the most participants' attention in terms of aesthetics and view point. It can therefore be concluded that people's preferences for various scenario selection have a direct correlation with a clearer view (Yang et al., 2013). The fact that the order of the answers is the same for both questions - ScD is followed by ScA, ScC, and ScB – makes this assertion even more compelling. ScB again received the least amount of public attention. Although the same type of tree was used in both ScD and ScB, their arrangement in the environment could have a significant impact on how people perceive this type of vegetation and supported Kuper' (2020) study's conclusion that the arrangement and plant entropy significantly affected

preference. This calls landscape architects' attention to the need to meticulously choose and incorporate various plant and tree species, especially when it comes to urban POS where various user groups will occupy the space.

When the total pavement and vegetation area were considered, various responses were surveyed. ScA and ScB received the most attention from participants for total pavement area, indicating that scattering greenery throughout the environment can affect people's perception of total paved areas. Because ScA and ScB adhere to the Persian garden typology, it can be concluded that the Persian Garden, in comparison to the SAC, stimulates more paved available area for the participants. However, ScD receives the highest score for the vegetation area, indicating that they chose the entire area in accordance with their aesthetic sensibilities. As a result, and persistent with (Kwong, 2022), there is a direct link between the preferred scenario and the total vegetation comprehend area and the effects of the environment on tree sizes and spatial patterns were mediated by species selection. As ScD is followed by ScA and ScC, then 'equal', and ScB is the last score, scattering vegetation throughout the environment may affect people's perceptions of the availability of more vegetation. Even though there are an equal number of trees, spreading the vegetation out over the area with trees that have wider crowns can contribute in more precepted vegetation of the environment and aesthetics (Kuper, 2020).

Psychological feedback from individuals regarding their amount of safety, happiness, stress, freedom, and freshness results in some intriguing outcomes for all of the aforementioned factors. ScD had the highest score and was unquestionably everyone's

top choice. ScC, which has three times preceded ScD in terms of happiness, freedom, and freshness, moves on to the next stage. For the two safety and stress-related factors, ScB has trailed D, while ScA has scored the lowest across the board. Hence, it can be concluded that people's first preferences were ScD and ScC, respectively. It's important to note that while Scenarios B and A are based on the Persian garden plan, Scenarios D and C are based on the SAC layouts. In contrast with (Barati et al., 2018; Latiff et al., 2017), it is therefore quite evident that this typology for Amirkabir Square, despite its widespread popularity throughout the nation, is not the ideal choice. However, it is conspicuous that individuals prefer *Platanus orientalis* over *Populus nigra 'Italica'*, therefore it can be concluded that people wanted to see more tree covering when strolling around the area and consistent with other studies emphasizes that designing green spaces with human perceptions and preferences may improve residential satisfaction and reinforce the beneficial physiological and psychological effects of trees in urban settings (Gerstenberg & Hofmann, 2016b; Sjöman et al., 2012). Additionally, because *Platanus orientalis* had a taller trunk, it was possible to perceive greater visibility to various areas of the environment. This is also positively related to the question regarding a better view to different areas of the environment, because ScD could also receive the highest score in that question.

There are some interesting findings when comparing how well people perform tasks like counting trees and shops. In contrast to people's aesthetic preference for which ScB received the lowest score, it performs best when it comes to ice cream and shoe shop counting. ScD received the lowest score in both of the shop counting tasks as well. which distinctively shows how people's preferences and behavior are at odds with one another

and that they could not perform well in the situation that they preferred more. The task of estimating the total number of trees is displaying that ScA and ScC with *Populus nigra* 'Italica' could be counted more accurately than ScD and ScB with *Platanus orientalis* resulting that taller trees with separated and less wide crowns can be counted more accurately than those with more involuted crowns in opposition with the suggestion that large crown trees should be planted in streets to improve both visual and thermal comfort (T. Chen et al., 2021).

5.2. Analyzing the thermal outputs:

It was mentioned that the WMO station 49769 is displaying an uncomfortable situation for both the months of May and July. Although the situation data indicated more comfortable situation in May, still some hours of 'moderate heat stress' were observed. One of the study's limitations was that the data provided from the WMO was a little far from the city center of Arak; if the station was closer, more accurate environmental results could be obtained. For the month of May, it was clear that the current situation required some justifications for shading, which in the study is supplied by trees. ScA and ScB for the 12th of May, when the situation is in 'moderate heat stress,' could bring the condition closer into the thermal comfort range. Aligned with other papers which have determined that trees have positive effects on the thermal comfort and ecosystem (Irmak et al., 2018; Sawka et al., 2013; Tan et al., 2016; Yilmaz et al., 2021; Q. Zhao et al., 2018) which is highly depended on the type of tree, particularly in urban areas plagued by UHI (Abreu-Harbach, Labaki, and Matzarakis 2015; Irmak et al. 2018; Nouri, Fröhlich, et al. 2018; Zölch et al. 2019), the influence of trees were also apparent in the current study

specially with decreased PS thresholds, representing the tree crown's ability to reduce vulnerability at pedestrian height during the hours when the canyon was exposed to direct solar radiation (Nouri et al. 2018). However, there were various evidences that planting layout have a greater impact on PET and mPET values in the environment than the tree types when the trees did not vary much from one another in terms of tree crown volume. Tmrt calculation also found very cohesive data with PET and mPET values, leading to the conclusion that they were directly corelated, higher PET and mPET values were observed whenever there was a high Tmrt value. This study's use of the mPET index afforded the chance to compare and use an updated PET version built on a better thermoregulation model developed by Chen and Matzarakis (2018). As the mPET values in both months of May and July did not exceed 'Extreme Heat Stress', the findings of this investigation were consistent with those made public by other scholars (Y. C. Chen & Matzarakis, 2018; A. S. Nouri, Fröhlich, et al., 2018) according to which the initial identification of bioclimatic conditions (PET and mPET variables) throughout the months of studies did not disclose PS values above that of 'Extreme Heat Stress'. mPET is always closer to thermal neutral/comfort conditions, especially at extreme/cold thresholds. It also has more nodes for calculating the thermal index and is capable of a better understanding of clothing layers. In other words, mPET values are less extreme and more realistic in comparison with PET values. Although calculation of mPET values takes more time due to its more complicated equations, it is more suitable for indication of PS grades and a more reliable thermal index. However, as indicated in previous studies, when dealing with large datasets and/or temporal windows, PET can still be the

adequate option in providing understandings of the relationship with the biometeorological system under shorter processing timeframes.

The suggested scenarios could prevent the thermal indices from exceeding 41°C with Tmrt values up to 55°C, and it can be stated that the scenarios could reduce the gained radiation in almost all hours in ScA and ScB. On May 11th, ScC and ScD provide a more uniform Tmrt distribution among POIs whereas ScA with ScB and ScC with ScD provide a similar Tmrt distribution on the other days. In July, the station experienced ‘strong heat stress’ on almost all days, necessitating physical intervention. In comparison to the current state, the scenarios could offer superior thermal conditions all throughout the environment. The *in-situ* Tmrt value is likewise quite high on July 12th, therefore they are not as effective at relieving the thermal stress when extreme heat stress occurs. It is also important that the *Populus nigra* ‘*Italica*’ used in ScA and ScC has shown a uniform PS grade throughout the environment, consonant with ScB and ScD which have utilized *Platanus orientalis* trees as their greenery coverage option, emphasizing (i) Planting layout strategies were more important in affecting the thermal condition than the tree types when there were a ‘high’ number of local trees; (ii) similar tree crown volume could lead to a similar PS grades; (iii) Furthermore, some Tmrt values of 45°C to 50°C degrees were observed in the ExS, but the ScA and ScB were able to reduce the occurrence of these extreme temperatures. However, because July is one of the hottest months in the city, some degrees of 55°C to 60°C in the scenarios’ POIs could still be seen. Because the POIs were in the same location in all scenarios and were exposed to the sun differently, the intention of two more POIs specification was to determine how differently the scenarios will perform if the point is completely covered by tree crowns

considering single point SVFs. In the POI10 and 11 study, all scenarios showed an effective role in attenuating heat based on the PS grades, and decreased the mPET values fluctuate between 'no heat stress' and 'moderate heat stress'. It is worth mentioning again that this study was not aiming at attaining perfect outdoor thermal conditions, as this was not realistic, rather to see the capacity of vegetation in reducing the identified local PS grades. According to the table 22, it is conspicuous that the PET, mPET and Tmrt values for different POIs and scenarios were very close to each other that the difference was mostly less than 1°C especially those with the same planting strategy. These findings admit the emphasize on using trees to optimize use of sunlight, lessening the effects of UHI (Irmak et al., 2018; QIU et al., 2013; Reis & Lopes, 2019; Tan et al., 2016; Teshnehdel et al., 2020; Y. Wang et al., 2016) and reduction of PET and mPET (A. S. Nouri, Fröhlich, et al., 2018).

5.3. Integration of VR and thermal studies:

Urban green space and landscape preference studies seek to identify environmental characteristics that consistently contribute to how much people like settings, for whatever reason (R. Kaplan & Kaplan, 1989). On the other hand, climate has a significant impact on pedestrian outdoor comfort, and because climate is constantly "changing," it should be increasingly taken into account that the use of urban greenery, particularly trees, is beneficial for the mitigation of the urban heat island (UHI) effect, as evidenced by a decrease in Ta, Tmrt, and thermo-physiological indices (Teshnehdel et al., 2020). This study tried to investigate thermal condition of Amirkabir pavement through 4 greenery scenarios and people's psychological feedbacks toward them using VR technology. The

swap between the two variables of people's opinion using innovative techniques such as IVEs and thermal studies must be thought for optimizing public square design, particularly in light of urban densification and climate change (Zölch et al., 2019).

As discussed before, peoples' aesthetically and psychologically preferred scenario was ScD which is not parallel with the thermal analysis results where ScA and ScB could almost equally and better than ScC and ScD reduce the PS grades in POIs and provide a more even thermophysiological condition all over the environment. This will raise the attention and better equip urban planning and design professionals to optimize the design of the urban greenscape in order to increase the probability that citizens will encounter or choose UGSs in their daily activity patterns and increase the time that city inhabitants will spend in them (van Dongen & Timmermans, 2019). On the other hand, the thermal environment in POSs influences the utilization of such areas by people, which is very relevant to an individual's thermal perception (Lin, 2009), thus employing an appropriate thermal index to better understand people's thermal condition is an absolute necessity. Hence, in this study two thermal indices of PET and mPET were concurrently used and compared. According to table 22, as the temperature rose, the differences between PET and mPET thresholds of the same POI increased. mPET appeared to be a more consistent and less extreme and more preferable to PET especially in hot climates (Y. C. Chen & Matzarakis, 2018; Lin et al., 2019). Furthermore, this contradiction of people's opinion and thermal data highlights further efforts of interdisciplinary interaction of psychological and thermal studies agenda that shall grow in significance in light of aggravating climate change impacts (Nikolopoulou & Steemers, 2003; A. S. Nouri & Matzarakis, 2019).

CHAPTER 6

CONCLUSION

This study has introduced a new methodology for participatory designs in which architects, landscape architects, and urban planners will be able to measure their decisions prior to implementation. Utilizing VR technology, first from the target group and in the known location of each project, then with desired changes, repeating the process several times to bring it to the best physical form and the most efficient state of thermal comfort to ensure the project's success in the future. Taking these concerns seriously into account in public square design will shift the greenery design from traditional models to innovative layouts where people's participation in design process will play a crucial role.

According to the thermal simulations and VR studies some conclusion remarks are mentioned:

Table 23. Final summarizing figure based on the points below.

Results' evaluation	Conclusion and possible recommendations
Scenario D received the highest votes for aesthetics and better views	Contrary to the notion that Persian gardens were the most prevalent form of landscaping in Iran
Scenario D could achieve the highest psychological scores	The most aesthetically pleasing scenario was also the most psychologically appealing

Scenario D got the lowest score in the task of shop and tree counting	People's preferences do not correspond to their performance
The study showed the reliability of virtual reality technology	Virtual reality should be considered as an interdisciplinary bridge by thermal researchers and environmental psychologists.
PET and mPET thresholds compared	Researchers use the mPET index to more thoroughly and precisely analyze public open spaces.
All the scenarios were successful on reducing the <i>in-situ</i> physiological stress grades	Admits the capability of trees to control total sun radiation and increase the possibility of more shadow cast
Scenario A and scenario B showed more productive in reducing physiological stress grades	(i) Persian garden typology is more reliable approach in Amirkabir Pavement (ii) Preferences, performance, and thermal studies on different design scenarios are not parallel
There were more harmonious thermal CTIS diagrams for scenarios A and B, and for scenarios C and D.	Planting layout had played a more considerable thermal role than the tree types
Trees with similar tree crow volume had similar physiological stress oscillation pattern	An opportunity for designers to employ tall trees within wide-crown trees without concern of negative thermal effects
People's preferences, performance and thermal studies are not necessarily in one direction	To ensure the success of any urban project, architects and urban planners must collaborate more closely.

- People's attitudes toward the aesthetics of public squares are directly related to their openness to various parts of that environment and their perception of the most amount of vegetation area; in this study, scenario D received the most votes in all mentioned subjects. It is however contradictory with the idea that Persian gardens were the most accepted outdoor greenery design in Iran.
- Scenario D could also achieve the highest psychological scores of safety, happiness, freedom, and freshness while having the lowest stress score between

scenarios. Scenario A, on the other hand, performed the worst in those evaluations. It is an answer for H2 which demonstrates that people's psychological reactions to urban squares are influenced by their greenery design characteristics and in the same direction as their overall aesthetic preference; in other words, what people voted as the most aesthetically pleasing was the same that they found psychologically more gratifying.

- Respondents performed best in scenario B and worst in scenario D in the task of shop counting. It is also becoming more significant when, in estimating the number of trees in the environment, scenario D performed poorly and received the lowest level. The scenarios with *Populus nigra 'Italica'* received the most correct votes in this task. These findings clearly answer sub-RQ1 and the first part of H1 that people's preferences do not correspond to their performance, and that what they have chosen as their psychologically preferred scenario is not the same as the scenario in which they could demonstrate the best performance.
- Alongside with responding to sub-RQ2, this research also admits the reliability of virtual reality technology and immersive virtual environments for urban greenery designs through participation of different groups of people. Virtual reality can be suggested to the urban planners and architects to better analyze people's preference and perception of outdoor environments for more sustainable design approaches. This study also raises the attention of thermal comfort researchers and environmental psychologists to virtual reality technology as an initial interdisciplinary bridge between thermal and psychological studies.

- The study evaluated the potential contribution of mPET, a recently updated thermo-physiological measure, and compared it with PET. It is suggested that scholars employ the updated version of PET index to better comprehend and more accurately analysis public open spaces in these types of studies and others with reasonable temporal resolution.
- Concordant with H3 and answering sub-RQ3, in comparison to existing situation, All the scenarios were successful on lowering the *in-situ* physiological stress grades influences in all the point of interests and physiological stress fluctuations all over the environment in different months, However, scenario A and scenario B showed more productive in reducing physiological stress grades. It proves that Persian garden typology in comparison with surrounding and center typology is more reliable approach in Amirkabir Pavement, Arak. This is complementary for H1, People's preferred scenario is different from the scenarios capable of providing a more thermally comfortable condition an also an answer to the RQ of the study, preference, performance and thermal condition were not convergent.
- In both months of May and July, rather than the tree types having more noticeable effects on the PS mitigations, planting layout had played a more considerable thermal role where more harmonious diagrams for scenario A with scenario B and scenario C with scenario D can be seen in point of interests. In the POI10 and 11 study, it is crucial to estate that in May, the scenarios employing Persian garden typology, were more successful on alleviating the PET, mPET and mean radiant temperature values.

- The volume of the tree crown has been demonstrated to have a crucial influence in urban green spaces because tree crowns offer more possibility for shading cast so lowering the total gained T_{mrt} . It may be stated that in an outdoor environment, when deciding which tree to employ, approximately the same thermal comfort can be reached with the same tree crown volume. It is also Important to mention that instead of employing wide-crown or big trees in the cities to reduce physiological stress grades as suggested in some studies, this paper emphasizes also on the height of trees. It allows urban planners and architects to focus more on other aesthetic and monumental characteristics of trees when defining the tree type, after guaranteeing adequate crown volume, ensuring both psychological and thermal performance of their landscape design.
- The innovative methodology of using people's opinions and thermal comfort studies paralleled to optimize the design of public open spaces clearly revealed that people's preferences, performance, and thermal studies on different design scenarios are not necessarily in one direction, which draws architects' and urban planners' attention to work more closely and pay more attention to these two important fields simultaneously to ensure the accomplishment of any urban project.

6.1. Limitations and suggestions for further studies:

One of the most important limitations of this study was that the psychological experiment took place in May which is not the hottest month of the year. The questionnaire did not ask for July, nor were thermal questions asked, hence the opportunity for further study

can cover thermal questions and more months. Moreover, the climatic data used in this study are obtained via World meteorological organization. If in-situ data were obtained using portable trackers, more accurate and local data could be used in the RayMan simulation. On the other hand, virtual reality technology has also some limitations. For example, lacking more control and interaction with the environment while watching the videos. However, these limitations could not be improved within the scope of this research but future advancements in immersive virtual environments will make VR studies more realistic and give wider options to the researchers to investigate any scientific question. The other drawback is that preparation takes longer for each participant than it does for non-immersive ones since virtual reality is not a technology that is commonly known and used by ordinary people. In this study, no one had any prior experience using virtual reality technology. A preparation session is required so that participants can gain more knowledge and comfort with the virtual environments, the experiment's methodology and the process. Therefore, virtual reality experiments typically take excessive time.

Finally, the inherent characteristics of the proposed green scenarios and tree types may vary depending on the season and weather (J. Zhao et al., 2017). Nevertheless, since the current study's primary objective was to study the hottest days of the year, the trees' representation in virtual reality was pertinent for spring and summer, coherent with the thermal analysis, which was conducted over the same two months during the same seasons. However, further virtual reality and thermal studies are required to apply the obtained results to the autumn and winter to acquire yearly data. The future study could also look at more data with higher temporal precision – including into the night.

Furthermore, this innovative study highlights the importance of future interdisciplinary investigations into psychological and thermal studies. Scholars must concentrate their attention on these two important research fields in order to better establish a bridge between them.



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APPENDICES



APPENDIX A. THE ETHICAL PERMISSION BY THE BİLKENT UNIVERSITY ETHICAL COMMITTEE



Bilkent Üniversitesi Akademik İşler Rektör Yardımcılığı

Tarih : 22 Mayıs 2022
Gönderilen : Seyed Mahziar Taghavi
Tez Danışmanı : Nadim Adi
Gönderen : H. Altay Güvenir
İnsan Araştırmaları Etik Kurulu Başkanı
Konu : “*Application of ...*” çalışması etik kurul onayı

Üniversitemiz İnsan Araştırmaları Etik Kurulu, 22 Mayıs 2022 tarihli görüşme sonucu, “*Application of virtual techniques to assess natural shading design preferences among public square users*” isimli çalışmanız kapsamında yapmayı önerdiğiniz etkinlik için etik onay vermiş bulunmaktadır. Onay, ekte verilmiş olan çalışma önerisi, çalışma yürütücüleri ve bilgilendirme formu için geçerlidir.

Bu onay, yapmayı önerdiğiniz çalışmanın genel bilim etiği açısından bir değerlendirmedir. Çalışmanızda, kurulumuzun değerlendirmesi dışında kalabilen özel etik ve yasal sınırlamalara uymakla ayrıca yükümlü olursunuz.

Kovid-19 salgını nedeniyle konulmuş olan kısıtlamaların yürürlükte olduğu süre içinde, tüm komite toplantıları elektronik ortamda yapılmaktadır; aşağıda isimleri bulunan Bilkent Üniversitesi Etik Kurulu Üyeleri adına bu yazıyı imzalama yetkisi kurul başkanındadır.

Etik Kurul Üyeleri:

Ünvan / İsim	Bölüm / Uzmanlık	
Prof.Dr. H. Altay Güvenir	Bilgisayar Mühendisliği	Başkan
Prof.Dr. Erdal Onar	Hukuk	Üye
Prof.Dr. Haldun Özaktaş	Elektrik ve Elektronik Müh.	Üye
Doç.Dr. Işık Yuluğ	Moleküler Biyoloji ve Genetik	Üye
Dr. Öğr. Üyesi Burcu Ayşen Ürgen	Psikoloji	Üye
Dr. Öğr. Üyesi Didem Özkul McGeoch	İletişim ve Tasarımı	Yedek Üye
Dr. Öğr. Üyesi A.Barış Özbilen	Hukuk	Yedek Üye

Kurul karar/toplantı No: 2022_05_22_01

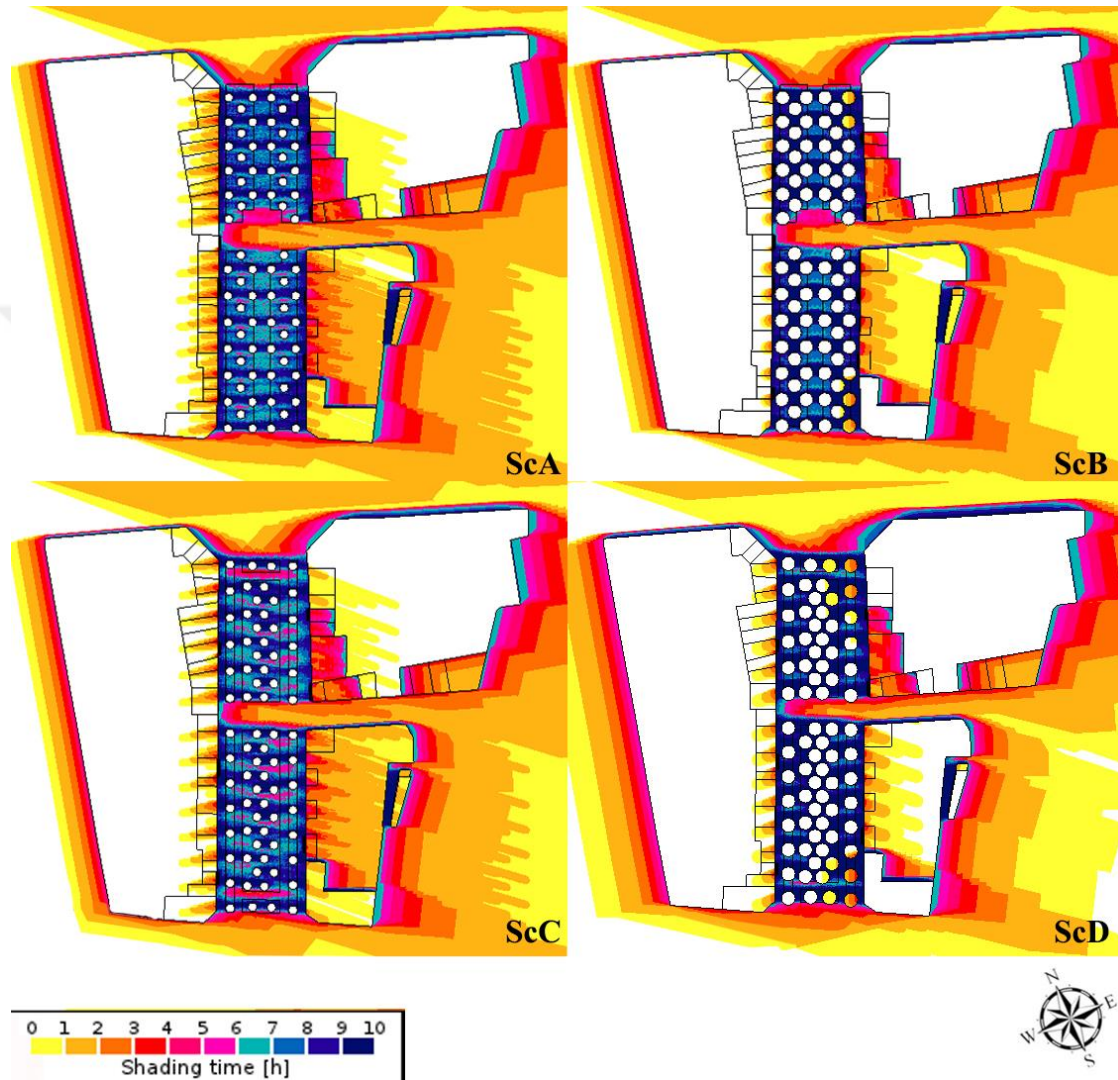
APPENDIX B. VARIETY OF GREENERY PLAN TYPOLOGIES IN ARAK

Vegetation pattern in Arak	Persian Garden 4 Bagh	Persian Garden 6 Bagh or more	Persian Gardens Not rectangular	Surrounding with centre	Just linear paths	Others
Quantity (96)	16	24	18	7	3	28
Percentage	16.67 %	25 %	18.75 %	7.29 %	3.13 %	29.17 %
	60.42 %			7.29 %	3.13 %	29.17 %
14 Masom	*					
Aftab		*				
Alaleh						*
Alamolhoda			*			
Alghadir		*				
Alghadir-2		*				
Amin town					*	
Amin		**				
Amirkabir 1						
Amirkabir 2						*
Arad						*
Artman						*
Arasis						*
Asanjarani		*				
Atlasi			*			
Avishan	*					
Azadegan		*				
Azadi Square			*			
Azadi						*
Azimi				*		
Baghizade		**				
Bahman						*
Baran						*
Beesat				*		
Chehelkaj						*
Daneshjo-1		*				
Daneshjo-2		*				
Didar		*				
Ehsan		*				
Elahie-1					*	
Elahie-2					*	

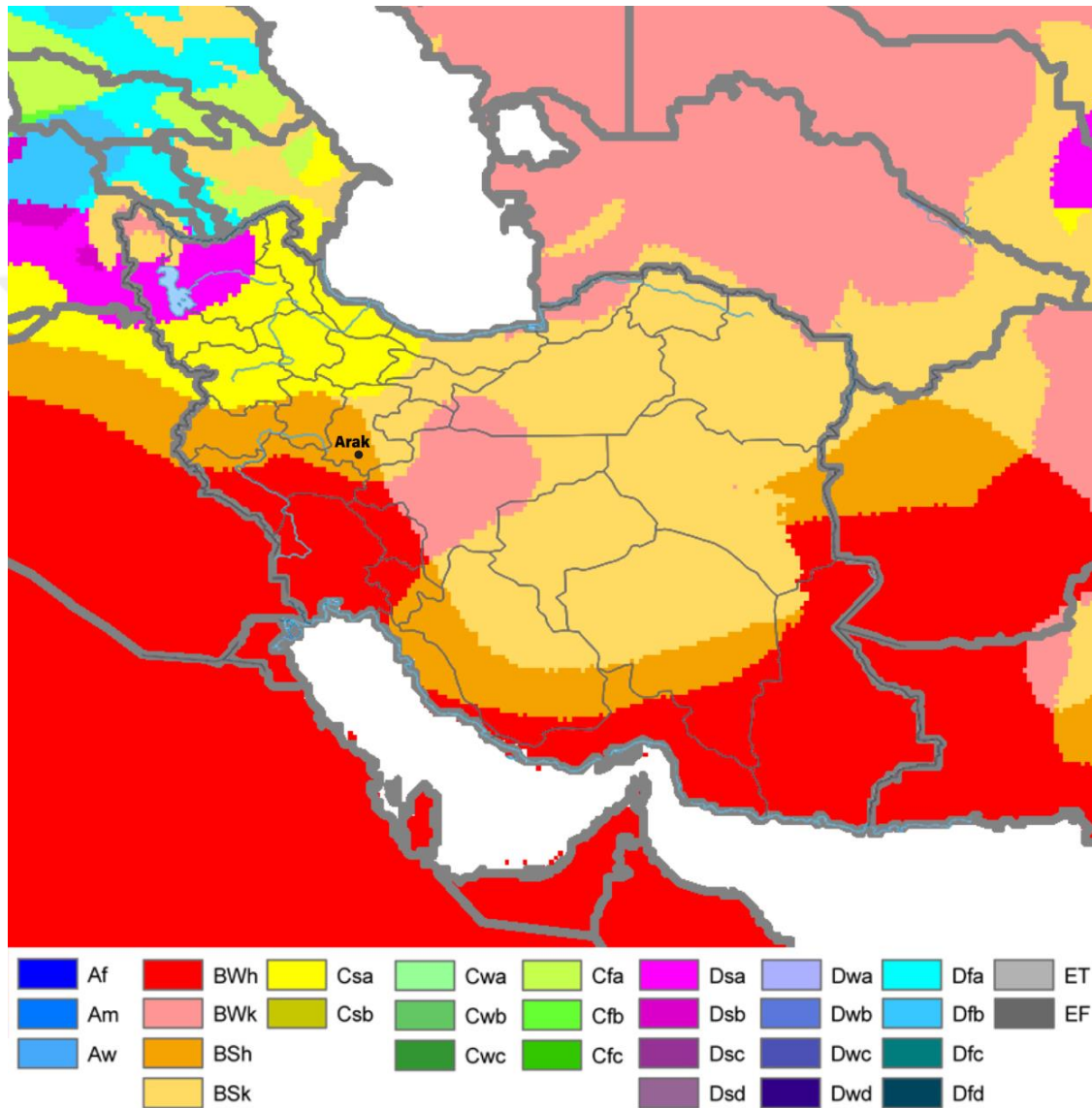
Erfan		*				
Fajr	*					
Faraji			*			
Fatemieh	*					
Gerdo						*
Ghaem			*			
Golbarg			*			
Golestan	*					
Hafeziyeh				*		
Hejrat				*		
Hekmat		*				
Hepco						*
Hepco-2						*
Imam Square			*			
Jame jam	*					
Janbazan	*					
Jannat						*
Javadiye	*					
Karimi			*			
Keshavarz	**					
Khayam			*			
Kheybar			*			
Kodak-1	*					
Kodak-2						*
Kodak-3						*
Kohsar						*
Ladies		*				
Laleh ha						*
Laleh		*				
Maadan		*				
Madar		*				
Mashahir		*				
Mellat			*			
Moallem-1						*
Moallem-2		*				
Moshaver		*				
Naghme-1		*				
Naghme-2	*					
Nasim				*		
Niloufar		*				
Olama						*
Orkid			*			

Paeizan						*
Pamchal			*			
Pardis	*					
Parniyan				*		
Patogh						*
Pirozi		*				
Poneh				*		
Rahahan			*			
Ranginkaman			*			
Razi						*
Rezvan						*
Roz	*					
Sanaat			*			
Sedaghatpour						*
Shaghayegh-1			*			
Shaghayegh-2		*				
Shahid Mostafa Khomeini			*			
Shahr						*
Shahrsanaati						*
Shohadaye Gomnam	*					
Tarannom						*
Toska	*					
Velayat	*					
Zanbagh						*

**APPENDIX C. SHADOW ANALYSIS OF THE SCENARIOS DURING
THE MAY 10TH**



**APPENDIX D. IRAN AND ARAK CLIMATIC CLASSIFICATIONS,
ACCORDING TO PEEL ET AL., (2007). EDITED BY AUTHOR**



APPENDIX E. THE QUESTIONNAIRE SURVEY

Section A: Please answer the following questions.

1. Age:
2. Gender: Female ☐ Male ☐
3. Education level: Middle and high school or lower ☐ University ☐ Master/ PhD ☐
4. Profession/ Department:
5. Nationality:
6. If yes, how many times a week do you visit Amirkabir pavement?

Section B: Please answer the following questions about each Scenario:

In scenario A:

- | | | | | | | |
|---|-----|-----|-----|-----|-----|------|
| 1. How many trees could you see | <30 | <40 | <50 | <60 | <70 | <80 |
| 2. How many ice cream shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| 3. How many shoe shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| | Few | | | | | Much |
| 4. How safe did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 5. How happy did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 6. How stressful did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 7. How much freedom did you feel? | ① | ② | ③ | ④ | ⑤ | |
| 8. How refreshing did you find it? | ① | ② | ③ | ④ | ⑤ | |

In scenario B:

- | | | | | | | |
|---|-----|-----|-----|-----|-----|------|
| 1. How many trees could you see | <30 | <40 | <50 | <60 | <70 | <80 |
| 2. How many ice cream shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| 3. How many shoe shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| | Few | | | | | Much |
| 4. How safe did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 5. How happy did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 6. How stressful did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 7. How much freedom did you feel? | ① | ② | ③ | ④ | ⑤ | |
| 8. How refreshing did you find it? | ① | ② | ③ | ④ | ⑤ | |

In scenario C:

- | | | | | | | |
|---|-----|-----|-----|-----|-----|------|
| 1. How many trees could you see | <30 | <40 | <50 | <60 | <70 | <80 |
| 2. How many ice cream shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| 3. How many shoe shops could you see | 5 | 6 | 7 | 8 | 9 | 10 |
| | Few | | | | | Much |
| 4. How safe did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 5. How happy did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 6. How stressful did you find it? | ① | ② | ③ | ④ | ⑤ | |
| 7. How much freedom did you feel? | ① | ② | ③ | ④ | ⑤ | |
| 8. How refreshing did you find it? | ① | ② | ③ | ④ | ⑤ | |

In scenario D:

4. How many trees could you see	<30	<40	<50	<60	<70	<80
5. How many ice cream shops could you see	5	6	7	8	9	10
6. How many shoe shops could you see	5	6	7	8	9	10
	Few					Much
4. How safe did you find it?	①	②	③	④	⑤	
5. How happy did you find it?	①	②	③	④	⑤	
6. How stressful did you find it?	①	②	③	④	⑤	
7. How much freedom did you feel?	①	②	③	④	⑤	
8. How refreshing did you find it?	①	②	③	④	⑤	

Section C, Personal opinions: Please answer the following questions.

1. Which design is aesthetically more pleasant for you?
2. In which scenario you had a better view to the different parts of the city?
3. Which one had more total pavement area?
4. Which one had more total green area?

Ⓐ Ⓑ Ⓒ Ⓓ =

Ⓐ Ⓑ Ⓒ Ⓓ =

Ⓐ Ⓑ Ⓒ Ⓓ =

Ⓐ Ⓑ Ⓒ Ⓓ =

APPENDIX F. THE EXPERIMENT INSTRUMENT



VR media Player application, VR BOX head-mounted display