Ain Shams Universtiy

Utilization of Outdoor Space through Microclimatic Responsive Design Approach

Knowledge Co-Production on Abdeen Square

A Thesis submitted in the Partial Fulfillment for the Requirement of the Degree of Master of Science in Integrated Urbanism and Sustainable Design

by

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July 2023

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Abstract

How can microclimate landscape elements be used to optimize the thermal performance of outdoor spaces? How do the users utilize the outdoor space? Is that optimum solution contextually suitable for the recipients utilizing the outdoor space? Questions need to be asked by every climate service provider and urban designer while designing or developing outdoor spaces, especially in the era of climate change. This study aims to reduce the gap between climate service providers and recipients while designing or developing outdoor spaces. It advocates for a more inclusive process aiming to reach an optimum solution for the outdoor space landscape setting, precisely, the trees' spatial arrangement, to enhance its thermal performance. The co-production process aims to achieve a more contextual solution by integrating the providers' and recipients' diverse knowledge and expertise. The study is carried out in Abdeen Square, an outdoor space that was recently developed. The study investigates the impact of co-produced knowledge in optimizing the tree spatial arrangement to enhance the outdoor thermal performance of Abdeen Square. As a result, an integrative methodological approach was used to ensure the presence of diverse knowledge during the empirical study. The study was divided into two sequential phases, in which Grasshopper was used as a simulation tool to assess thermal performance. While an onsite survey and semi-structured interview were used to investigate user suitability. Consequently, various results were found regarding the thermal performance of Abdeen Square and user suitability, which were outlined and then correlated. The interrelation between the diverse knowledge on Abdeen Square resulted in a new co-produced knowledge that was more contextual and usable in real-life situations, resulting in optimizing a spatial arrangement of trees while considering the thermal performance and the user suitability, thus enhancing the utilization of Abdeen's Square. On this basis, designing or developing outdoor spaces must be accompanied by prioritizing the integration of diverse stakeholders with different knowledge and experience throughout these processes to create more contextual and optimum solutions for the utilization of outdoor spaces.

Keywords: Knowledge Co-Production – Thermal Performance – User Suitability – Outdoor Space Utilization - Trees Spatial Arrangement

Acknowledgment

After coming to the end of this challenging and inspiring journey, thank you, God, for showering me with your blessings and guiding m throughout each step of this journey.

Very special gratitude to my supervisors, Dr. Salheen and Dr. Wessam, for their feedback. Dr. Salheen, I was lucky to have you as my supervisor; thank you for always pushing me forward and giving me time throughout your busy schedule. Our discussions taught me a lot, not just about research but also about me and life; you inspired me on a personal level. Dr. Wessam, thank you for your time and feedback; I also learned a lot from you on a personal level.

I want to express my endless gratitude to my family, my backbone, and my main motivators and supporters. Mama, thank you for always being supportive and caring through this journey. Pavly, I would not have made it without your kind support and follow-up at each step; I owe you a lot, dear; thank you for being my role model.

For my friends, especially Miriam, Maria, and Kiro. Thank you for being who you are, for your constant support, always cheering me up, keeping me sane, and always lifting me.

It was an inspiring journey that I enjoyed.

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List of Acronyms

UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
COP	Conference of the Parties
ACE	Action for Climate Empowerment
ASHRAE	The American Society of Heating, Refrigerating, and Air-Conditioning Engineers
MRT	Mean Radiant Temperature
PMV	Predicted Mean Vote
PET	Physiological Equivalent Temperature
UTCI	Universal Thermal Climate Index
MEMI	Munich Energy Balance Model
LAD	Leaf Area Density
LAI	Leaf Area Index

Chapter 1: Outdoor Spaces Thermal Performance and Knowledge Co-production

1.1. Background

Outdoor spaces are essential to our daily lives, influencing our overall well-being and enhancing our quality of life. These spaces hold great significance for our community as they serve as a hub for social interaction, relaxation, connecting with nature, and offering opportunities for diverse activities (Nasution and Zahrah, 2018; Han *et al.*, 2022). The utilization of outdoor spaces is influenced by many factors, on which the outdoor spaces which are utilized effectively are spaces that fulfill the users' needs and offer a good quality of their physical and spatial structure (Abbasi, Alalouch and Bramley, 2016).

Due to the impact of climate change leading to continuous increases in temperatures, the thermal performance of outdoor spaces has significantly impacted its quality, thus, affecting the utilization of outdoor spaces (Vukmirovic et al., 2019; Wei et al., 2022). Accordingly, enhancing the thermal performance of outdoor spaces has been of considerable interest in much research and practice (Eslamirad *et al.*, 2022). Despite this interest, many of these contributions are not completely efficient due to a lack of integration between climate service providers and recipients; in which one contributing factor to this situation is the predominance of physical sciences in such cases (Bojovic *et al.*, 2021).

This study aims to reduce the gap between climate service providers and recipients while designing or developing outdoor spaces. It advocates for a more inclusive and collaborative process between the climate service provider and recipients to ensure the integration of different knowledge and expertise, aiming to reach an optimum solution for the outdoor space landscape setting while considering thermal performance and user suitability.

1.1.1. Co-Production of Knowledge for Outdoor Thermal Performance

The co-production of knowledge is a process that gained widespread recognition in the discourse on climate services. In this process, recipients and providers of a climate product work together to make integrative decision-making about such a product (Norström *et al.*, 2020; Bojovic *et al.*, 2021). The significance of community engagement in decision-making in urban climate planning has been highlighted in prominent global declarations, tracing back to the Rio Declaration that was formulated during the United Nations Conference on Environment and Development (UNCED) in 1992. Article 6 of the declaration underlines the significance of citizen engagement and involvement in climate initiatives (Hügel and Davies, 2020).

It explicitly emphasizes the active participation of diverse stakeholders, particularly lay citizens, in discussions related to urban climate design. This participation is crucial to uphold procedural justice, ensuring public acceptance, and attaining successful implementation of a climate service (Satorras *et al.*, 2020).

1.1.2. Cairo Outdoor Spaces Context

Cairo's continuous urbanization and removal of green areas in which the average share of green spaces for each person has decreased to 0.74 m2, resulting in increasing urban heat island effect and heat stress, have had a significant impact on the thermal performance of outdoor spaces, human thermal comfort, quality of life, thus the usability of outdoor spaces (Aly & Dimitrijevic, 2022; Hamdy, 2022).

In recent years, Cairo has witnessed two notable development examples in its outdoor spaces. The first instance is like the development of the Heliopolis district, which aimed to address traffic congestion by focusing on that specific side without considering other aspects such as environmental quality and user satisfaction. However, this development resulted in the removal of green infrastructure and its replacement with grey infrastructure, leading to a decline in the thermal performance of the outdoor space and negatively impacting its suitability for users (Hefnawy et al., 2022). The second practice involves developing outdoor spaces using landscape design without adequately involving users in the process, resulting in a product that needs more contextual relevance.

In general, both practices rarely consider the integration of climate service providers and users in the development of outdoor spaces, directly influencing their thermal performance and user suitability.

1.2. Problem Statement

Despite the increased interest in enhancing the thermal performance of outdoor spaces using micro-climate landscape design and the advocacy for integrating the climate service provider and recipient in the decision-making. In Cairo, while designing or developing outdoor spaces, there needs to be more consideration for two factors, designing or developing outdoor spaces using microclimatic responsive landscape design and integrating knowledge between the climate service provider and recipient while designing or developing those spaces. This Practice resulted in an ineffective non-contextual design which impacts thermal performance and user suitability, thus the utilization of the outdoor spaces.

1.3. Scope of Study

The research will focus on the second type of development in outdoor spaces mentioned, as the first type, like what happened in Heliopolis and Nasr City, was already assessed and showed its consequences. (Hefnawy et al., 2022). The chosen area is Downtown Cairo, located in the western part of Cairo (Figure 1). It has witnessed many transformations in its outdoor spaces through different eras. Downtown's last development resulted from the relocation of the governmental building to the New Administrative Capital, aiming to avoid overcrowding and creating a cultural-political hub boasting a modern and efficient infrastructure that significantly improves the quality of life in the region (UN-Habitat, 2012; Shalaby and Omar, 2022). Accordingly, outdoor spaces played a role in this development plan aiming to create vibrant spaces and major Squares linked together with green networks and efficient pedestrian-friendly pathways (Shalaby and Omar, 2022); however, this development lacks the factor of integrating the knowledge of the provider and recipient to reach this development goal. Abdeen Square was the chosen outdoor space located in Downtown Cairo; it is an outdoor space that was developed using landscape design from a car parking to a space with diverse activities and enhanced landscape patterns (UN-Habitat, 2016); more details about the case study selection will be mentioned later in Chapter 5.

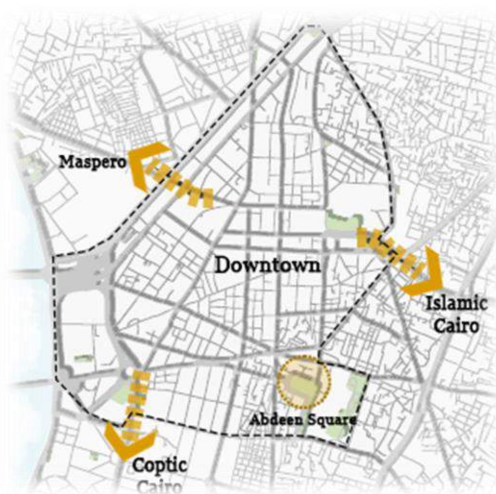

Figure 1: Downtown Context (Source: Author)

1.4. Research Objectives and Questions

1.4.1. Research Objectives

The main objective of this research is to investigate the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square. In this regard, it contributes to reducing the gap between climate service providers and recipients while designing or developing outdoor spaces in urban design field and urban research.

To achieve the main objective, these sub-objectives are set:

1. Exploring the characteristics of the knowledge co-produced climate service.
2. Determining the adequate thermal index to assess the user perception in the outdoor spaces.
3. Developing and testing the adequateness of trees' spatial arrangement scenarios in enhancing the thermal performance of Abdeen Square.

1.4.2. Research Questions

The main research question that this research is going to investigate is:

How can the co-produced knowledge impact the trees' spatial arrangement optimization to enhance the outdoor thermal performance of Abdeen Square?

This leads to other sub-questions that this research investigates. Those sub-questions are:

1. What are the characteristics of a knowledge co-produced climate service?
2. What is an adequate thermal index to assess user perception in outdoor spaces?
3. What is the adequate spatial arrangement of trees that enhances the thermal performance of Abdeen Square?

1.5. Research Methodology

To fulfill the research aim, the research adopted different methodologies, starting with reviewing the literature to explore the characteristics of the co-produced knowledge, the thermal performance of outdoor spaces, and the impact of trees on enhancing the thermal performance of outdoor spaces. Following that, an integrative methodological approach was used to perform the empirical study. The results are then portrayed and correlated to infer the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square. The research will finally propose implications for future research and recommendations for urban designers and practitioners.

1.5.1. Research Ideation Framework

The research's main ideation (Figure 2) is built on the integrity between climate service providers who provide the technical knowledge resulting in enhanced outdoor thermal performance. On the other hand, recipients provide information regarding real-life experiences. The result of this integrity is more contextually co-produced knowledge that is more applicable in real-life situations. In other words, the new co-produced knowledge will result in a solution that is optimum for the thermal performance of outdoor spaces and the user's suitability, thus enhancing outdoor space utilization.

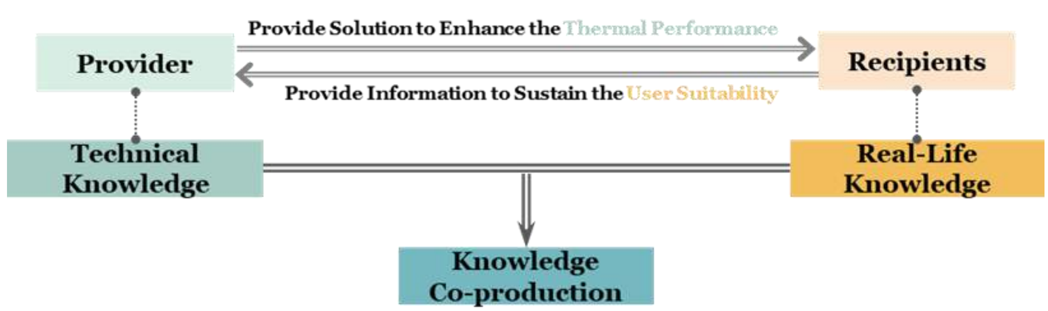

Figure 2:Research Ideation Framework (Source: Author)

1.5.2. Methods and Tools

The field research was divided into two phases – the co-explore phase and the co-develop phase, and each phase has its hard and soft system tools. The co-explore phase was designed to assess the thermal performance of Abdeen Square using Grasshopper as a simulation tool while, on the other hand conducting an on-site survey and semi-structured interview to have the recipients as active contributors in assessing the current situation to understand their needs. Building on the co-explore phase, the co-develop phase was designed to assess the impact of the four trees' spatial arrangement on enhancing the thermal performance of Abdeen Square using Grasshopper as a simulation tool. On the other hand, conducting an on-site survey and semi-structured interviews to collaborate with the recipients to evaluate the proposed solutions and know their preferences. Finally, these two phases' outcomes were analyzed, and a solution was developed from the coproduced knowledge to investigate its impact on thermal performance and user suitability.

1.5.3. Research Outline

The research is divided into three main phases, which are the exploring phase, the performing phase, and the developing phase (Figure 3). The following lines show the outline of each phase.

Phase one, "The Exploring Phase,": This phase covered the reviewed literature that aimed to answer the first and second questions. After the introduction, chapter 2 will explore the relevant literature, tackling literature on the history of community engagement in climate action, then the knowledge coproduction of climate services, precisely the characteristics of the process and product of the co-produced knowledge of the climate service. Chapter 3 will explore the thermal performance of outdoor spaces, focusing on thermal perception and the user's outdoor comfort, followed by exploring the different outdoor thermal comfort indices. Chapter 4 will focus on the trees as a microclimate landscape element in outdoor spaces, understanding the characteristics of the trees and exploring the impact of the spatial arrangement of the trees on enhancing the thermal performance of the outdoor spaces. This chapter will aid in building knowledge to answer the third question in the next phase.

Phase Two, "The Processing Phase": This phase will cover the empirical study and include the field research methodology through Chapter 5, which will objectively describe the area of investigation and the methods and tools for conducting the research. It will also portray the results and findings through Chapter 6, which will answer the third and main research questions.

Phase three, "The Progressing Phase": This phase covers the last chapter summarizing the findings and linking them to the initial conceptual framework. It will propose helpful implications for future research and recommendations for urban designers and practitioners.

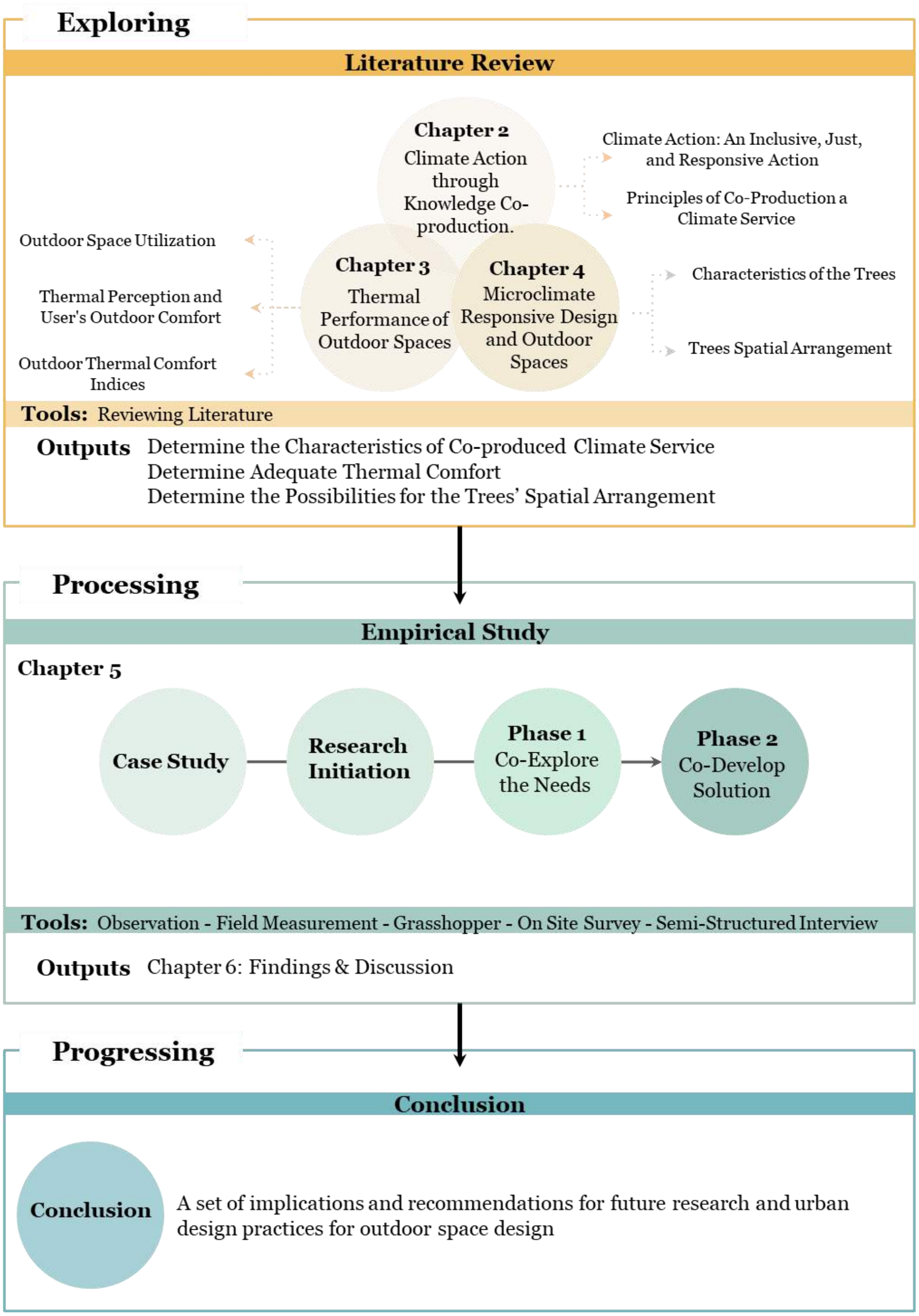

Figure 3: Conceptual Framework (Source: Author)

1.6. Limitations

1. Trees were selected as the micro-climate landscape element that will be used for optimization due to the time limitation, as trees are known as the most effective landscape element in enhancing the thermal performance of outdoor spaces (Chen *et al.*, 2022).
2. Envi-Met is known for giving a better result for the impact of trees on enhancing the outdoor thermal performance of outdoor spaces; however, the simulation time takes a long time. Accordingly, and due to the limitation of time, the Grasshopper tool and its plugins were used as they have an acceptable accuracy in assessing outdoor thermal comfort (Yazıcıoğlu and Dino, 2021), and its simulation period is limited compared to other tools, such as ENVI-met (Pacifici and Nieto-Tolosa, 2021).
3. The methodological approach of the research can be generalized to other contexts. However, the results of the co-produced knowledge of the case study could not be generalized as the results are context-related to Abdeen Square.

Chapter 2: Climate Action through Knowledge Co-production

The active participation of diverse stakeholders in discussions related to urban climate planning traces back to the Rio Declaration formulated during the UNCED in 1992, which ensures this participation is crucial for successfully implementing a climate service (Hügel and Davies, 2020; Satorras et al., 2020). The knowledge co-production approach has gained widespread recognition in the discourse on climate services aiming to ensure the knowledge transferability between climate provider and recipient, thus implementing a more contextual product (Zurba *et al.*, 2021).

The narrative of this chapter starts by showing the historical timeline for the importance of communities' participation as a fundamental right to have their views and needs integrated into the decision-making process. Then, the chapter shows the main characteristics of the product resulting from the knowledge co-production process and the methods used to co-produce knowledge to be used further during the empirical study.

2.1. **Climate Action: An Inclusive, Just, and Responsive Action.**

The United Nations Framework Convention on Climate Change (UNFCCC) has specifically addressed the involvement of the public in the climate change legal regime in Article 6. This article has undergone continuous development during the conference of parties (Figure 4), emphasizing the importance of meaningful participation of different stakeholders. The term "meaningful" participation implies that stakeholder involvement should not be superficially done to meet formal requirements. Instead, the engagement should empower citizens to actively express their views and incorporate their needs into the process, ultimately influencing the outcome (Amin et al., 2021).

During the 8th Conference of the Parties (COP 8) held in India, participating countries collectively agreed to adopt the New Delhi work program on Article 6 of the Convention. This marked the beginning of an initiative designed to provide a foundation for prompt action on activities related to Article 6 under the provisions of the Convention (UNFCCC, 2002). Fast forward ten years later, in 2012, during COP 18 in Doha, the participating parties reaffirmed the significance of the six elements in Article 6 in achieving the goal of the Convention by adopting the Doha work program on Article 6 for eight years. The parties also urged the SBI to organize a yearly in-session Dialogue on Article 6 of the Convention to facilitate the exchange of ideas, effective approaches, and knowledge gained from implementing the work program (UNFCCC, 2013).

The year 2014 marked a turning point regarding Article 6 of the Convention during the Lima Ministerial Declaration on Education and Awareness-raising. The declaration called for increased efforts to integrate formal and informal education and raise public awareness to promote sustainable development and climate resilience. Moreover, it urged governments to include climate change in their national education plans and enhance the participation of individuals in making informed decisions and addressing climate change (UNFCCC, 2015).

During COP 22, a consensus was reached among the participating parties to enhance the effectiveness of the Doha work program on Article 6 of the Convention. It was also urged that all parties continue promoting the incorporation of gender-sensitive and participatory education, training, public awareness, public participation, and public access to information in all mitigation and adaptation efforts under the convention and the Paris Agreement. This includes the implementation of their nationally determined contributions and the development of long-term plans. The parties also agreed to refer to efforts related to implementing Article 6 of the Convention as Action for Climate Empowerment (ACE) (UNFCCC, 2017).

At the COP 24 summit, the ACE decision was adopted as part of the Paris Agreement's work program, emphasizing its strong connection to the Sustainable Development Goals. Countries were urged to appoint national focal points for ACE and create national strategies to promote it. Additionally, the decision recommended that the six elements of ACE be integrated into all adaptation and mitigation efforts implemented under the convention and the Paris Agreement (UNFCCC, 2019).

At the COP 26 summit, a 10-year plan known as the Glasgow work program was approved by all parties to reinforce the implementation of ACE. This program offers a flexible framework that enables countries and other involved parties to improve their ACE implementation endeavors while emphasizing the importance of promoting all six ACE elements in a well-balanced manner (UNFCCC, 2022). During the last COP, great emphasis was given to engaging youth through climate action by highlighting the importance of youth and children in taking climate action and co-organizing the first youth-led climate forum (UNFCCC, 2023).

In line with the UNFCCC convention's Article 6 and Article 12 in the Paris Agreement, several commitments and agendas have been established to emphasize the significance of community engagement in taking climate action.

In 2016, the New Urban Agenda established a list of worldwide commitments to achieve sustainable urban development centered on people, protecting the planet, and responding to the needs of different age and gender groups. These commitments underscore the importance of community engagement in climate action. Several of these commitments highlight the need to encourage climate action at every level, internationally, nationally, and locally. The focus is on mitigating and adapting approaches to climate change, with a particular emphasis on aiding not just local governments but also all members of society in executing these actions successfully. Furthermore, the New Urban Agenda envisions participatory cities, encourages civic engagement, prioritizes outdoor spaces that are safe, inclusive, accessible, green, and of high quality, and fosters social harmony, inclusion, and security (United Nations, 2017).

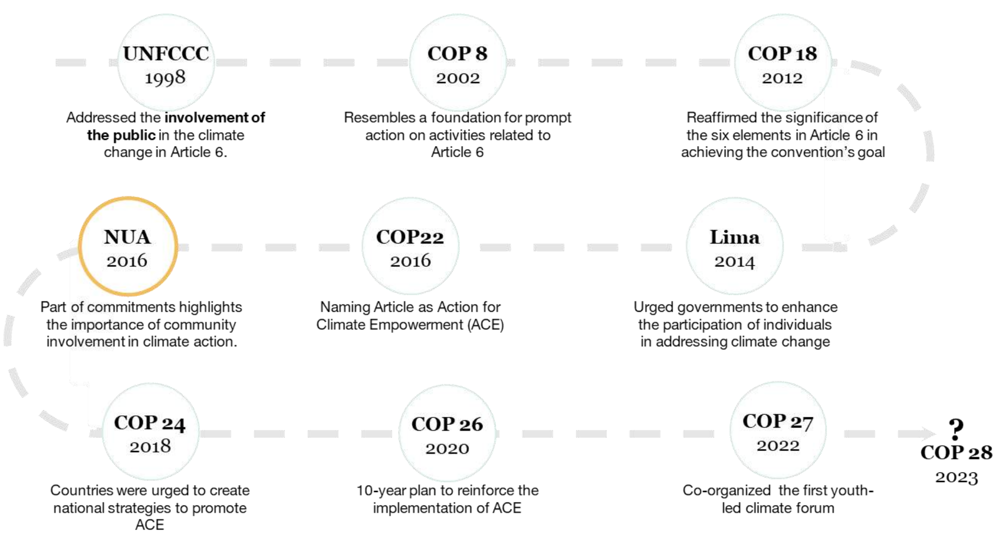

Figure 4: Community Engagement in Climate Action through COPs & NUA (Source: Author)

2.2. Origins of Co-production

Climate change poses a multifaceted risk that calls for innovative insights. Even with the wealth of climate data that is readily available, effective planning and adaptation are only sometimes achieved. This has led to a usability gap wherein climate data is generated but needs to be more effectively utilized by decision-makers. The traditional supply-driven model is now being challenged by a collaborative knowledge production approach that promotes co-production to create a tailored and targeted service that is credible, salient, and legitimate. Although co-production is a new concept in climate change, its effectiveness has been demonstrated in other fields where involving users in the production process enhances the credibility and legitimacy of information (Vincent et al., 2021).

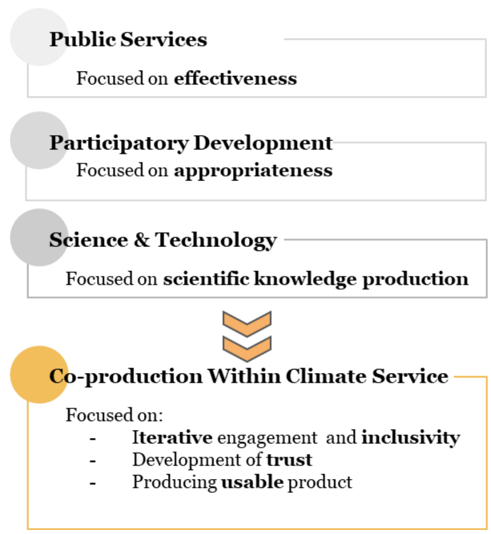

Figure 5: Knowledge Co-production Origin (Source: Author)

The term knowledge co-production was first introduced by Elinor Ostrom in public services administration (Figure 5) during the late 1970s, with the notion that effective and responsive public services necessitated the active involvement of citizens in both the production and consumption of such services (Ostrom *et al.*, 1978). This perspective advocated for a departure from conventional linear service delivery and establishing of novel relationships between service providers and consumers, which blurred traditional roles and boundaries (Ostrom, 1996).

Concurrently, in the early 1980s, there was significant criticism of the top-down approach to socioeconomic development. This resulted in broad demand for participatory models encouraging recipients to participate in development interventions. The socio-economic development paradigm has undergone a participatory shift in recent years, highlighting the significant value of local populations' experiential knowledge alongside scientific approaches. This shift in perspective has led to adopting co-production as an analytical lens to understand the interdependence of science and society (Rogers, 2003).

Co-production has emerged as a normative goal of science policy, encouraging collaborative approaches between knowledge providers and users to address shared problems. As a result, co-production has become an essential component of environmental management processes, notably in climate change adaptation policy, practice, and climate service development (Vincent *et al.*, 2018). Co-production blurs boundaries between providers and users of information, challenging power differences resulting from science production and use. Knowing how power operates in knowledge-making and use is crucial for co-production in science and technology studies, where collaborative work is now a standard approach to addressing problems and finding solutions (Vincent *et al.*, 2021).

2.3. Knowledge Co-production of Climate Services

Seven principles (Figure 6) have been identified for creating a functional, co-created climate service based on (Vincent *et al.*, 2018, 2021; Norström *et al.*, 2020). These principles are divided into two categories, four for the product and three for the process. The process and product are an integral part of a co-production knowledge cycle to obtain climate services, including stakeholder identification, decision exploration, solution development, delivery, and evaluation (Vincent *et al.*, 2018).

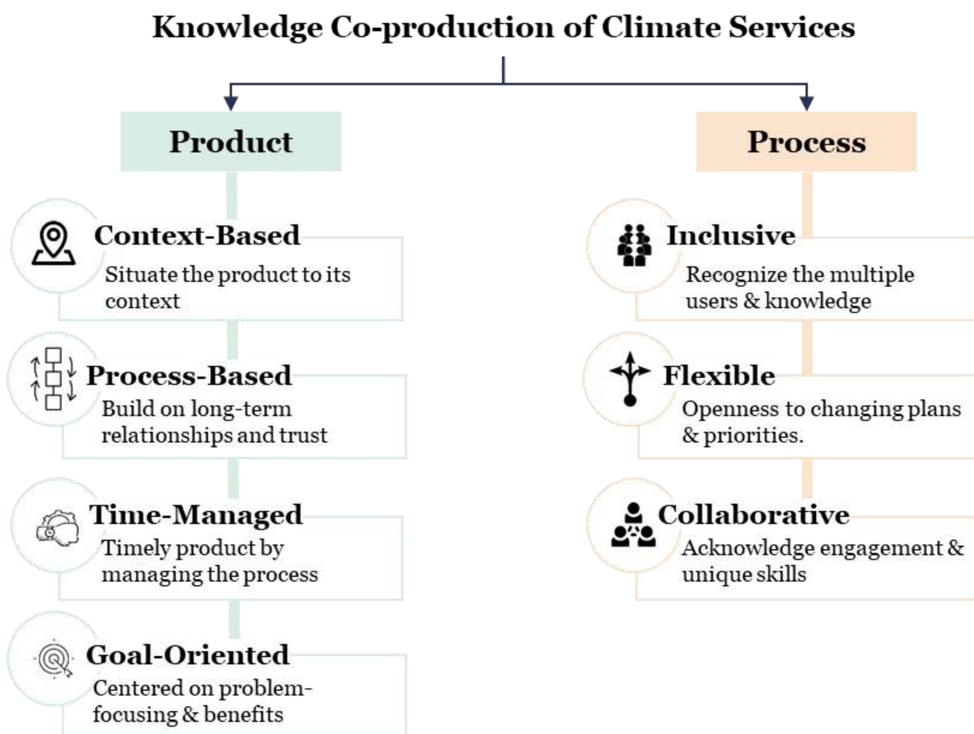

Figure 6: Knowledge Co-production of Climate Services (Source: Author)

2.3.1. Co-produced Product Characteristics

This section shows the characteristics of the product resulted from the knowledge co-production which are decision-driven, process-based, and time-managed.

2.3.1.1. Context-based

In the realm of climate information, the distinction between a climate product and a climate service lies in the fact that the latter is specifically created to cater to a user's needs and is therefore driven by decisions. The decision-making context can significantly influence the identification of the most critical issue. Nevertheless, identifying user needs can prove to be challenging (Steynor *et al.*, 2016). Both users and providers may identify a climate product that is not always the best fit for the intended decision, necessitating iteration to develop a service that addresses the decision (Vincent *et al.*, 2018).

The process and outputs of co-production should be tailored to the specific context and needs of the decision-making process. This means considering the social, economic, and ecological factors surrounding and impacting the process. Additionally, it is crucial to acknowledge the needs, interests, and beliefs of the various stakeholders involved or affected by the challenge. It is also important to consider power dynamics and remain aware of the level of contribution that may result from the process (O'Connor *et al.*, 2019; Norström *et al.*, 2020). To situate a co-production process, questions must be asked about who will be impacted and who holds the power to enable or constrain action. It is equally essential to describe these processes using contextually appropriate language based on a shared understanding of key concepts and terminology (Vincent *et al.*, 2021).

To identify the decisions a climate service can inform, it is vital to undertake co-exploratory processes between providers and users. Such scoping is frequently carried out using workshops, town meetings, questionnaires, and surveys. This phase is commonly called the "intelligence phase" (McNie, 2007).

Examining the decision context can aid in the co-production of a more usable climate service. Furthermore, ongoing knowledge exchange, monitoring, and learning throughout the co-production cycle aid in determining where such refinement is required. The co-production of climate services may face challenges from conflicting time frames of interest among stakeholders. To ensure the usability of such services, it is crucial to align the forecast time frames with the relevant decision-making periods. Timeliness and sustainability of service delivery are critical components of effective climate services co-production (Zurba *et al.*, 2021).

2.3.1.2. Process-based

The notion of a process-based product emphasizes that a climate service constitutes not only the product itself but also the process of its development, testing, and refinement, as well as the establishment of long-term relationships and trust between providers and users. To ensure the effective co-production of equitable and inclusive climate services, a process-based approach can be implemented in diverse ways, such as defining priorities, responsibilities, expectations, and goals. Various models of knowledge exchange, including embedding researchers and utilizing knowledge brokers, can further contribute to the process-based co-production by bringing together different actors (Wall, Meadow and Horganic, 2017; Vincent *et al.*, 2018)

2.3.1.3. Time-managed

As mentioned by (Wall, Meadow and Horganic, 2017; Vincent *et al.*, 2018; Norström *et al.*, 2020), managing the co-production cycle efficiently to produce a timely product is essential. This involves identifying relevant actors, exploring their needs, developing and delivering the service together, and evaluating it afterward. Appropriate time allocation must be made for each process stage to achieve this. The entire process is crucial to ensure that a timely product is produced.

2.3.1.4. Goal-oriented

Knowledge co-production for sustainable climate service is goal-oriented and benefits from participants sharing clearly defined and meaningful goals. All parties must have a shared knowledge of the challenges at hand and a measure of success. Success can take various forms, including changes in policies and practices, shifts in attitudes and views, and forming collaborative networks. It is important to recognize that there are often multiple possible pathways to reach an agreed goal (Norström *et al.*, 2020).

2.3.2. Knowledge Co-production Process Characteristics

This section shows the characteristics of the knowledge co-production process, which is a process that is inclusive, flexible, and collaborative.

2.3.2.1. Inclusive

An inclusive co-production cycle is crucial in developing an effective, decision-driven climate service; it requires a deliberate recognition of the multiple ways of knowing and doing. To attain inclusive co-produced knowledge, individuals from many sectors with varying epistemological and ontological origins and various skills and types of knowledge and expertise should be included in the process. This variety leads to an enriched comprehension of the different aspects of a sustainability challenge. Accordingly, enhancing knowledge outcomes with appropriate conditions (Norström *et al.*, 2020).

This involvement in the knowledge co-production process results in usable knowledge production, establishing legitimacy and fostering greater confidence in its utilization. Inclusivity encompasses two interdependent components: individuals and knowledge. By integrating these components, an inclusive approach can be achieved, ensuring that all stakeholders' needs and perspectives are considered throughout the co-production cycle (Vincent *et al.*, 2018).

Climate science experts formulate climate service proposals that attach great importance to the relevance and potential users of the information. Historically, scientific research has been focused on developing and verifying theories, but the co-production process involves collaboration between individuals with diverse perspectives and beliefs (Fazey *et al.*, 2014; Vincent *et al.*, 2018). This approach facilitates the generation of knowledge and enhances the credibility and usefulness of information for decision-making. By jointly exploring information needs, decision-makers can identify and address critical gaps, leading to more informed and well-considered decisions (Vincent *et al.*, 2021).

When making decisions related to climate services, it is imperative to consider the impact of inclusion. Diverse groups possess unique information needs and communication preferences, necessitating a concerted effort to identify and rectify any biases affecting decision-making. Failure to do so will result in inadequate and exclusive decisions regarding climate services. (Vincent *et al.*, 2018).

The co-production knowledge processes have challenges like higher costs and the need for a broad coalition of relevant actors. The coalition should include experts with relevant experience and interests to address sustainability challenges and contribute to scientific knowledge effectively. Failure to consider inclusivity could result in the inadvertent exclusion of marginalized or less powerful groups, reinforcing existing inequalities and producing unusable knowledge in a specific context (Fazey *et al.*, 2014).

2.3.2.2. Flexibility

Flexibility plays a critical role in the co-production of climate services. A process-based approach to decision-driven service production implies that it is impossible to fully outline the entire process at the outset. Hence, it is imperative to conceptualize the contribution of co-production to the broader theory of change in climate service development (Vincent et al., 2018, 2021). To achieve a favorable outcome, embracing adaptive management and maintaining flexibility is crucial to be open to changing plans, timelines, and priorities when necessary (Fazey *et al.*, 2014). This fosters iterative processes of frequent and sustained interaction between climate service providers and recipients, which builds the development of practical climate services (Vincent *et al.*, 2018).

2.3.2.3. Collaborative

Collaboration is essential for co-production and related terms such as co-exploration and co-develop, which prioritize the process over the product (Vincent *et al.*, 2018). Co-exploration occurs early in the coproduction process and is a consultation approach emphasizing fact-finding, followed by the shared formulation of the challenge. This is followed by the co-development phase of the coproduction process entails collaboration on product or service development and evaluation (Bojovic et al., 2021). Reflexivity is essential for successful collaboration through a co-exploration, co-develop, and co-delivery approach (Zurba *et al.*, 2021).

Collaboration is crucial in co-produced climate services to achieve common goals that link closely to the processes of knowledge integration through building relationships and partnerships between providers and users throughout the cycle, with the active involvement of individuals with diverse needs and knowledge systems (Norström *et al.*, 2020; Korhonen-Kurki *et al.*, 2022). This approach requires active communication and acknowledgment of the unique skills and expertise that each person brings to the table. Collaboration enhances shared ownership, sustaining climate services beyond the project. Providers and users must understand each other's decision-making environments to foster meaningful collaboration, which requires empathy. Collaboration should occur through continuous knowledge exchange and learning (Vincent *et al.*, 2018).

Continuous and meaningful engagement among participants fosters ongoing learning and establishes trust through dialogue (Vincent *et al.*, 2021). Furthermore, consistent interaction among all stakeholders enhances the perceived credibility, relevance, and legitimacy of the knowledge generated. This ensures that the outputs are scientifically sound, relevant to user needs, and fair and respectful to all actors involved (Vincent *et al.*, 2018; Loeffler, 2021). The successful execution of this process necessitates the presence of a conscious facilitator to ensure that all participants are brought on board as necessary and actively engaged in the process (Vincent *et al.*, 2021).

2.4. **Outcome**

This chapter delved into the norm of community engagement in climate action through various declarations and focused on the knowledge co-production process of climate services that foster community engagement. It aimed to understand the characteristics of the co-produced climate service knowledge that ensures the integration between the providers and recipients of such a service. The co-produced knowledge boasts distinct characteristics concerning its product and process, on which its product must be context-based, process-based, time-managed, and goal-oriented. Simultaneously, its process must be inclusive, flexible, and collaborative.

It also delved into the methods used to engage the recipients during the knowledge co-production process to select the method that will be used during the empirical study. It was found that the Abdeen's Square recipient's engagement can be achieved through workshops, town meetings, questionnaires, and surveys. Accordingly, an onsite survey and semi-structures interviews were selected due to the thesis time limitation, so it would be the most appropriate method to engage users as knowledge contributors to optimize the thermal performance of Abdeen Square. This approach ensures a contextual, user-oriented solution tailored to the community's needs.

Chapter 3: Thermal Performance of Outdoor Spaces

The anthropogenic climate change is undeniably contributing to an alarming rise in the frequency and intensity of extreme heat events. This phenomenon is especially noticeable in outdoor spaces (Zhao et al., 2018; Foshag et al., 2020). Accordingly, utilizing outdoor spaces is affected by their thermal performance (Vukmirovic, Gavrilovic and Stojanovic, 2019). In this regard, thermal comfort is paramount when designing outdoor spaces (Samira, Abdou and Reiter, 2017).

This chapter's narrative review builds upon the knowledge presented in the previous chapter and concentrates on outdoor thermal performance as a climate service product. This chapter shows the various factors that affect user thermal comfort in outdoor spaces and concentrates on the indices used to measure outdoor thermal comfort. Building on the first chapter, this chapter aims to determine the appropriate thermal index for assessing outdoor thermal comfort.

3.1. Outdoor Space Utilization

Outdoor space utilization is of great importance to the social life of cities due to its capacity to be conducive to interactions among members of the public and serve as meeting spaces (Vukmirovic et al., 2019). Users utilize the outdoor spaces for diverse activities (Gehl, 2010), where the physical structure of the outdoor spaces, including its softscape and hardscape elements, tends to affect how the users utilize the outdoor spaces (Aisyah and Rahmah, 2020).

3.1.1. Reason for Utilization

Gehl (2010) classified outdoor activities into necessary, optional, and social activities. Each one demanded certain criteria of the physical environment (Figure 7) in which climate is an important factor for the quality of the physical environment. In contrast, other factors include safety, furniture, and visual attractions. Necessary activities, such as commuting or work, must be done regardless of the physical condition of the outdoor space. Optional activities, like jogging, are non-essential pastimes that individuals participate in to improve their well-being. The success of these activities depends on the physical conditions, with climate conditions being a crucial requirement for utilizing the outdoor space.

Lastly, social activities rely on the presence of others in outdoor spaces, such as playing and having conversations. This category emerged because of the combination of the two preceding categories, wherein individuals occupying the same area commenced engaging with one another. By improving the overall physical conditions of the environment, there was a subsequent increase in the duration of outdoor space utilization.

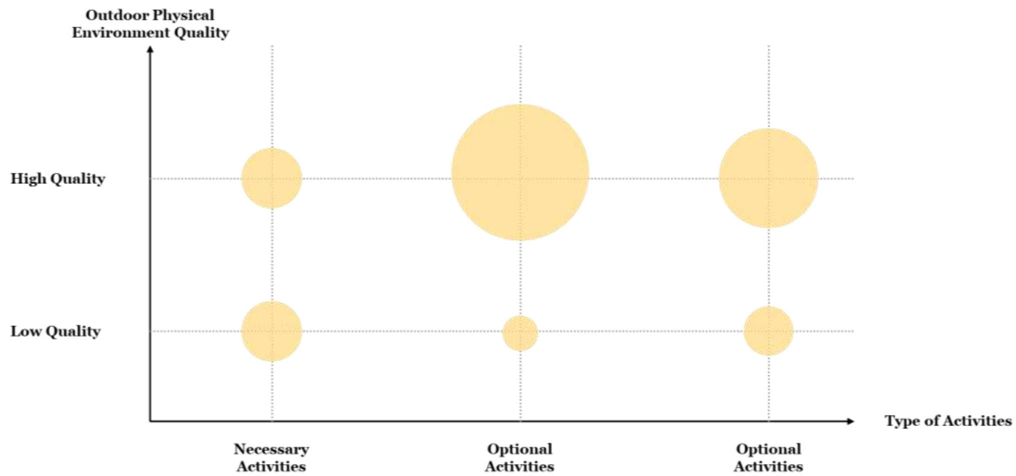

Figure 7: Outdoor Physical Quality and Outdoor Activities Relation (Source: Gehl,2010)

3.1.2. Ways of Utilization

A clear correlation can be observed between people's space usability and it's landscape pattern. People prefer seating choices and certain trends in outdoor spaces. Benches that provide a clear view of the surrounding activities are more popular than those with limited or no view of others (Gehl, 2011). Moreover, seating areas that are frequently occupied are typically positioned near the flow of pedestrians, allowing observers to observe people quietly without engaging in direct eye contact (Gehl, 2010).

Furthermore, Whyte (2012) discovered that the availability of seating significantly impacts the presence of users, as people tend to choose seating areas where there are already places to sit. Also, a correlation was found between the user's tendency to utilize space and the presence of softscape elements. Users tend to utilize spaces that provide soft scape elements, such as trees and water features, which create an atmosphere conducive to relaxation (Gehl, 2011).

3.1.3. Thermal Comfort as a Quality of Outdoor Spaces Utilization

Many qualities affect outdoor space utilization, such as comfort, safety, social interaction, and diverse activities. Shedid and Hefnawy (2021) through the results of their questionnaire that assessed the most influential factor affecting the utilization of outdoor spaces. It was found that comfort is the most influential factor affecting the utilization of outdoor spaces.

Comfort plays a crucial role in the success of outdoor spaces, as the amount of time people spend in an outdoor space is an indication of their comfort level (Gehl, 2011). The complexity of comfort is evident in how the external environment affects various aspects, such as thermal, visual, acoustic, and tactile comfort. However, In the context of climate change and densely populated urban areas, the importance of thermal comfort in evaluating the quality of outdoor spaces become even more pronounced (Vukmirovic, Gavrilovic and Stojanovic, 2019).

Wen, Albn, Albertt and Von Haaren (2018) showed that the thermal comfort of outdoor spaces is particularly important, as it greatly influences people's activities and is a key factor in attracting them to utilize the space.

To enhance the quality of public spaces and increase their utilization, it is crucial to consider microclimatic conditions and users' preferences during the design process. These factors optimize outdoor spaces for optimal comfort levels (Samira, Abdou and Reiter, 2017).

3.2. Thermal Perception and User's Outdoor Comfort

Thermal comfort is an important concept when designing outdoor spaces, particularly in cities. It is not only related to how people feel in response to their thermal environment but also their overall satisfaction with space. As a result, it is a subjective process with many factors affecting it. Lad et al. (2022) and Khan

(2021) have outlined these factors in detail from two perspectives the physiological and adaptation perspectives.

3.2.1. User Outdoor Thermal Comfort from a Physiological Perspective

From the physiological perspective, According to ASHRAE (2017), thermal comfort is defined as “the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform enclosure” (ASHRAE, 2017). The equilibrium of heat transfer to and from the body is upheld while concurrently ensuring that the skin's temperature and sweat rates are maintained at a comfortable level (Li, et al., 2019). This perspective divides thermal comfort into climatic, environmental, and behavioral factors (Figure 8).

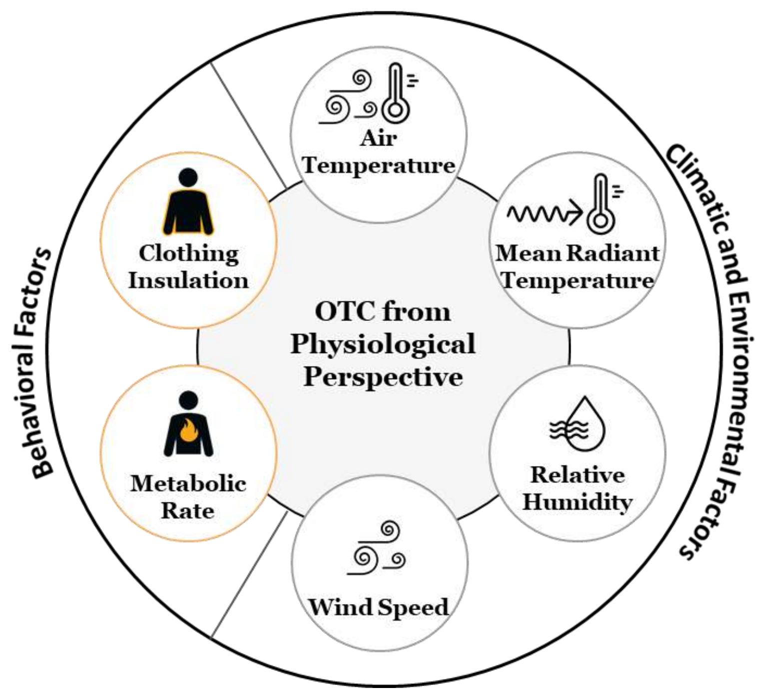

Figure 8: OTC from Physiological Perspective (Source: Author)

3.2.1.1. Climatic and Environmental Factors

These factors are related to urban microclimate conditions and the urban thermal environment, which are primarily considered when assessing thermal comfort, including mean radiant temperature, air temperature, wind speed, and humidity.

The mean radiant temperature (MRT) is the most influential in determining outdoor thermal comfort. ASHRAE (2001) defines MRT as” the temperature of a hypothetical enclosure where the radiant heat transfer from the human body equals that of the actual non-uniform enclosure.” In simpler terms, it denotes the average temperature of all surfaces surrounding an individual, encompassing buildings, the ground, and other objects. The MRT assumes paramount importance as it determines the extent of heat exchange between the human body and the environment, considering all the body's exposed short- and long-wave radiation fluxes (Matzarakis and Amelung, 2008; Thorsson *et al.*, 2014; Chen *et al.*, 2016).

As highlighted by Watkins et al. (2007), wind speed can significantly impact an individual's perception of thermal comfort. This can be attributed to wind removing heat released by the human body through different movements. A controlled increase in the wind speed can be a useful strategy to remove heat, thus facilitating a cooler environment rapidly. Santamouris analyzed the heat island effect, examining the characteristics and magnitude of the effect in different regions. According to his findings, an increase in wind speed can result in a lower intensity of Urban Heat Island in the same area (Santamouris, 2015).

Relative humidity refers to the relationship between the quantity of water vapor in the air and the maximum amount of water vapor the air can hold at a given temperature. Regarding thermal comfort, a relative humidity reading ranging from 40% to 70% is considered acceptable (Barakat, Ayad and El-Sayed, 2017). However, prominent humidity levels lead to increased heat stress in the body by hindering the evaporation of sweat and reducing the cooling effect on the skin, making individuals feel more uncomfortable. This can result in a rise in perceived temperature even when the actual air temperature remains unchanged (Zou and Zhang, 2021).

The outdoor air temperature directly influences the convective heat exchange between the human body and the surrounding environment, while it indirectly influences the radiative, evaporative, and respiratory heat exchange. Several research investigations have established air temperature as the most crucial parameter in outdoor thermal comfort among the four microclimatic factors (Lai *et al.*, 2020a).

3.2.1.2. Behavioral Factors

Behavioral factors are intricately linked to individuals' daily habits and actions, which are strongly influenced by the surrounding built environment and thermal conditions that may be uncomfortable. These factors can result in physical adaptations and modifications to achieve thermal comfort. For instance, individuals in outdoor settings may adjust to their thermal environment by altering their clothing and seeking shade.

Clothing insulation, often known as "Clo." is one of the most commonly observed behavioral characteristics. The level of thermal insulation offered by clothes to resist sensible heat transmission is usually measured in units of 0.155 m2 °C/W (0.88 ft2h°F/Btu). In addition, the metabolic rate represents the rate at which chemical energy is converted into heat and mechanical work through metabolic activities. It is measured in'met' units, with one met equaling 58.2 W/m2 (18.4 Btu/hft2) of energy generated by the human body per unitary surface area of an average sat-at-rest individual. Cultural elements are also crucial to address because, like psychological components, they are dynamic and subjective (Potchter *et al.*, 2018; Lai *et al.*, 2020a; Khan and Azari, 2021).

Evaluating these behavioral characteristics necessitates extensive data collection, which observations, interviews, or questionnaire surveys can gather.

3.2.2. User Outdoor Thermal Comfort from a Psychological Perspective

Thermal comfort is not only related to the thermal balance in the human body but is also influenced by thermal adaptability. The comprehensive definition of "adaptation" encompasses the gradual reduction of an organism's response to repetitive exposure to a stimulus, integrating all the measures taken to optimize their survival in such an environment. In the context of thermal comfort, adaptation may comprise all the processes that individuals undergo to optimize the match between the environment and their needs (Lam *et al.*, 2021). Thermal adaptation can be based on physical or psychological factors (Figure 9).

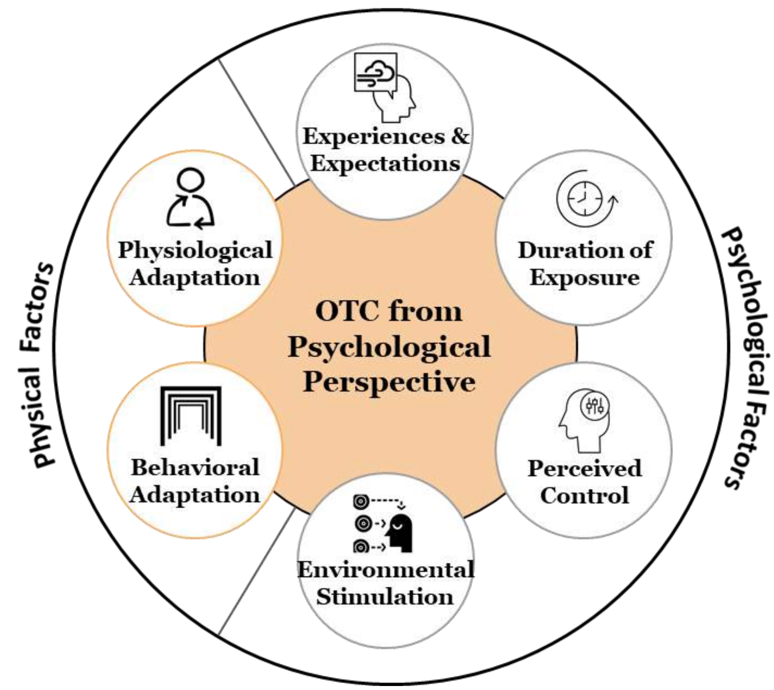

Figure 9: OTC from Psychological Perspective (Source: Author)

3.2.2.1. Psychological Factors

Psychological factors are non-climatic and non-physiological factors that affect the perception of comfort in the human brain. Nikolopoulou and Steemers (2003) characterized these factors into six types: expectations, experiences, naturalness, exposure duration, perceived control, and environmental stimulation.

Expectations and experience are of greater importance to climate change adaptation because they are closely interrelated. Experience enables individuals to be more mentally prepared to cope with weather fluctuations, enhancing their ability to adapt to such alterations (Cheung and Jim, 2018).

The phenomenon known as perceived control refers to the ability of individuals to tolerate environmental discomfort when they possess a strong degree of control over it. Those who engage in leisure, relaxation, exercise, and similar activities enjoy a high degree of autonomy, as they can leave the area or relocate as desired. Conversely, individuals who attend work have little autonomy in such situations. Studies have shown that groups with prominent levels of autonomy tend to experience greater thermal comfort or a more neutral thermal perception than those with low autonomy levels. This observation suggests that the level of perceived control plays a crucial role in determining individuals' level of comfort in a given environment (Elnabawi, Hamza and Dudek, 2016; Lai *et al.*, 2020b).

These dynamic and subjective factors have been proposed to result in variable adaptive neutral thermal comfort ranges varying up to 10 °C in different cities (Nikolopoulou & Lykodis, 2006). Due to its complexity, the data on these factors can be collected through surveys and interviews.

3.2.2.2. Physical Factors

Physically, thermal adaptation can be physiological or behavioral (Nikolopoulou, 2011). Behavioral adaptation refers to the extensive adjustments an individual makes to either conform to the environment or modify it to suit their needs. This could be a reactive adaptation, where individuals start to make personal changes, such as altering clothing levels, or an interactive adaptation, which involves using adaptive equipment or tools or altering the environment (Lam et al., 2021).

Physiological adaptation is based on human thermoregulatory mechanisms. These processes enable the human body to maintain its core internal temperature at 37 °C, which is essential for the brain to function properly. At the same time, the body allows the skin temperature to fluctuate to maintain equilibrium, also known as thermal equilibrium or 'homeostasis.' The body's complex active thermo-physiological processes, such as vasomotion, sweating, and shivering, help to maintain this equilibrium (Khan and Azari, 2021).

3.3. Outdoor Thermal Comfort Indices

In this regard, different thermal indices have been developed to measure a range of factors to assess outdoor thermal comfort accurately. In 1905, Haldane suggested the first model for measuring wet bulb temperature, the first appropriate expression of heat stress. Subsequently, other models were developed primarily considering the climatic factors, only developed to consider personal parameters such as clothing level and human activity (Elnabawi and Hamza, 2019).

Outdoor thermal comfort models can be divided into two groups, depending on their coverage of dynamic aspects of human adaptation. The first is the steady-state evaluation model, which analyzes how heat is exchanged and proposes that the human body has a steady-state thermal equilibrium, making it a simpler way to assess outdoor thermal comfort. This method was introduced by the Fanger heat balance equation, which developed the Predicted Mean Vote (PMV) to assess indoor thermal comfort (Fanger, 1970; Zhao, Lian and Lai, 2021). Moreover, the Pierce two-node model, created by Gagge et al. (1986), is also employed in this approach. Later, thermal indices such as PET, UTCI, SET, and OUT_SET were developed to assess outdoor thermal comfort and are widely used for this purpose.

The second category is the adaptive approach or non-steady-state evaluation model, which considers factors such as behavior adjustment, physiological and psychological aspects. It relies on experimental conditions to offer a more realistic representation of thermal acceptance levels (Walls, Parker and Walliss, 2015; Elnabawi and Hamza, 2019).

The indices outlined below have been meticulously selected from the latter group based on their prevalence and frequency of use in the literature over the past two decades. In a comprehensive review conducted by Potchter et al. (2018), which analyzed 110 peer-reviewed articles exploring outdoor thermal comfort between 2001 to 2017, it was concluded that the three most utilized indices are the Physiological Equivalent Temperature (PET), the Predicted Mean Vote (PMV), and the Universal Thermal Climate Index (UTCI) respectively. Also, Potchter et al.'s (2018) comprehensive literature review of outdoor thermal comfort articles reveals that the PET index is the most widely used, accounting for 30.2% of articles. Accordingly, a more comprehension of the PET index is illustrated in the next section.

3.3.1. Physiological Equivalent Temperature

Hoppe introduced the Munich energy balance model (MEMI) in the mid-1990s, founded on the parameters of the human energy balance equation and Gagge's two-node model. MEMI presented a model for assessing outdoor thermal comfort based on physiology (Yang et al., 2022). The notion of physiological equivalent temperature (PET) was later introduced to study outdoor thermal comfort.

PET is used extensively in urban areas to assess the outdoor thermal environment. PET is a widely recognized physiological temperature indicator derived from the human body's energy balance equation, measured in Celsius degrees. Depending on the climate zone being evaluated, the comfortable thermal sensation range ranges from 18 to 23 degrees Celsius (Table 1: Ranges of PET for different categories of human thermal sensation and grades of thermo-physiological stress (Source: Matzarakis et al. 1999). The PET standard defines human thermal comfort by considering air temperature, relative humidity, wind speed, mean radiant temperature, and personal factors such as clothing and metabolic rates. (Kumar and Sharma, 2020).

PET [°C]	Thermal sensation	Level of thermal stress
< 4°C	very cold	extreme cold stress
4.1 - 8°C	cold	strong cold stress
8.1 - 13°C	cool	moderate cold stress
13.1 - 18°C	slightly cool	slight cold stress
18.1 - 23°C	**neutral (comfortable)**	**no thermal stress**
23.1 - 29°C	slightly warm	slight heat stress
29.1 - 35°C	warm	moderate heat stress
35.1 - 41°C	hot	strong heat stress
41°C >	very hot	extreme heat stress

Table 1: Ranges of PET for different categories of human thermal sensation and grades of thermo-physiological stress (Source: Matzarakis et al. 1999)

Besides, Potchter et al.'s (2018) study on outdoor thermal comfort revealed that the PET index is the most widely used thermal index, accounting for 30.2% of articles. Notably, the index is not limited to hot or cold climates, as it is suitable for all climatic regions (Chen and Ng, 2012; Nikolopoulou, 2011). Additionally, it simplifies the complex outdoor climatic environment into an indoor scenario, which makes it easy for professionals outside the meteorological physiological fields, such as planners, to comprehend (Chen and Ng, 2012; Fang et al., 2018; Nikolopoulou, 2011). Furthermore, the value is expressed in degrees Celsius, making it understandable for a broader audience. Finally, the PET index is readily calculable through software models such as EnviMet and RayMan (Fang et al., 2018; Nikolopoulou, 2011)

3.4. Outcome

This chapter covered the utilization of outdoor spaces. It narrowed down the discussion about the thermal performance of outdoor spaces as it is the most impactful factor affecting the usability of outdoor spaces. The chapter then focused on the factors affecting the thermal sensation of the users in outdoor spaces and the thermal indices used to assess the thermal performance of outdoor spaces.

The chapter showed that different factors affect the user's thermal comfort while utilizing the outdoor spaces as the physical and physiological aspects. The chapter also showed that PET is the most used index in assessing the thermal performance of outdoor spaces and simplifies complex outdoor spaces. Accordingly, PET was selected as a thermal index for evaluating the thermal performance of Abdeen Square.

Chapter 4: Microclimate Responsive Design and Outdoor Spaces

A climate-responsive design approach is used for climate action to regulate the thermal condition of the urban environment, particularly the urban microclimate. This approach typically works on three interrelated scales: the building envelope, urban landscaping, and urban planning (Teoh et al, 2022). This chapter will focus on the micro-climatic responsive design at the urban landscaping level, specifically trees, as it is considered the most effective strategy to reduce heat stress in outdoor areas (Vukmirovic et al., 2019).

This chapter's narrative review builds upon the knowledge presented in the previous chapter and concentrates on the role of trees in enhancing the thermal performance of outdoor spaces. This chapter shows the role of trees in outdoor spaces and the characteristics of the trees. Finally, it analyzes similar examples to show the impact of the trees' spatial arrangement on enhancing the thermal performance of outdoor spaces, thus the human thermal comfort.

4.1. Trees' Role in Outdoor Spaces

Trees play a crucial role in outdoor spaces, providing various benefits to the environment and people (Figure 10). This section shows the microclimate benefits through the provision of a cooling effect in which shading, and evapotranspiration have been identified as the most significant contributors to the cooling effect (Wong *et al.*, 2021). Also, the other tree's benefits as the environmental, social, and economic benefits.

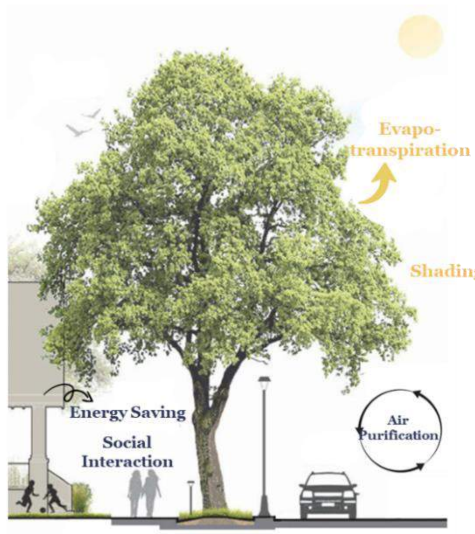

Figure 10: Trees' Role in Outdoor Spaces
(Source: Author)

4.1.1. Shading

The shading effect of tree canopies plays a crucial role in reducing solar radiation input and thus enhancing human thermal comfort (Kasim, Shahidan and Yusof, 2018). The solar radiation intercepted and reflected by trees helps prevent urban surfaces from absorbing too much heat, which in turn reduces the amount of heat radiated back into the atmosphere, thus, minimizing the impact of anthropogenic heat sources (Gunawardena, Wells and Kershaw, 2017; Wong *et al.*, 2021). The modification of the mean radiant temperature (MRT), which is a key parameter of thermal sensation, as discussed in the previous chapter, is achieved through this shading effect (Kasim, Shahidan and Yusof, 2018).

Trees exhibit two primary shading properties: branching and leaf cover. These properties create a canopy density that results in a direct shading effect on pedestrians while also contributing to the reduction of air and surface temperatures within the shaded area parameter. As a shading device, tree canopies effectively moderate heat transfer from direct sunlight to the ground, building roofs, or surfaces (Kasim, Shahidan and Yusof, 2018).

The magnitude of shading intensity varies depending on the density of the tree canopy, the leaf area index, and the tree species (Gunawardena, Wells, and Kershaw, 2017; Wong *et al.*, 2021).

4.1.2. Evapotranspiration

Evapotranspiration of trees, a natural process, is essential in improving human thermal comfort by increasing relative humidity, reducing temperature, and introducing vapor into the atmosphere. Evaporation, whereby liquids are converted into their gaseous state, occurs from water bodies, wet soils, and transpiring vegetation. The latter process, transpiration, is the evaporation of water that has passed through plants. Soil evaporation and plant transpiration happen concurrently in nature, and thus, evapotranspiration describes the entire process of water transfer from vegetated land surfaces into the atmosphere. (Erell, Pearlmutter and Williamson, 2011; Gößner, Mohri and Krespach, 2021).

It provides moisture cooling as the absorbed solar energy increases latent heat, causing the water in vegetation to evaporate into the atmosphere. As a result, this process cools the leaf surfaces and the surrounding air, as evidenced by (Yang et al., 2019). Also, it reduces the temperature by up to 5% (Elbardisy, Salheen and Fahmy, 2021), therefore enhancing human thermal comfort and the thermal performance of outdoor spaces.

4.1.3. Other Benefits

In addition to their significant climate control impact and enhancement of outdoor thermal comfort, trees provide numerous environmental benefits, such as increased biodiversity, reduced stormwater runoff, and improved air quality.

Trees provide economic and ecological benefits, such as energy savings (Mehrotra, Bardhan and Ramamritham, 2019; Ren *et al.*, 2023). Moreover, trees provide important social benefits that enhance a given location's usability and visual aesthetic. By considering their scale and proportion in spatial distribution, trees can engage in social interaction and contribute to a place's unique identity (Elbardisy, Salheen and Fahmy, 2021).

4.2. Trees' Characteristics

The cooling effect of trees is subject to numerous factors, primarily the physical properties of the trees and their arrangement. The physical properties are determined by the Leaf Area Density (LAD) and Leaf Area Index (LAI) effect, the size of the canopy, the height of the trees, the density of the tree coverage, and overall tree density. The following lines show a more comprehension of these factors.

4.2.1. LAI and LAD

Leaf area index (LAI) and leaf area density (LAD) are fundamental environmental parameters used to model the canopy of trees in relation to their heat exchange with the environment (Fahmy, Sharples and Yahiya, 2010). These parameters play a crucial role in urban heat balances. LAI is defined as the area of the tree canopy per its ground shadow. The interception of direct solar radiation by the canopy is 100% when the canopy shadow equals the ground planting area (Asef, Tolba and Fahmy, 2020). As a result, LAI for the same tree can vary seasonally due to deciduousness and from one tree to another due to growth (Fahmy, Sharples and Yahiya, 2010). LAI frequently describes the number of leaves in a tree canopy since leaf surfaces are the major energy and mass exchange surfaces. As a result, critical activities, including canopy interception, evapotranspiration, and gross photosynthesis, are directly proportional to LAI (Fang and Liang, 2014).

LAD is the determination of the tree canopy outline, in which its distribution index is an essential index used to characterize vertical and horizontal crown structures. It is the total one-sided leaf area per unit volume (Oshio *et al.*, 2015; Asef, Tolba and Fahmy, 2020). In a recent study conducted by (Asef, Tolba and Fahmy, 2020), the impact of three trees was compared through simulating four different scenarios. After rigorous calculations and simulations, their quantitative analysis concluded that the tree canopy with a higher LAI and LAD generates a greater impact on microclimate.

4.2.2. Tree Densities and Crown Density

Increasing tree density has been proven to reduce air temperature significantly. Srivanit and Hokao (2013) conducted a study that revealed that a 20% increase in tree coverage resulted in an average maximum air temperature decrease of 2.27 ◦C at 15:00 during the summer season. Moreover, Morakinyo *et al.* (2018) found that compared to the reference case with no trees, the presence of 7.2% and 30% greenery coverage ratios caused a reduction in maximum air temperature by 0.4 ◦C and 0.5-1.0 ◦C, respectively. Furthermore, these greenery coverage ratios decreased average PET by 1.6 ◦C and 3.3-5.0 ◦C, respectively.

According to a study by Aboelata and Sodoudi (2020) in Cairo, implementing a 50% tree scenario has significantly reduced air temperatures by 0.5 K in high-density built-up areas. Also, this implementation has been observed to improve the space's thermal performance by adjusting the PET value.

According to Zhang, Zhan, and Lan's (2018) findings, the potential of various species may differ under the same planting density. It has been observed that trees with a wider crown that offer more shading enhance thermal comfort conditions during hot seasons significantly. A study conducted in Hong Kong indicates that to achieve a reduction of approximately 1 ◦C in pedestrian-level air temperature, an area of approximately 33% of the urban region needs to be dedicated to tree planting (Ng et al., 2012).

4.2.3. Canopy Size and Tree Height

Tree canopy size and height are crucial in regulating air temperature by intercepting solar radiation (Amani-Beni *et al.*, 2018). The size of a tree canopy and its height directly affects the air temperature, with larger canopies resulting in lower temperatures. This assertion has been validated through a study conducted by Sodoudi *et al.* (2018), where two different canopy sizes were tested. The study affirmed that trees with a larger canopy have the best cooling effect.

Another study by Morakinyo et al. (2017) investigated the thermal comfort improvement potential of eight types of trees. They assessed the impact of the leaf area index (LAI), trunk, and total tree height. The findings indicated that tall trees with higher trunks, short crown width, and less dense foliage are optimal for high-density areas where shadowing effects are more dominant. On the other hand, the reverse is proposed for low-density and open areas.

Larger trees provide significant microclimatic benefits, but their size can challenge urban areas Abu Ali, Alawadi, and Khanal (2021). Planting larger trees can increase the risk of disruption to public areas and property damage during dust or rainstorms. Therefore, it is important to carefully consider the location and size of trees in urban areas, balancing the benefits and potential challenges they may pose.

4.3. Trees Spatial Arrangement

A study by Zhao, Sailor, and Wentz (2018) on the spatial arrangement of trees in a neighborhood revealed that three different layouts were proposed - clustered, equal interval, and dispersed. The study found that the equidistant arrangement of trees provided the most significant benefits in terms of microclimate and human thermal comfort in the neighborhood, reducing the PET value by 1-1.5 °C. This outcome was attributed to the crucial role of tree shading in the hot arid desert environment. The study also revealed that the second most effective arrangement was the clustered tree layout without canopy overlap. The research findings also recommend avoiding tree canopy overlap while proposing trees' spatial arrangement to allow airflow and saturated vapor to flow around and between the trees.

Another study conducted by Fan, Myint, and Zheng (2015) in Phoenix, Arizona, aimed to compare the effectiveness of two distinct spatial arrangements - clustered and dispersed - in reducing the land surface temperature. The study yielded noteworthy results indicating that the clustered arrangement of trees was significantly more effective than the dispersed pattern in lowering surface temperatures. The study suggests that less fragmented urban vegetation patterns can effectively reduce land surface temperature, particularly during summer daytime. Also, Sodoudi *et al.* (2018) revealed that PET's optimal cooling effect and reduction were achieved through the equidistant arrangement of trees with a spacing of 6.25 m. This was followed by the equidistant arrangement of trees with a spacing of 12.5 m and then the clustered arrangement.

Moreover, A study by Elbardisy, Salheen, and Fahmy (2021) at El Nozha Street, Cairo, aimed to optimize urban green infrastructure to reduce solar irradiance. The study's findings revealed that the highest percentage of canopy covering of 4% resulted in a substantial reduction in mean radiant temperature among the various developed plantation layouts in the middle island. The temperature reductions were 1.3, 1, and 0.75 °C for single-side and cluster trees, cluster-side trees with a single center arrangement, and cluster-side tree configurations, respectively. This research suggests that using both linear and clustered trees improve the thermal performance of outdoor environments and, as a result, human thermal comfort.

These findings suggest that a well-planned and properly spaced tree arrangement can significantly contribute to the cooling of the environment and reduction of PET, enhancing outdoor thermal comfort.

4.4. Outcome

Trees play a crucial role in enhancing the thermal performance of outdoor spaces through their evapotranspiration and shading effects. However, the trees' characteristics play an essential role in such enhancement. This chapter aimed to identify the possible optimization solutions for the trees' spatial arrangement to be simulated and tested to enhance the thermal performance of Abdeen Square. Accordingly, four studies were analyzed and found that the various arrangements of trees have a different impact on the thermal performance of outdoor spaces and human thermal comfort. Accordingly, the chapter identified four possible spatial arrangements of trees from the previous four studies that will be simulated and tested in the empirical study to enhance the thermal performance of Abdeen Square, thus the human thermal comfort.

Chapter 5: Empirical Research Framework: Co-produced Knowledge Process.

After reviewing the characteristics of coproduced knowledge, the thermal performance of outdoor spaces and trees as microclimatic landscape elements enhance outdoor spaces' thermal performance. The importance of integration between different types of knowledge was clear to address the complexity of coproducing a usable product. The provider helps provide the technical knowledge while the recipient helps provide the real-life experience. Accordingly, the methodological approach was developed based on two approaches. The first is the hard system, which tackles the technical complexity, and the second is the soft system which tackles the real-life knowledge complexity.

Then, the first step towards investigating the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square. is to objectively describe the studied area and elaborate on the reason behind the case study selection. The second step presents the empirical study framework of the data collection and analysis methods, divided into two phases.

5.1. Abdeen Square Case Study

Abdeen Square was chosen as the case study, falling between the latitude of 26° 50'N and 30° 45'N, accordingly, characterized by a hot arid climate, making it particularly vulnerable to heat stress. Abdeen Square has undergone recent development to transform it from a car parking to an outdoor space with various activities. This section shows the selection criteria, Downtown Cairo background, and Abdeen Square background.

5.1.1. Case Study Selection

Deriving from the research problem discussed earlier in chapter one and by the research, a set of criteria was developed to select the case study as follows:

- An Outdoor space in a highly dense urbanized area, which is particularly susceptible to heat stress. Therefore, understanding the performance of outdoor spaces in terms of thermal comfort and user suitability becomes essential, as this knowledge allows for the utilization of micro-climate responsive landscape design in creating a more livable space.
- An Outdoor space that had undergone recent development in its landscape pattern and functionality to investigate the impact of development in the thermal performance and user suitability of the current situation and how the coproduced knowledge can enhance this development.
- An Outdoor space located within an area that is expected to be developed in the future. This ensures that the co-produced knowledge generated from the empirical study can be transferred and applied within the wider development area.
- An Outdoor space that has a unique value through different decades, so the users are attached to it and frequently use it, also the presence of diverse activities in this space.

To fulfill the criteria, new urban communities were initially excluded due to their lower population density. Subsequently, outdoor spaces in Heliopolis, Nasr City, and Downtown were proposed as they had recently undergone development. However, Heliopolis and Nasr City were ruled out as the assessment of what happened in Heliopolis and Nasr City was already studied and shown its consequences (Hefnawy et al., 2022). An outdoor space in the Downtown area was suggested due to its expected future development following the relocation of governmental buildings to the New Administrative Capital. By carefully evaluating the historical significance of various outdoor spaces, Abdeen Square and Tahrir Square were singled out. Following a site visit to both Squares, Abdeen Square was ultimately chosen due to its diverse range of activities compared to El Tahrir Square. Also, its recent transformation aimed to renovate Abdeen Square to be an inclusive and green outdoor space.

5.1.2. Outdoor Spaces in Downtown Cairo Background

Downtown Cairo is in the western region of Cairo and is known for its diverse uses(Figure 11).

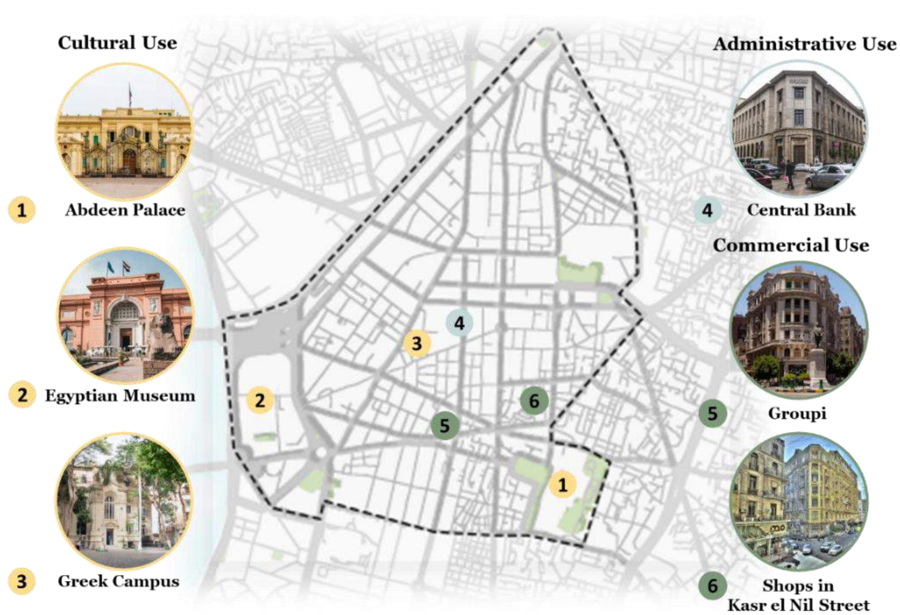

Figure 11: Downtown Uses (Source: Author)

It has a rich history that dates to the Khedival era of Khedive Ismail in the 1870s. Inspired by Haussmann's planning ideas from Paris and his travels to Europe, Khedive Ismail set out to transform the heart of Cairo and give it a modern identity. This led to the creation of Khedival Cairo, which became the new downtown area. The modernization of Cairo's physical landscape began with the introduction of Haussmann's planning ideals. Straight boulevards and spacious Squares were integrated into the city's existing urban fabric, where these new boulevards not only brought light and ventilation and improved the traffic flow. Additionally, pedestrian passages and social spaces were established, enhancing the city's connectivity and social interaction.

After the 1952 revolution, the district began to experience a decline in its urban qualities. This was primarily due to policies that enforced land reforms and promoted rapid and insensitive construction. Despite numerous attempts since 1992 to preserve its historical heritage and enhance the urban environment, downtown Cairo has faced significant challenges and failed to achieve its goals. Over time, Downtown Cairo has transformed into a densely populated area, largely due to the concentration of government buildings. In response, a new vision for downtown Cairo emerged in 2010 (Shalaby and Omar, 2022).

After January 2011, the vision underwent a transformative shift, aiming to create a global, inclusive, and sustainable city through a series of projects that address various issues in Cairo's urban fabric. Among the proposed strategies to achieve this overarching vision is revitalizing the downtown area (UN-Habitat, 2012; Shalaby and Omar, 2022). As part of this plan (Figure 12), the government ministries' headquarters were intended to be relocated to new urban communities, after that, to be situated in the New Administrative Capital while also lowering the population density by attracting residents to new cities. Additionally, the downtown area is intended to be transformed into a cultural-political hub, boasting a modern and efficient infrastructure that significantly improves the quality of life in the region (UN-Habitat, 2012).

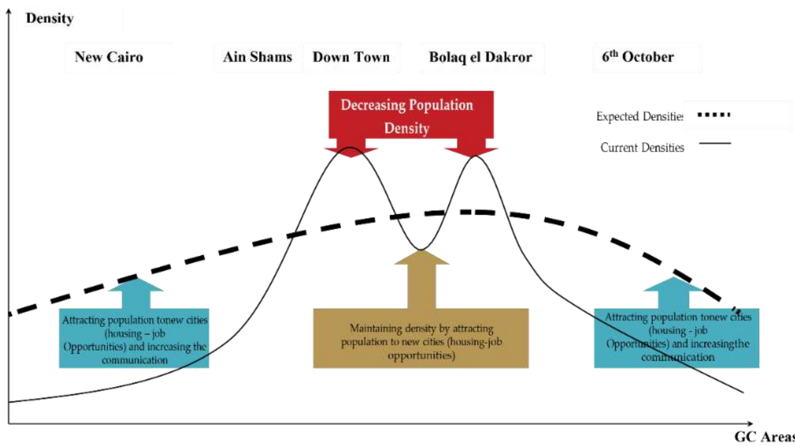

Figure 12: Downtown in Greater Cairo Development Strategy Source: (UN-Habitat, 2012)

Outdoor public spaces played a pivotal role in the revitalization process of Khedival Cairo (Figure 13), as they link urban space and the city's identity. This process is integral to preserving the historic structures that define the city's image. Therefore, the revitalization efforts focus on upgrading urban spaces such as Squares, sidewalks, and pedestrian paths, while ensuring the conservation of the facades of heritage buildings. Since 2014, the revitalization of Khedival Cairo has been recognized as a national project. This is due to the involvement of multiple ministries and governmental bodies and the dive and funding sources. The project operates on two levels of intervention: the first level addresses the urban level, while the second level focuses on the architectural level (UN-Habitat, 2016; Shalaby and Omar, 2022).

Figure 13:Khedival Cairo Development Plan (Source: UN-Habitat,2016)

Regarding the urban level, various spaces have undergone development (Figure 14), focusing on the upgrading of pedestrian streets, such as El Alfy Street and El Sharefeen Street, as well as the upgrading of Squares like El Tahrir Square and Abdeen Square. (UN-Habitat, 2012; Shalaby and Omar, 2022).

Figure 14: Downtown Public Spaces Development (Source: Author)

5.1.3. Abdeen Square Context

Abdeen Square is one of downtown Cairo's most popular outdoor spaces covering approximately 3.5 feddan. The Square is surrounded by Abdeen Palace, considered a heritage from Khedivial Cairo and governmental buildings, and residential and mixed-use buildings. The institutional use has 50% of the surrounding including the governorate land uses that, include the governorate building and Abdeen palace, 25% for ground floor mixed-use buildings, 10% for residential and commercial uses, and 5% for religious use (Figure 15) (UN-Habitat, 2016).

The Square is accessible from the main roads El Tahrir Street, Hassan el Akbar Street, El Sheikh Rehan Street, Mohamed Farid Street, and the secondary road El Gomhoreya Street. Also, the nearby Mohamed Naguib metro station, which is far from the Square within two minutes walking distance, makes the Square accessible to different groups of users.

Figure 15: Abdeen Square Context (Source: Author)

Abdeen Square has a rectangular form with three main entrances from the main and secondary paths. Also, the Square has one main axis, which enhances the visual axis of Abdeen Place, and two secondary axes (Figure 16).

Figure 16: Abdeen Square Entrances (Source: Author)

5.1.3.1. Abdeen Square Historical Background

Its history dates to the Khedival era when in 1863, Khedive Ismail ordered to build of Abdeen Palace as the official royal residence. In response, Abdeen palace was built, and the boulevards of the Abdeen area - the center of Cairo -

once spread out from this area and were met with a collection of stagnant pools. These included the al-Fra'in Pond, now the site of the current Abdeen Square, as well as the Al-Saqain Pond, al-Fawala Pond, al-Nassria Pond, and many other small ponds and swamps (UN-Habitat, 2016; Badawy, 2020).

As time passed, the condition of Abdeen Square deteriorated, with two lawns separated by a parking area in the middle. However, in 2016, Abdeen Square played an integral role in Khedivial Cairo's Redevelopment Plan (Figure *17*), which seeks to create vibrant spaces and major Squares linked together with green networks and efficient pedestrian-friendly pathways while also adding to a multi-modal public transit network strategy. The UN-Habitat, the General Organization of Physical Planning, and the Cairo Governorate collaborated to create a renovation plan for Abdeen Square. The goal was to transform the square into an inclusive and accessible green public space that can be enjoyed by people of all ages and social classes, especially families from nearby neighborhoods and other parts of Cairo. As a result, Abdeen Square has become a lively destination with various activities available (figure 18).

Despite changing times, Abdeen Square has maintained its unique value and has become a popular destination for people of all backgrounds to engage in various social activities (UN-Habitat, 2016).

Figure 17: Abdeen Square in the Khedivial Development Plan (Source: UN-Habitat,2016)

Figure 18:Abdeen Square Development Timeline (Source: Author)

5.1.3.2. Spatial Use

Five main zones were observed where the users performed different activities (Figure 19). These zones are the main path, the secondary path, the green lawns, the cafes, and the kid's area. Different activities were held in the different zones of the Square, including sitting, social interaction, playing, taking photos, eating, and jogging.

Figure 19: Abdeen Square Spatial Use (Source: Author)

5.1.3.3. Landscape Pattern

Abdeen Square has a different landscape pattern (Figure 20). Regarding the plantation patterns, first, Palm Phoenix is located on the main path to enhance the main visual axis to Abdeen Palace, and the evergreen tree Ficus Nitida is located in the other Square zones. The grass is used as a ground cover for the green lawn zones. Also, along the Square, some shrubs and flowers are located.

Regarding Abdeen's Square furniture, there are two typologies of benches on the Square. The first typology is concrete benches without a back located on the main path, and the second one is wooden benches with a back on the main and secondary paths. Otherwise, tables and seats exist in the cafe's zones. Three main materials are used on the Square, grey granite for the main path, yellow tiles for the secondary path, and apart from the main path and stone for the sitting area of the cafes. Also, light structures were observed as the food booths and shading elements.

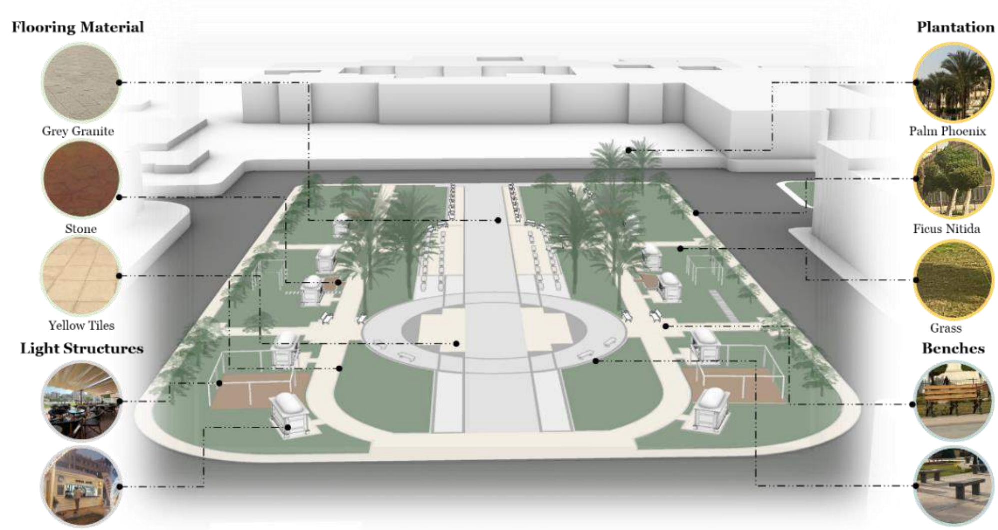

Figure 20: Abdeen Square Landscape Pattern (Source: Author)

5.2. Empirical Study Framework

The field research was divided into two phases – the co-explore phase and the co-develop phase- as mentioned before, and each phase has its hard and soft system tools (Figure 21). However, it was crucial to have a research initiation phase before implementing the two phases. This phase was designed to build the researcher's background. This phase started by selecting the simulation toolkit that will be used to assess and optimize the thermal performance of Abdeen Square and identifying the actors involved during the second two phases.

Following that, the co-explore phase was designed to assess the thermal performance of Abdeen Square using Grasshopper as a simulation tool while, on the other hand conducting an on-site survey and semi-structured interviews to have the recipients as active contributors in assessing the current situation to understand their needs.

Building on the co-explore phase, the co-develop phase was designed to assess the impact of the four trees' spatial arrangement on enhancing the thermal performance of Abdeen Square using Grasshopper as a simulation tool. On the other hand, conducting an on-site survey and semi-structured interviews to collaborate with the recipients to evaluate the proposed solutions and know their preferences.

However, due to the limitation of the thesis time and to ensure reaching the same users who will contribute to the onsite survey. The onsite survey was conducted during the co-develop phase to investigate the user needs regarding the current situation and their preference regarding the proposed solutions for optimizations.

The results of the two phases were then analyzed, and a new solution was developed and assessed to investigate the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square.

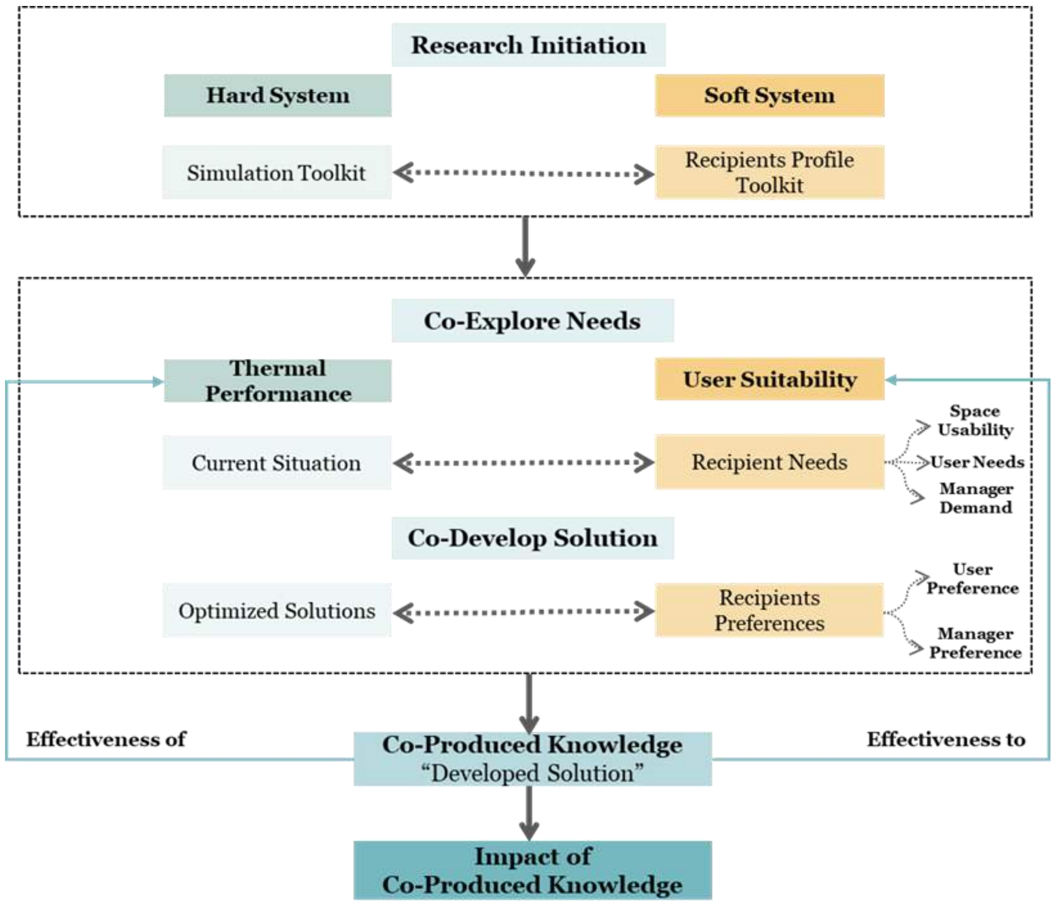

Figure 21: Empirical Study Framework (Source: Author)

5.2.1. Hard System and Soft System as a Methodological Approach

Hard system and soft system approaches were developed as an approach to investigate the impact of their integration on achieving coproduced knowledge, thus optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square while considering user suitability.

The hard system approach tackles the technical complexity, while the soft system tackles the real-life complexity (Mkandawire et al., 2021). The hard system approach is an approach that is dependent on understanding the system through an objective point of view (Avilés Irahola *et al.*, 2022). Modelling and simulation tools represent a significant contribution from hard systems methodologies on which problem solutions are deliberated, preferred solutions are selected, and a final chosen solution is further developed, implemented, and evaluated (Pan, Valerdi and Kang, 2013; da Costa, Diehl and Snelders, 2019). Accordingly, simulation was used to investigate the thermal performance of Abdeen Square from a technical perspective.

The soft system is an approach that is dependent on understanding the system through a subjective point of view (Avilés Irahola *et al.*, 2022). Participatory design through interviews, workshops, or surveys is from the soft system methodologies. It aims to bring accommodation between distinct value positions and can generate commitment among stakeholders to implement agreed objectives. It allows designers to adapt and reconfigure solutions better to fit the system's needs during the process (Pan, Valerdi and Kang, 2013; da Costa, Diehl and Snelders, 2019). Accordingly, an onsite survey and semi-structured interview were conducted to ensure the acquisition of real-life knowledge to sustain the suitability of proposed solutions for the consumers.

5.2.2. Empirical Study Phases

This section shows the methods and tools of the research initiation, the co-explore phase, and the co-develop phase.

5.2.2.1. Research Initiation

This section introduces the research initiation toolkit, including the simulation toolkit that will serve the hard system approach and the recipient profile toolkit that will serve the soft system approach.

- **Simulation Toolkit**

This section covers the reason behind selecting grasshopper as a simulation tool selected, the validation results of the simulation tool, the criteria for selecting the date and time to perform the simulation, and the criteria behind selecting the receptor points that will be used to assess the thermal performance of Abdeen Square. Finally, the tree types selected and the possible trees' spatial arrangement that will be simulated.

Grasshopper as a Simulation Tool

Grasshopper is an advanced graphical algorithm editor which has been seamlessly integrated with the Rhinoceros modeling tool. It is a user-friendly and intuitive software application that simplifies complex algorithmic modeling processes (Pacifici and Nieto-Tolosa, 2021). Ladybug is a plugin that runs within the Grasshopper framework. The main purpose of using it through research is to help assess the current environmental situation and evaluate proposed solutions. This plugin is a collective free, open-source computer application and is an essential tool for environmental analysis and design, as it supports a wide range of simulation engines. Specifically, Ladybug connects and integrates various simulation engines to assess human thermal comfort and the built environment within a specified period (Roudsari and Pak, 2013).

Previously undertaken research showed that the grasshopper tool and its plugins have acceptable accuracy. (Yazıcıoğlu and Dino, 2021) used Grasshopper and its plugin Ladybug to assess the outdoor thermal comfort on the streets showing an acceptable regression value which shows that it can support the calculation of outdoor comfort.

Moreover, Kamel (2021) provided an intricate simulation workflow to model the intricate relationship between urban microclimate, building energy usage, and thermal comfort outdoors, expertly utilizing the Ladybug and Honeybee and Butterfly plugins through the grasshopper interface, also Elwy *et al.* (2018) through their findings highlighted that the utilization of Ladybug Tools in representing the outdoor microclimate parameters is adequate in which both numerical and visual data presented support this conclusion. This tool was selected as the simulation period is limited compared to other tools, such as ENVI-met (Pacifici and Nieto-Tolosa, 2021).

Validation of the Simulation Tool

A field measurement was conducted to validate the results for air temperature, relative humidity, and wind speed to ensure the accuracy and reliability of the simulation tool's results in assessing the current situation and developing solutions for the upcoming phase.

On July 13th, air temperature and humidity were measured using a portable TroTec device (TROTEC) for nine hours from 09:00 till 19:00. These parameters were recorded at the height of 1.5m above ground level, which is the approximate breathing level for humans (Elbardisy, Salheen and Fahmy, 2021).

The device used has an accuracy of ±1°C for measuring air temperature and ±2% for measuring relative humidity (TROTEC). The wind speed was measured using a Techno Line ea3000, an advanced device designed to provide real-time wind speed and direction measurements at a specific location (Handheld Anemometer). The results obtained from the field measurements were analyzed and compared with the ladybug results obtained

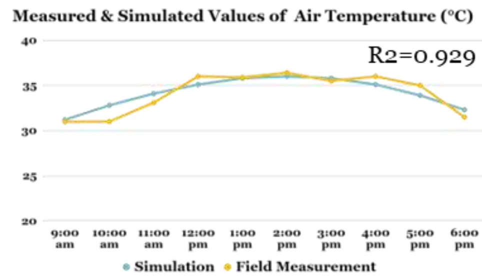

Figure 22: Correlation between Measured and Simulated Values of Air Temperature (Source: Author)

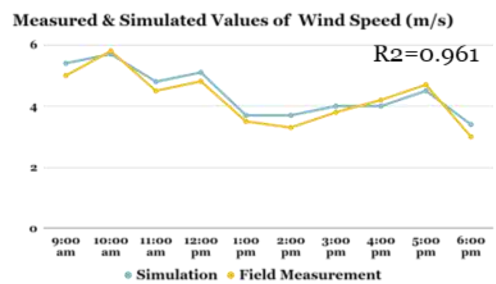

Figure 23: Correlation between Measures and Simulated Values of Wind Speed (Source: Author)

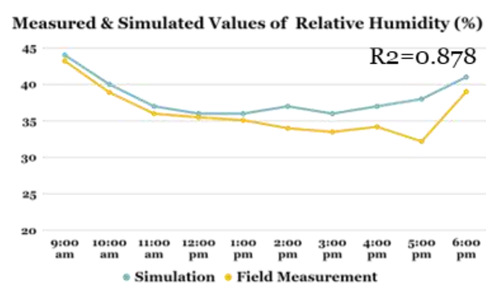

Figure 24: Correlation between Measures and Simulated Values of Relative Humidity (Source: Author)

on the same day. To verify the accuracy of the predicted outputs and the onsite measurements, Pearson's coefficient of determination (R2) was calculated. The desirable values of the coefficients are close to 1, showing a strong correlation between the predicted outputs and the onsite measurements. The results reveal a robust correlation between the air temperature and wind speed, with respective values of 0.929 (Figure 22) and 0.961 (Figure 23). Conversely, the relative humidity displayed a moderate correlation, recording a value of 0.878 (Figure 24).

Simulation Time

Initially, the researcher utilized the Meteonorm tool to generate a precise local weather file for Abdeen Square (Meteonorm, 2022) to be used in the simulation. This tool is calibrated to generate weather data for the designated location in adherence with WMO measurements (Mahmoud and Elbardisy, 2023). Its accuracy has been corroborated in many research studies (Kalogeropoulos *et al.*, 2022; Mahmoud and Elbardisy, 2023). Thus, the 21st of July was selected for simulation as it stands for the typical peak temperature of a summer day in the examined weather file (Figure 25). The simulation has been conducted at various times of the day to provide a comprehensive understanding of the thermal conditions at the site. The time series selected for the simulation are 12:00 pm, which is the midday heat that can lead to heat stress and discomfort. According to the weather file, 2:00 pm, which is considered the peak hour, 4:00 pm and 7:00 pm, during which the usability frequency of the Square increased.

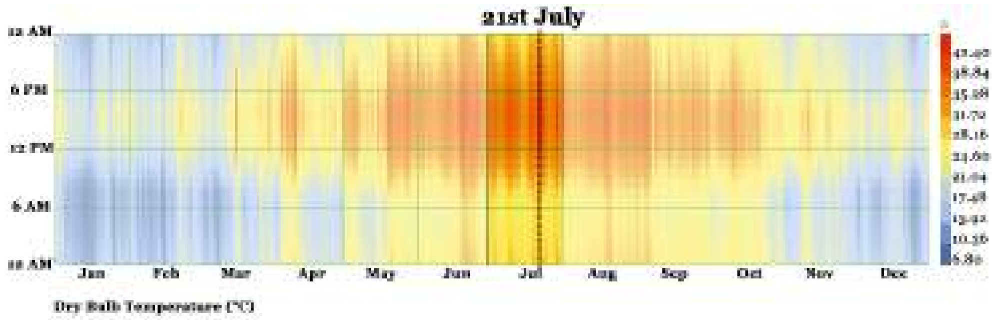

Figure 25: Selected Simulation Day (Source: Author)

PET as a Thermal Index Assessment

As mentioned before, PET was selected to assess the outdoor thermal comfort of the users at Abdeen Square. From the field visit done and observing the activities performed by the users, the dominant activities were static as sitting. Accordingly, the metabolic rate selected for calculation was one met, and for the clothing rate, 0.7 clo was selected according to the clothing of the users.

Receptor Points

Five receptor points were chosen (Figure 26) based on the spatial utilization of Abdeen Square. These points were selected to evaluate the PET value for the current situation and to ease the comparison of PET values for proposed scenarios in the next phase. The first receptor point (R1) is along the main path, while the second (R2) is on the secondary path. The third receptor point (R3) is within the green lawn zone, followed by the fourth (R4) point in the cafe zone. The fifth receptor point (R5) is in the kid's area zone. This selection of receptor points was made to ensure an accurate and comprehensive evaluation of the PET value of Abdeen Square.

Figure *26:* Receptor points locations (Source: Author)

Tree Selection and Location

Before performing the optimization, selecting the type of trees to be used in the simulation and its location was necessary (Figure 27). Palm Phoenix was used at the main path to enhance the users' thermal comfort while considering the visual axis of Abdeen Palace. Also, a study conducted by (Elbardisy, Salheen and Fahmy, 2022) described the presence of Palm Phoenix as essential as it has a minor impact on the wind pattern. Ficus Nitida was described in the same study as the most effective tree for providing cooling and shading, thus improving thermal comfort, so it was first planned to be used as an evergreen tree in the Square zones. While after interviewing with the Square's manager, as will be illustrated later, Citrus Lemon was used instead of Ficus Nitida as it's an edible tree and provides the same climatic function as Ficus Nitida (El-Bardisy, 2014). Cassia Nodosa is a deciduous tree that was used also used at the Square's zone as it is commonly found in parks in Cairo, accordingly well-adapted to hot climates, and it provides sufficient shade in the summer and heat in the winter (Elbardisy, Salheen and Fahmy, 2021).

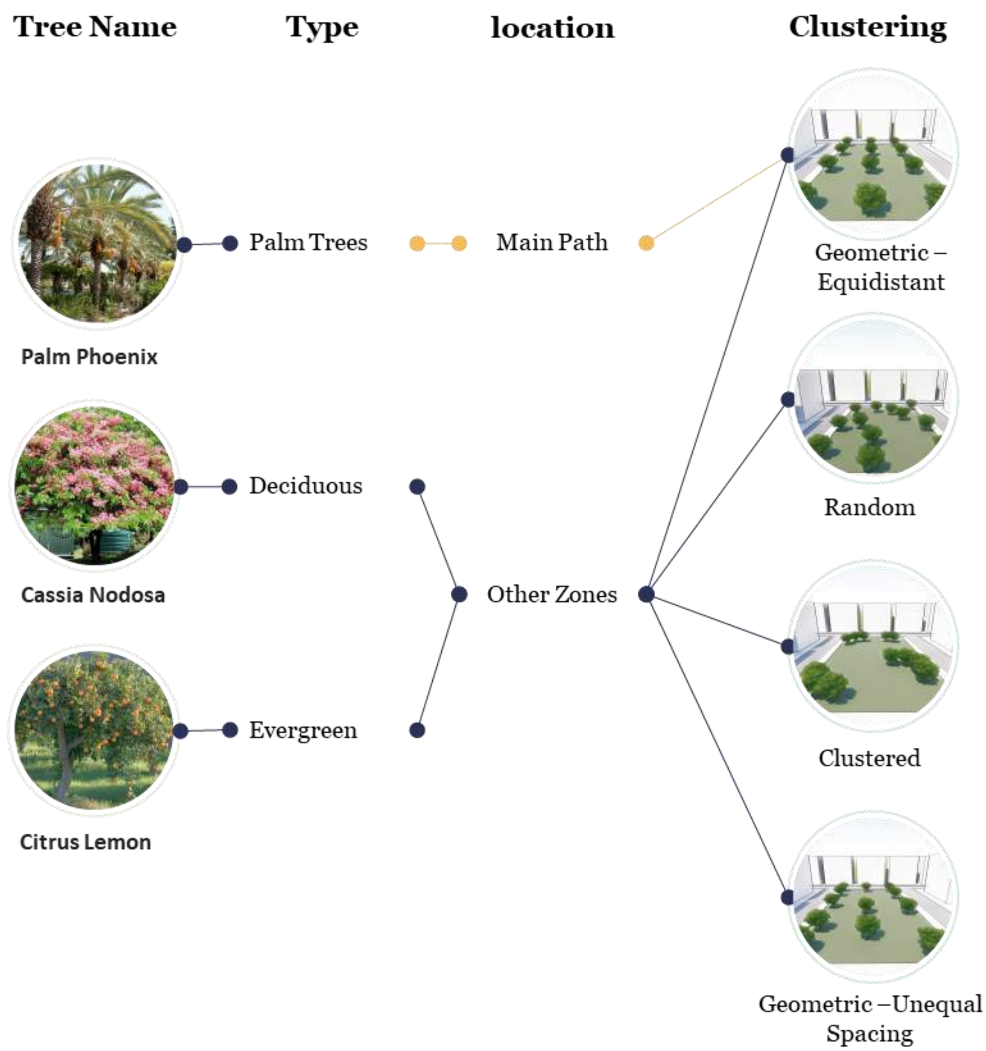

Figure 27: Tree's Types and Locations for Optimization

Trees Spatial Arrangement Possibilities

According to the reviewed literature, four possible spatial arrangements for trees were shortlisted concerning the whole Square, considering the limitation on the main path regarding the visual axis of Abdeen Palace (Figure 28). In all four scenarios, a linear arrangement of Palm trees was deemed optimal for the main path. Moving forward, for the entire Square, four different arrangements were considered: geometric equidistant arrangement, geometric arrangement unequal spacing, clustered arrangement, and random arrangement. To assess the thermal performance of these proposals compared to the current situation and a no-vegetation scenario, rigorous testing using Grasshopper was conducted at the previously discussed relevant time intervals. The results of this evaluation provide valuable insights into the potential thermal performance of each arrangement.

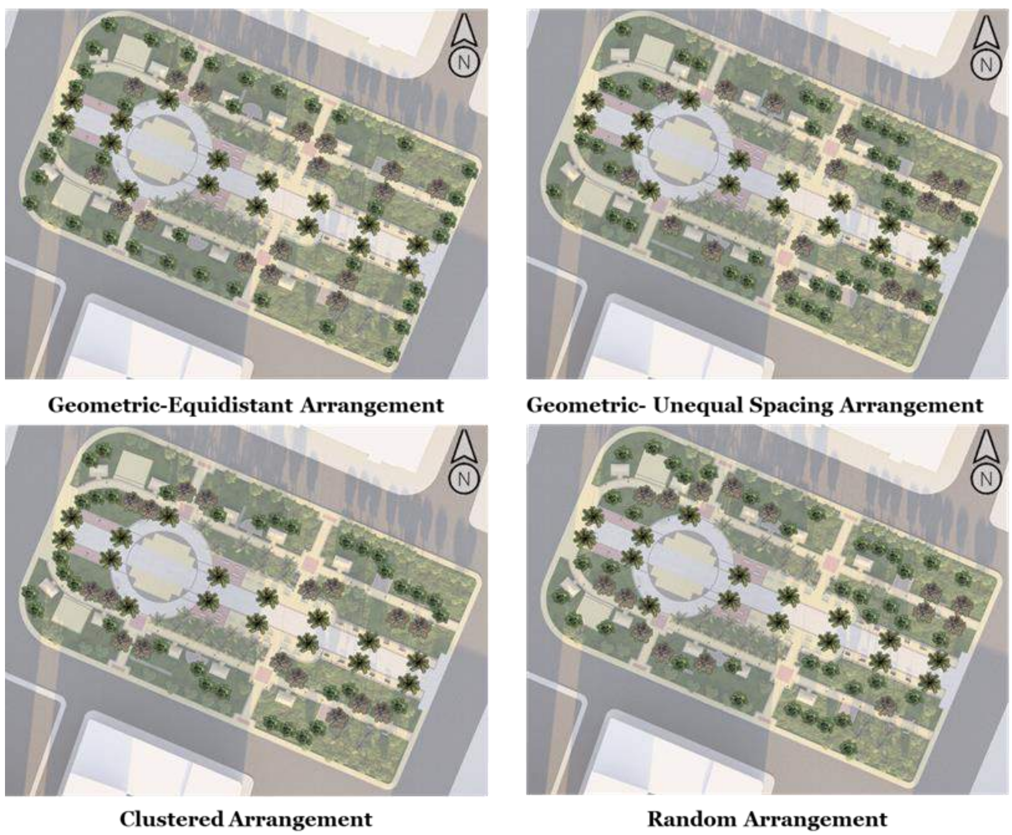

Figure *28*: Trees' Spatial Arrangement Possibilities (Source: Author)

- **The Recipient Profile Toolkit**

This section will cover two aspects first, defining the research participants and their roles during the two phases of the research, and second, defining the way of connection that will be used to communicate with the different participants.

Stakeholders Mapping

Participants' mapping and roles were developed to ensure the inclusivity of knowledge co-production (Figure 29). Four participants were mapped. First, the provider provides technical knowledge and facilitates the process. Second, for the recipients, the first participant mapped are the users of Abdeen Square, including the visitors and the employees of Abdeen Square as a provider with local knowledge and real-life experience. Lastly, the last two participants from the recipients are the manager and the cafes managers. By exploring who is responsible for the Square's management, it was investigated that it is under the presidential palace's administration. At the same time, it was rented to a private company managing the Square meanwhile. As a result, the third participant is the manager of the private company managing the Square. This participant is responsible for providing the permit for conducting the empirical study and providing knowledge about the applicability of the solutions. The cafes managers are responsible for providing knowledge about the applicability of the solutions.

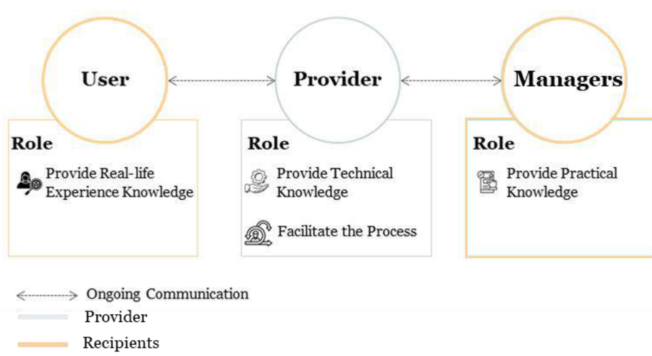

Figure 29: Stakeholders Mapping (Source: Author)

Ways of Connection

A key factor in sustaining the knowledge coproduction process and effectively sharing knowledge with others is finding an appropriate means of communication among diverse participants (Tengö *et al.*, 2017; Korhonen-Kurki *et al.*, 2022). Consequently, an on-site survey was selected as the preferred method of communication with users. This approach aimed to encourage active participation, foster constructive discussions between users and providers, and establish trust by physically sharing knowledge with them. Additionally, semi-structured interviews were chosen to communicate between the provider and the manager, and the cafes managers.

Also, to make the knowledge in a form that is easily shared and comprehended by participants with diverse backgrounds, three techniques were used. Firstly, 3D visuals were utilized in the survey responses to represent the information visually. Additionally, participants were presented with boards featuring 3D visuals during the onsite survey to aid in comprehending the assessment of the current situation and the presentation of optimized solutions, which will be discussed in the next sections. Lastly, technical terminology was simplified when discussing with the users and the manager to facilitate better understanding.

Site Permit

A meeting was convened with the manager to formally request permission to conduct an empirical study in the Square. Initially, a call was made to the manager to discuss the case study and provide a brief introduction. The manager expressed initial acceptance of the idea but requested a formal permit request. Subsequently, a meeting was arranged where the permit request was submitted, and a comprehensive discussion regarding the study took place.

5.2.2.2. Phase 1: Co-Explore Needs

This phase aims to co-explore the needs from two different perspectives, the first one is the provider, and the second is the recipients. This section covers the methods and tools for data collection of each part of this phase.

- **Assessing the Current Situation of Thermal Performance**

Grasshopper and Ladybug were used to measure the PET value and were presented on maps. These values were converted to their equivalent thermal perception grade to assess the outdoor thermal comfort of the users to determine the spaces of higher discomfort on Abdeen Square.

- **Manager Demand**

During this phase, the manager's semi-structured interview was conducted to investigate his demands regarding the current situation of Abdeen Square and the applicability of applying the proposed solutions for Abdeen Square. Questions were asked to investigate the applicability of using the selected trees and arrangement in real-life situations, also the tendency to apply these proposals in real-life situations to enhance the thermal performance of Abdeen Square.

- **Space Usability and User Needs of Abdeen Square**

This part will be discussed in the next section due to the limitation mentioned regarding conducting the on-site survey.

5.2.2.3. Phase 2: Co-develop Solution Phase

This phase aims to co-develop the solutions according to the two different perspectives of the provider and the recipients. This section covers the methods and tools for data collection of each part of this phase.

- **Assessing the Thermal Performance of the Optimized Solutions**

Tree types used in optimization were first selected based on the reviewed literature and the manager demand, as mentioned before, then the proposed spatial arrangement of trees was developed based on the reviewed literature. After that, Grasshopper and Ladybug were also used to measure the PET value and were presented on maps, and these values were converted to their equivalent thermal perception grade to assess the outdoor thermal comfort of the optimized solutions.

- **Recipient Preference**

A- User Preference

An onsite survey was conducted with Abdeen Square's visitors and employees to involve them as active knowledge contributors in assessing the current state of Abdeen's Square and identifying areas that require improvement according to their perception. In addition, to collaborate with them in evaluating the provided proposed solutions and asking their feedback to incorporate any modifications they deem necessary to enhance the proposed solutions.

Introducing the Study

The participants were provided with a concise overview of the study regarding the reason behind conducting the study, and they were requested to fill in a survey composed of three sections (Figure 30). They also were presented with an illustrative evaluation of the OTC of Abdeen Square. Illustrations and visuals were used to enhance the way of communication with the participants. The participants had seen a map presenting the map of the current situation of OTC assessment during the introduction to the study. To easily understand the PET value chart presented on the map, the participants were provided with the information that places with red color indicate zones where they can feel very hot on it. In contrast, the blue color indicates where they can feel warm. Also, photos of these zones were pointed out from the map so the participants could easily comprehend the locations presented on the map.

Subsequently, they were requested to complete the initial two sections of a questionnaire. Upon the two sections of the survey's completion, they were introduced to various landscape techniques that could be used to enhance the thermal performance of Abdeen Square, and that the primary emphasis of the study is using trees to enhance the thermal performance of Abdeen Square. Finally, the proposed solutions were presented to the participants, and they were asked to select their preferred solution based on their perception in the third part of the questionnaire and to vote for it on an envelope (Figure 31).

Visuals presented on four boards were used to facilitate the way of communication while presenting the proposed solutions to the participants; each board included the layout of one of the proposed solutions to describe the method of the tree arrangement on this proposal supported by a 3d illustration for the type of arrangement (Figure 32). After adding the trees, a 3d visual for different zones of the proposed solution for Abdeen Square was presented on the board so the users could easily comprehend the difference between the proposed solutions for optimization. The researcher also described the name of the types of arrangements in simpler terminology so the users can understand it easily: “This proposal is the random arrangement so you can see the trees arranged spontaneously without a definite grid.”

Figure *30*: Provision of Concise Overview of the Study (Source: Author)

Figure *31*: Users Selecting their Preferred Solution (Source: Author)

Figure *32*: Sample of the 3D visuals of the Proposed Solution (Source: Author)

- **On-Site Survey Sections**

The survey was divided into three sections; section one was the user's background, section two was the user needs, and usability of Abdeen Square, and the third part was the users' opinion on proposals to improve outdoor thermal comfort. The aim of each section will be illustrated in the next paragraphs.

First Section: User Background

The first section aimed to gather the user's background information, providing a comprehensive understanding of the respondent's demographics and prior experience with Abdeen Square to provide a valuable context for the subsequent sections. This section was composed of three questions age, gender, and purpose of visit.

Second Section: Space Usability and User Needs of Abdeen Square

This section aimed to achieve key insights into the current condition of Abdeen Square by investigating first the space usability and second the participant's needs to improve the current situation of Abdeen Square from their experience with the space. Regarding space usability, the participants were asked to answer four questions about the reason for the visit, preferable activities, preferable time of visit, and the preferable zones. While the user needs were investigated by asking the users six questions about outdoor spaces that they prefer to visit and the reason for their preference, Abdeen Square quality and areas of improvement, the sufficiency of green elements, and suggested zones to increase the green elements on.

Third Section: Users' Perception of the Optimized Solutions

The last section of the survey aimed to assess the respondent's perceptions of the proposed solutions. The users were requested to answer three questions: preferences regarding the tree's arrangement, if they have suggestions for improvement, and their suggestions for improvement.

5. Cafes' Manager Preference

Accompanied by the on-site survey, a semi-structured interview was conducted with the cafes managers to investigate their preference and their perspective regarding the applicability of applying the proposed solutions.

5.2.2.4. The Developed Solution

After conducting phase one and phase two, the results of the co-produced knowledge gained from the simulation and, on the other hand, the onsite survey and the semi-structured interview were analyzed. This knowledge was translated into a developed solution that respects the simulation and user recommendation to assess its effectiveness.

- **The Thermal Performance of the Developed Solution**

Grasshopper and Ladybug were also used to measure the PET value and were presented on maps. These values were converted to their equivalent thermal perception grade to assess the outdoor thermal comfort of the optimized solutions.

Chapter 6: Findings and Discussion: Processing Knowledge Co-production

This chapter is divided into two sections; the first section presents the findings of the empirical study obtained from the two phases of the study, using both the soft and hard systems approach as a methodological approach. The findings will include the simulation results, showcasing the current situation's thermal performance, the optimized solution, and the developed solution. Furthermore, the onsite survey analysis results regarding user suitability, which includes space usability, user needs, and user perception, will also be discussed. Additionally, the semi-structured interview results regarding the developed solution's applicability will be discussed.

These findings will be further correlated in the second section to achieve the research objective of investigating the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square.

6.1. Empirical Study Findings

This section shows the findings of the two phases of the empirical study and the effectiveness of the developed solution regarding the users suitability and thermal performance.

6.1.1. Co-Explore Phase Findings

This section presents the outcomes of the simulation analysis conducted to assess the thermal performance of the current situation. Additionally, this section discusses the findings of the onsite survey regarding the two first sections, which evaluated the user suitability in terms of space usability of the Square and user needs. Also, it shows the finding of the manager semi-structured, showing the applicability of the four proposed solutions.

6.1.1.1. The Current Situation Thermal Performance Assessment

The current situation of Abdeen Square was assessed by comparing the PET values of the no vegetation scenario and the current situation and the PET value of the existing situation. By comparing the PET value with the current situation, it was clear the impact of vegetation and shading elements on enhancing the thermal perception with PET values 0.8,0.6, and 2.2 °C, respectively, at 12:00 p.m., 2:00 p.m., and 4:00 p.m However, at 7:00 pm, it was witnessed that the PET value of the existing scenario was slightly higher compared to the no vegetation scenario (Figure 33) because the heat and humidity trapped under the tree canopy are released, causing a warmer pattern.

Also, by assessing the PET value of the current situation, which records 45.3, 46.8, and 41.3 °C, respectively, at 12:00 p.m., 2:00 p.m., and 4:00 p.m., which records extreme heat stress. However, at 7:00 p.m., it records 25 °C, which records slight heat stress according to the PET value.

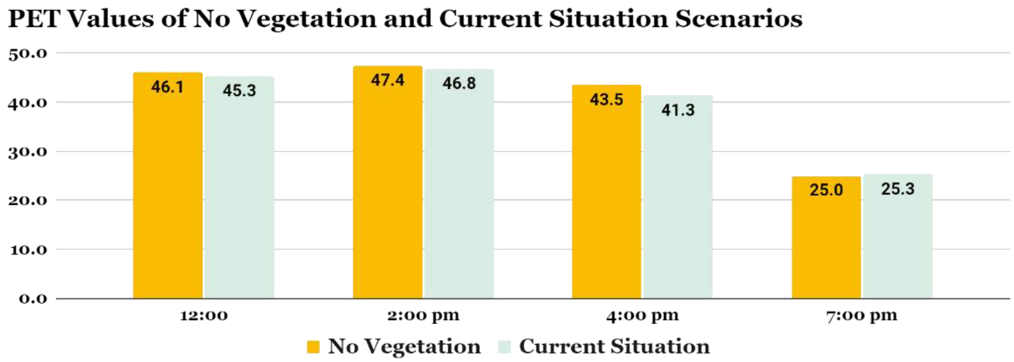

Figure *33*: PET Values of No Vegetation and Current Situation Scenarios (Source: Author)

During the hours of 12:00 p.m., 2:00 p.m., and 4:00 p.m., the receptors recorded a PET value exceeding 41.1 °C, resulting in categorizing the thermal perception to be very hot. However, in the case of R2, at 2:00 p.m., the thermal perception was classified as hot, while at 4:00 p.m., it was categorized as warm. At 7:00 p.m., the receptors registered a PET value ranging from 25 to 25.3 °C, leading to a slightly warm thermal perception (Figure 34).

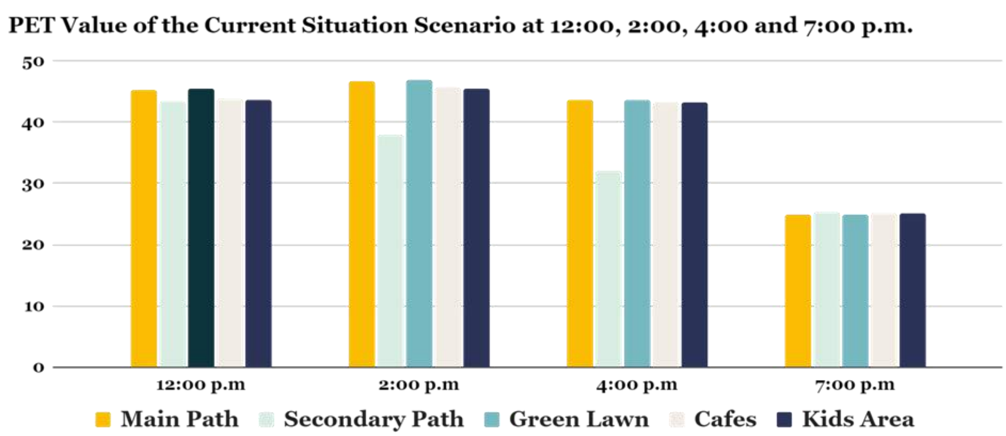

Figure *34*: PET Value of the Current Situation Scenario at 12:00, 2:00, 4:00, and 7:00 p.m. (Source: Author)

6.1.1.2. Recipient Needs Findings

This section shows the first two sections of the onsite survey findings regarding the users' background, space usability, and users' needs. Also, it shows the findings of the semi-structured interview conducted with the manager regarding his demands.

A. Onsite Survey Findings: Space Usability and User Needs

- **User Background Results**

This section shows the results of the first part of the onsite survey aiming to provide a valuable context for the subsequent sections by getting to know the users' demographics.

Gender and Age

According to the survey results, a total of 49 respondents participated in the survey. (Figure 35) shows that out of these, 26 respondents were male, representing an overall percentage of 53.06%. On the other hand, 23 respondents were female, representing an overall percentage of 43.94%. Additionally, (Figure 36) shows that the survey included 20 respondents who fell within the age range of 13-19. There were also 15 responses from individuals aged 20-30, six from individuals aged 31-44, and five from individuals aged 45-60. Also, three respondents were younger than 13 years old.

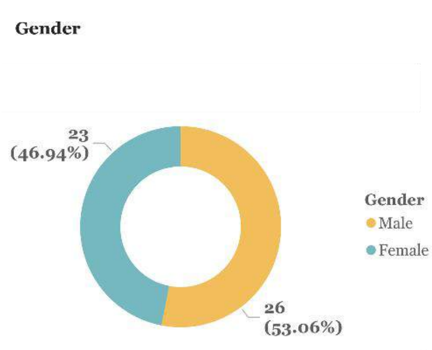

Figure35: Gender Distribution (Source: Author)

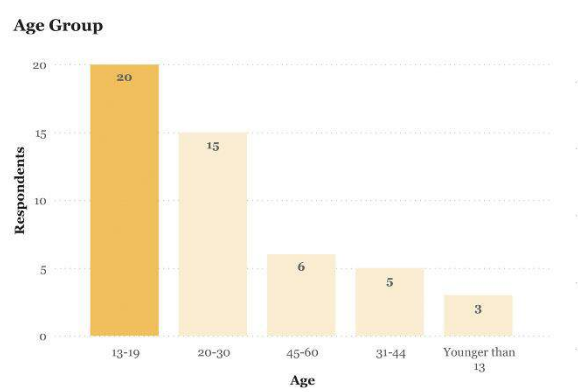

Figure 36: Age Range (Source: Author)

Purpose of Visit

A question was asked about the purpose of visiting Abdeen Square to gain insight into the demographic of Abdeen Square's visitors versus its employees and specify their interest in visiting the Square. (Figure 37) shows that 42 respondents indicated that they were visitors to the Square, and the remaining seven indicated that they were employees.

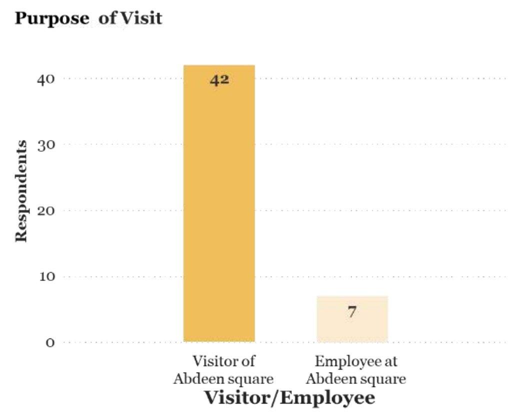

Figure *37*: *Purpose* of Visit (Source: Author)

- **Space Usability and User Needs Results**

This section shows the findings of the second section of the onsite survey regarding space usability and user needs.

- **Space Usability**

Reason for Visit

(Figure 38) shows an overview of the reason for visiting Abdeen Square. It was apparent that the two primary reasons for visiting Abdeen Square were relaxation and enjoying nature or social interaction. The survey garnered 106 responses; out of the 106 respondents, 34 preferred visiting Abdeen Square for relaxation, 25 preferred visiting to enjoy nature, and the same number of respondents reported that they preferred visiting Abdeen Square for social interaction.

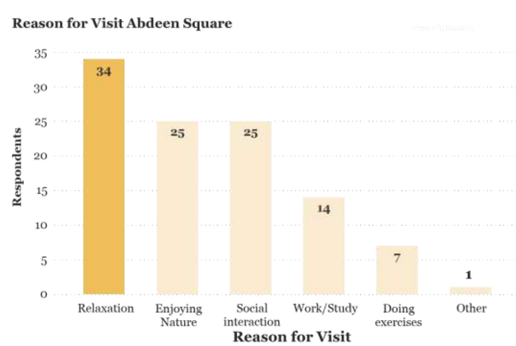

Figure *38*: Reason for Visit (Source: Author)

Users' Preferable Activities

Regarding the preferable activities question, (Figure 39) shows that the two main preferable activities are sitting and taking photos. Out of 127 responses collected, 36 reported that they preferred sitting; the second was taking photos with 29 responses, and the third was jogging with 26 responses. The least preferable activities reported by the users were studying and enjoying the identity of the Square, with responses for each.

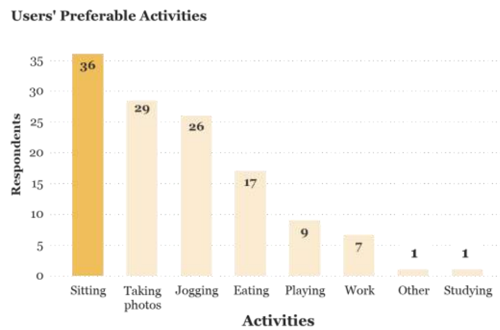

Figure *39*: Users' Preferable Activities (Source: Author)

Preferable Time of Visit

Regarding the time of visit question, it was obvious that people enjoy going to Abdeen Square in the afternoons, as indicated in (Figure 40), with 42.47% preferring to visit between 4:00 and 7:00 pm. While a percentage of 28.77% was, the second most popular period was between 7:00 p.m. to 12:00 a.m. Following this, 20.55% of the users preferred visiting from 12:00 to 4:00 pm, and 8.22% preferred visiting from 6:00 am to 12:00 p.m.

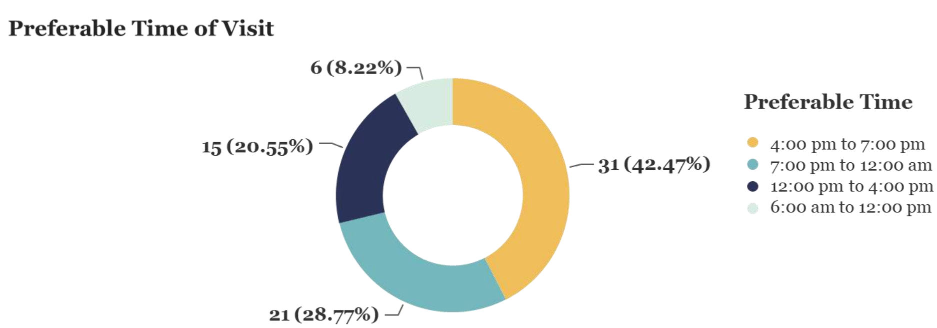

Figure *40*: Preferable Time of Visit (Source: Author)

User Preferable Zones

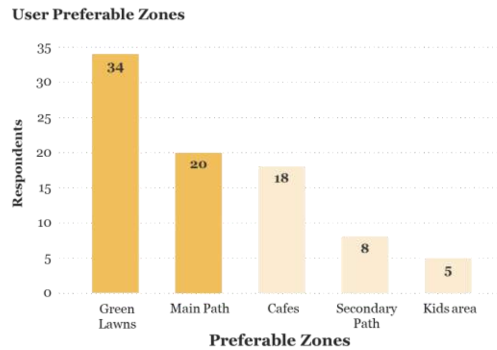

Figure *41*: User Preferable Zones (Source: Author)

Upon closer investigation, the findings of the preferable zones depicted in (Figure 41) demonstrate a consistent trend regarding the preferred seating areas within Abdeen Square. The green lawns and the main path emerged as the two most preferable areas respectively for visitors to spend their time. Following closely, cafes ranked as a third preference. Based on the data collected from 85 participants, the green lawns received 34 responses, while the main path received 20 responses. The secondary path and kids' area were the least preferred spaces, with only 8 and 5 responses, respectively.

- **User Needs**

Preferable Outdoor Spaces and Reasons for Preference

Regarding the user's preferable outdoor spaces, El Azhar Park and the Downtown streets were the most preferable outdoor spaces. (Figure 42) based on the data collected from 46 participants, El Azhar Park received 15 responses as the most preferred outdoor space, followed by five responses for the Downtown streets and four for the family park.

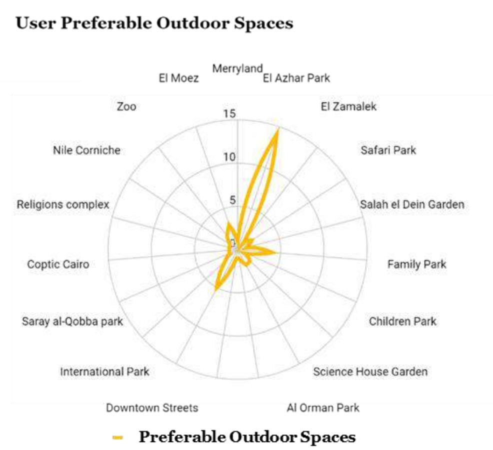

Figure *42*: User Preferable Outdoor Spaces (Source: Author)

Upon closer investigation of the reason for preference, the user indicated the availability of green spaces and various activities as a priority for their preference.

Quality of the place and Areas for improvement

(Figure 43) shows that the users rated the quality of Abdeen Square as good quality by 46.94% of respondents, while 24.49% rated it as neutral. Only 12% of respondents rated the quality as very good, and a mere 4.08% rated it as poor.

A deeper insight was gained by asking about the suggestions for improvement. Increasing the shading percentage and the green elements were the two main suggestions for improving the quality of Abdeen Square. As shown in (Figure 44), 99 responses were collected, with 36 suggesting an increase in shading percentage, 32 suggesting an increase in green elements, and 14 suggesting an increase in facilities. Other suggestions included shaded seating, improved lighting, and clustered seating. Finally, 7 respondents suggested increasing the seating capacity.

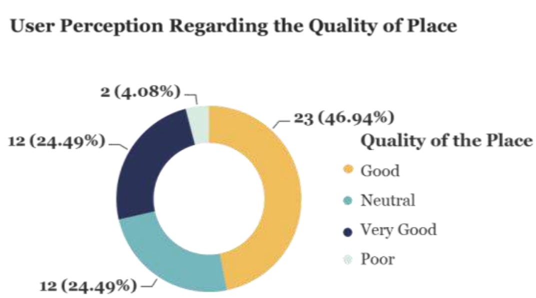

Figure *43*: User Perception Regarding the Quality of Place (Source: Author)

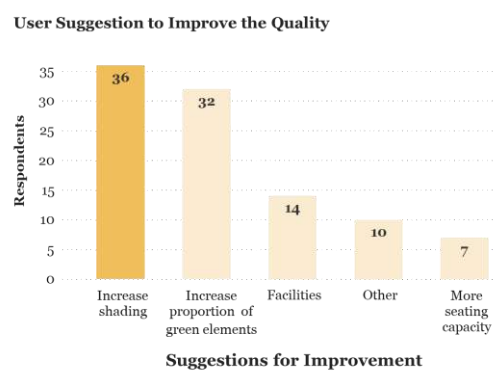

Figure *44*: User Suggestion to Improve Abdeen Square's Quality (Source: Author)

User Perception Regarding the Sufficiency of Green Elements

(Figure 45) shows the perception of respondents regarding the sufficiency of green elements. The majority, accounting for 59.18%, considered the percentage of green elements insufficient, while 40.82% found it to be sufficient. Regarding the suggested zones for incorporating green elements, the green lawns were the most favored, while the least preferred options were the kids' area and cafes. (Figure 46) Out of 57 responses, 25 suggested increasing the percentage of green elements on the green lawns. Following closely, the main path was identified as the second most desired space, with 17 responses.

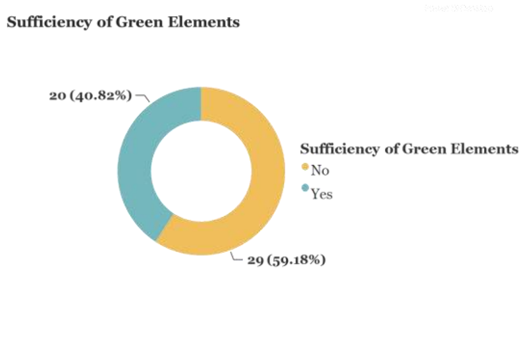

Figure 45: Sufficiency of Green Elements in Abdeen Square (Source: Author)

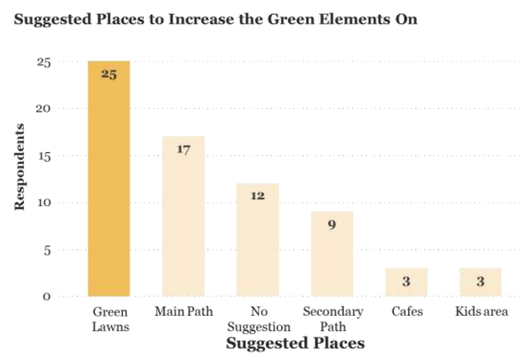

Figure *46*: Suggested Places to Increase the Green Elements on (Source: Author)

B. Semi-structured Interview Findings: The Manager's Demand

Abdeen Square's manager portrays several demands regarding the trees type used in the possible spatial arrangements while conducting the interview. He said that using edible plants is a requirement for designing outdoor spaces. Also, he mentioned his interest in designing outdoor spaces using a micro-climate responsive design approach to sustain the thermal performance of these spaces.

"We are interested in the projects related to enhancing the thermal performance of the outdoor spaces, regarding the type of trees used, it is required to use edible plants in these projects." (Abdeen's Square Manager)

6.1.2. The Co-Develop Solution Phase Findings

This section presents the simulation analysis of the four potential clustering options for Abdeen Square. The results highlight the most effective proposal for enhancing the Square's thermal performance. On the other hand, this section discusses the findings of the last section of the on-site survey, which evaluated user suitability in terms of the user perception of the optimized solutions. Also, it shows the finding of the cafes' managers semi-structured, showing the applicability of the four proposed solutions.

6.1.2.1. The Optimized Solutions Thermal Performance Assessment

By comparing the average PET value at the receptor points, which was previously illustrated in (Table *1*), for each of the solutions. The results indicated that all proposed solutions positively enhanced the PET value compared to the existing situation. Nevertheless, it was observed that the geometric-equidistant arrangement exhibited the most optimal performance in reducing the average PET value. It is worth noting, however, that this solution did not prove to be the best option for all receptors.

PET at 12:00 p.m.

(Figure 47) shows that in all scenarios, it was witnessed that the average PET was reduced in comparison to the existing situation by 2.5 to 3.3 °C with the maximum reduction obtained by the geometric-equidistant arrangement with a value of 39.4 °C instead of 42.6 °C. This significant reduction in the case of the geometric-equidistant arrangement greatly improved the thermal perception of the users, transitioning from feeling very hot to feeling hot. Conversely, the clustered arrangement showed the least reduction in PET.

For receptor 1 (R1), the PET was reduced by 3.7 to 5 °C compared to the current situation by maximum reduction obtained by random arrangement while the minimum reduction is by the clustered arrangement. For receptor 2 (R2), the PET was reduced by 1.9 to 10.8 °C in comparison to the current situation, in which clustered arrangement made a clear reduction while the random arrangement obtained the minimum reduction.

For receptor 3 (R3), the PET was reduced by 1.2 to 9.7 °C compared to the current situation by maximum reduction obtained by clustered arrangement while the minimum reduction is by the geometric-equidistant. For receptor 4 (R4), the PET was reduced by 0.8 to 11.7 °C compared to the current situation, in which the geometric-equidistant arrangement made a clear reduction. In contrast, the clustered arrangement obtained the minimum reduction. Finally, in receptor (5), the PET was reduced by 1.2 to 10.9 °C compared to the current situation by maximum reduction obtained by clustered arrangement while the minimum reduction is by the random arrangement.

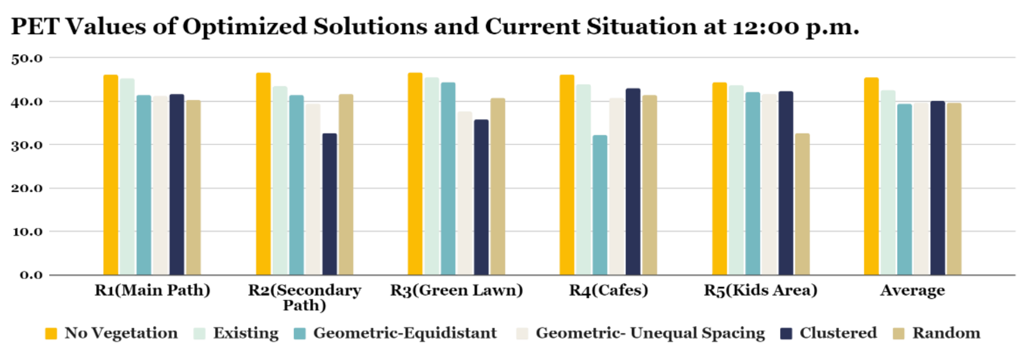

Figure 47:PET Values of Optimized Solutions and Current Situation at 12:00 p.m. (Source: Author)

PET at 2:00 p.m.

(Figure 48) shows that in all scenarios, it was evident that the average PET was decreased by 2.4 to 3.3 °C compared to the current situation. The geometric-equidistant arrangement exhibited the highest reduction, with a value of 40.9 °C instead of 44.1 °C. This remarkable temperature decreases enhanced users' thermal perception, transitioning their perception from feeling very hot to feeling hot. Conversely, the clustered arrangement yielded the minimum reduction.

For receptor 1 (R1), the PET was reduced by 10.2 to 11.1 °C in comparison to the current situation by maximum reduction obtained by random arrangement while the clustered arrangement obtained the minimum reduction. For receptor 2 (R2), the PET was reduced by 1.3 to 4.9 °C compared to the current situation, in which clustered arrangement made a clear reduction while the random arrangement obtained the minimum reduction.

In the case of receptor 3 (R3), the PET temperature was reduced by 0.8 to 13.2 °C compared to the current situation. The maximum reduction was achieved through a geometric unequal-spacing arrangement, while the geometric-equidistant arrangement resulted in the minimum reduction. Finally, for receptor 4 (R4), the PET temperature decreased by 0.9 to 12.5 °C relative to the current situation. The random arrangement made the most significant reduction, while the clustered arrangement obtained the minimum reduction. Finally, in receptor (5), the PET was reduced by 2.4 to 3.3 °C compared to the current situation by maximum reduction obtained by clustered arrangement, while the geometric-equidistant arrangement achieved the minimum reduction.

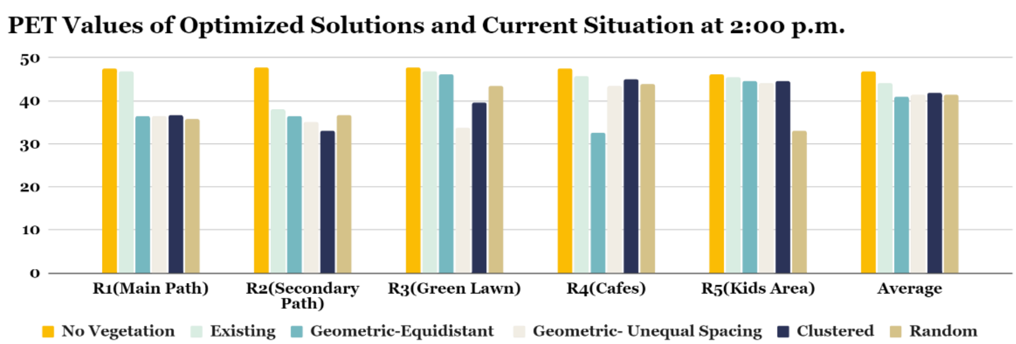

Figure *48*: PET Values of Optimized Solutions and Current Situation at 2:00 p.m. (Source: Author)

PET at 4:00 p.m.

(Figure 49) shows that in all scenarios, it was evident that the average PET was reduced by 2.2 to 2.6 °C compared to the existing situation. The geometric-equidistant, geometric equal-spacing, and random arrangement achieved the maximum reduction, resulting in a value of 38.7 °C instead of 41.3 °C. This remarkable temperature decreases greatly enhanced users' thermal perception, transitioning their perception from feeling very hot to feeling hot. On the other hand, the clustered arrangement yielded the minimum reduction.

For receptor 1 (R1), the PET was decreased by 11.9 to 12.1 °C compared to the current situation. The random arrangement demonstrated the highest reduction, while the other arrangements showed a minimum. Regarding receptor 2 (R2), the PET was reduced by 0.4 to 1.4 °C in comparison to the current situation. Notably, the geometric-equidistant and random arrangement had the most significant reduction, while the clustered arrangement led to the minimum reduction. For receptor 3 (R3), the PET was reduced by 0.1 to 1.8 °C in comparison to the current situation by maximum reduction obtained by clustered arrangement while the minimum reduction is by the geometric-equidistant.

For receptor 4 (R4), the PET was reduced by 0.9 to 12.5 °C in comparison to the current situation. Notably, a clear reduction was achieved with the random arrangement, while the clustered arrangement resulted in the minimum reduction. Lastly, for receptor 5, the PET was reduced by a range of 0.3 to 12.5 °C compared to the current situation. The maximum reduction was obtained through a random arrangement, while the geometric-equidistant and clustered arrangements resulted in the minimum reduction.

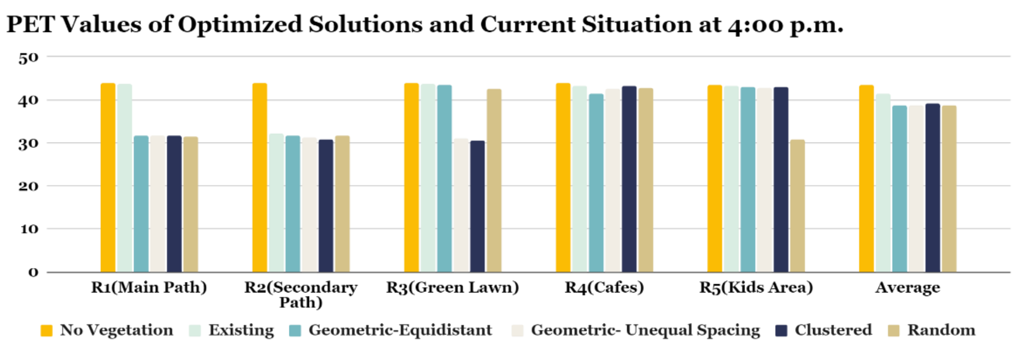

Figure *49*: PET Values of Optimized Solutions and Current Situation at 4:00 p.m. (Source: Author)

PET at 7:00 p.m.

(Figure 50) shows that in all scenarios, it was witnessed that the average PET was increased in comparison to the existing situation by 0.3 to 0.4 °C, with the minimum increment obtained by the clustered arrangement, while the maximum increment was obtained by the other arrangement with a value of 40.9 °C. This increment in the PET value did not affect the thermal perception of users, as it kept the user feeling slightly warm.

For receptor 1 (R1), the PET was increased by 0.5 to 0.7 °C compared to the current situation by minimum increment obtained by geometric-equidistant and random arrangement. In contrast, the maximum increment was obtained by the clustered arrangement. For receptor 2 (R2), the PET was increased by 0.2 to 1 °C compared to the current situation, in which clustered arrangement made a clear increment while the minimum increment is obtained by the geometric-equidistant and random arrangement.

For receptor 3 (R3), the PET was increased by 0.1 to 1.4 °C compared to the current situation by minimum increment obtained by geometric-equidistant and random arrangement while the maximum increment was obtained by the clustered arrangement. For receptor 4 (R4), the PET was increased by 0.2 to 1 °C compared to the current situation, in which the geometric-equidistant arrangement made a clear increment while the minimum increment was obtained by the clustered arrangement.

For receptor 5 (R5), the PET was increased by 0.3 to 0.4 °C compared to the current situation by minimum increment obtained by clustered arrangement while the other arrangements obtained the maximum increment.

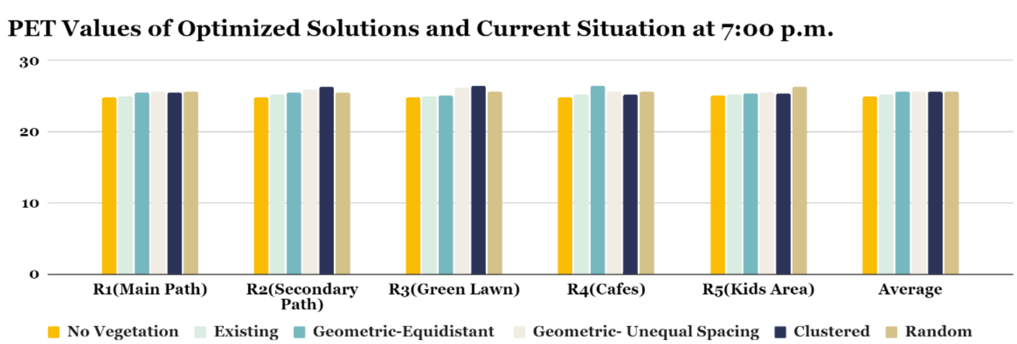

Figure *50*: PET Values of Optimized Solutions and Current Situation at 7:00 p.m. (Source: Author)

6.1.2.2. Recipients Preferences Findings

This section shows the findings of the third section of the onsite survey regarding the user perception of the optimized solutions and the semi-structured interview with the cafe manager showing their preference regarding the optimized solutions.

- **Users' Perception of the Optimized Solutions**

This section shows the third part of the on-site survey results, showing the user perception regarding the four proposed solutions and their feedback for enhancing the selected proposal.

User Perception Regarding the Tree's Arrangement

(Figure 51) the majority, comprising 48.98% of the participants, indicated their preference for the geometric equidistant arrangement. They found this arrangement to be organized, visually comfortable, provide equal shading, and fit the space perfectly. On the other hand, 20.41% of the respondents voted for the clustered arrangement as they believed it offered a kind of privacy and provided shading at multiple spots. Another 20.41% of the participants favored the random arrangement as they felt it offered better space utilization by providing superior shading to the area.

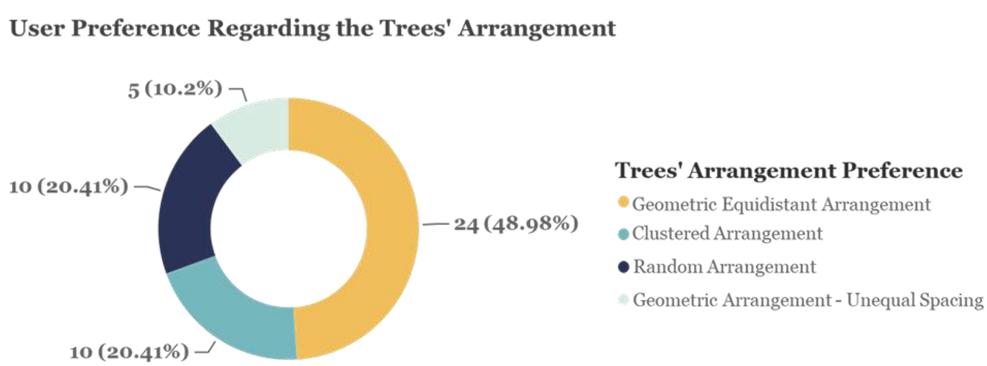

Figure *51*: User Preference Regarding the Trees' Arrangement (Source: Author)

The participants' suggestions for enhancing the proposals showed a preference for adding more soft scape elements, as shown in (Table 2). Among 36 respondents, 11 recommended adding more soft scape elements such as fragrant trees, flowers, and shrubs, and 11 respondents also suggested adding water elements such as fountains. On the other hand, the most suggested hardscape element was shaded benches with 5 respondents.

Elements	Categories	Mentioned Times
Softscape	Fragrant Trees, Flowers, and Shrubs	11
	Water Elements as Fountains	11
	22	
Hardscape	Shaded Benches and Pergolas	5
	Replace the Concrete Material of the Benches	2
	More Light Poles	2
	Variety of Benches for Different Social Activities	3
	12	

Table 2: Suggested Landscape Elements for Enhancing the Proposed Solution (Source: Author)

- **Cafes' Manager Preference**

During the interview, Abdeen's Square cafes' managers portrayed several concerns regarding the proposed solutions during four semi-structured interviews with four managers. They highlighted the importance of using a geometric-equidistant arrangement for the Palm Phoenix to emphasize the main path. Also, two managers were concerned about the trees on the green lawns in the frontage of their restaurants, which may block the view, as shown in (Figure 52). They also mentioned that users rarely utilize these two lawns.

"The trees located in the green lawns in the frontage of our cafes will block the views of our cafes; instead of using the tree, shrubs would be a better solution to be placed in these green lawns." (Café's Manager 1,2)

"If there are any modifications that will be done on these proposals, you need to keep the geometric-equidistant arrangement of the Palm phoenix trees on the main path to emphasize the visual axis of Abdeen Palace." (Café's Manager 1,3,4)

Figure *52*: Concerns about some Trees' Spatial Location

6.1.3. The Developed Solution

As a result of phases one and two, it was clear that the geometric equidistant arrangement has the optimum performance. On the other hand, users prefer to stay on the green lawns and the main path, and they suggested increasing the percentage of green elements. On, also they preferred the geometric equidistant arrangement. Building on this knowledge and according to the manager's demand regarding the types of trees and the cafes managers' concerns regarding some spatial locations of trees. The developed solution (Figure 53) was performed to assess the effectiveness of the co-produced knowledge regarding thermal performance while responding to the user's suitability. This developed solution concentrates the trees on the two most preferable zones: the green lawns and the main path.

Figure 53: Trees' Spatial Arrangement of the Developed Solution (Source: Author)

6.1.3.1. The Developed Solution Thermal Performance Assessment

The study revealed significant improvements in the PET value when comparing the PET value of the developed solutions in comparison to the geometric-equidistant arrangement at receptor 1 and receptor 3. These receptors correspond to the main path and green lawns, which were identified as the preferred zones for the users. Meanwhile, there was a slight improvement observed in the other receptors. Furthermore, the PET value at receptor 4 showed a noticeable increase. However, no considerable change was observed when observing the average PET value compared to the geometric-equidistant arrangement.

PET at 12:00 p.m.

The PET value reduction was apparent across all receptors when comparing the optimized arrangement to the existing situation. Additionally, upon comparing the geometric equidistant arrangement with the optimized arrangement, it was observed that the average PET value remained unchanged, as shown in (Figure 54). Hence, in terms of thermal sensation, users will still feel hot. However, significant reductions were noticed for receptors R1 and R3, with temperature differences of 5.5 and 10.3 °C, respectively, with a value of 39.4 °C. As a result, the thermal sensation of users along the main path remains hot while transitioning the thermal sensation on R3 from feeling hot to feeling warm. Slight reductions also occurred for receptors R2 and R5, with PET differences of 1.3 and 1.9 °C, respectively. Conversely, receptor R4 exhibited an increase in PET value, with a difference of 8 °C.

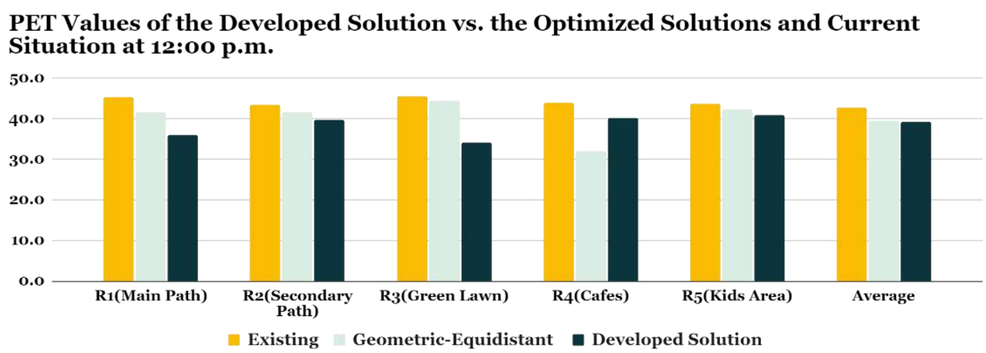

Figure *54*: PET Values of the Developed Solution vs. the Geometric-Equidistant Arrangement and Current Situation at 12:00 p.m. (Source: Author)

PET at 2:00 p.m.

The same result of the PET value at 12:00 p.m. happened in which the PET value was reduced across all receptors by comparing the optimized arrangement with the existing situation. Also, upon comparing the geometric equidistant arrangement with the optimized arrangement, it was observed that the average PET value remained the same, as shown in (Figure 55). Hence, in terms of thermal sensation, users will still feel hot. Notably, R3 exhibited a significant decrease of 12.9 °C in PET value, resulting in transitioning the thermal sensation from feeling hot to feeling warm. Additionally, receptors R1, R2, and R5 experienced slight reductions in PET value, with differences of 0.5 °C, 1.4 °C, and 1.1 °C, respectively. In contrast, receptor R4 showed an increase in PET value, with a difference of 10 °C.

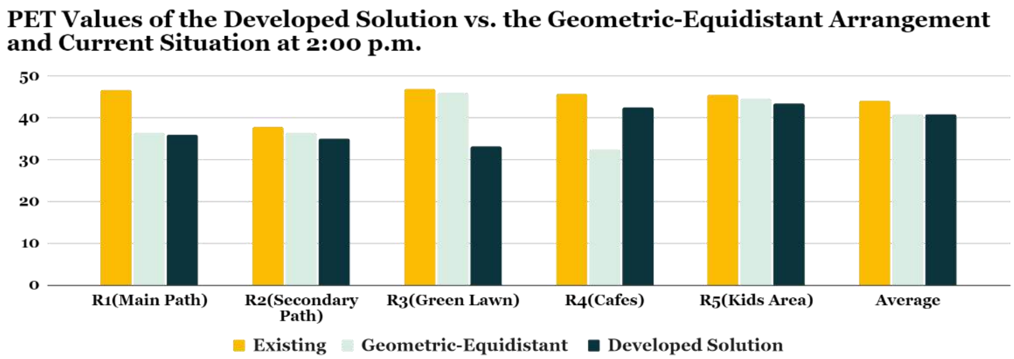

Figure *55*: PET Values of the Developed Solution vs. the Geometric-Equidistant Arrangement and Current Situation at 2:00 p.m. (Source: Author)

PET at 4:00 p.m.

It was evident that the PET value has been reduced across all receptors by comparing the optimized arrangement with the existing situation. Additionally, a comparison between the geometric equidistant and optimized arrangements, as shown in (Figure 56), revealed no change in the average PET value, except for receptor R4, where a significant reduction of 7.7°C was observed. Hence, regarding thermal sensation, users will still feel hot, while a transition from feeling hot to feeling warm happened on R4. Slight reductions were also noted for receptors R3 and R5, with a PET difference of 2.8 and 0.8°C, respectively. It is worth noting that, on the other hand, the PET value of receptors R1 and R2 increased, with a difference of 0.7 and 10.6°C, respectively.

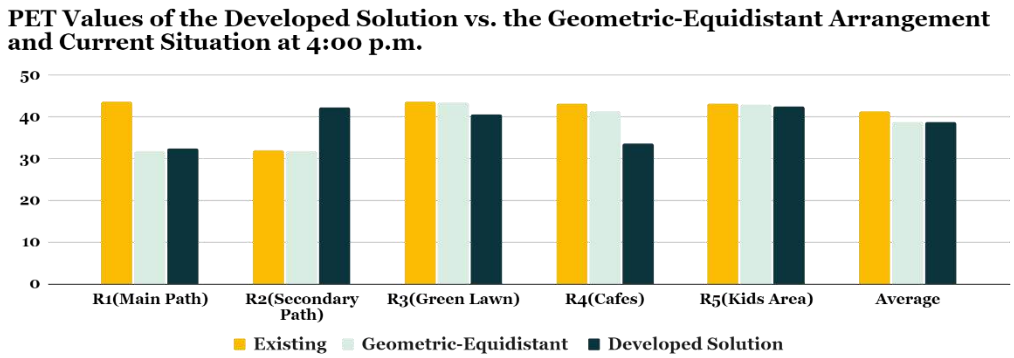

Figure *56*: PET Values of the Developed Solution vs. the Geometric-Equidistant Arrangement and Current Situation at 4:00 p.m. (Source: Author)

PET at 7:00 p.m.

The PET value demonstrated a clear increase across all receptors when comparing the optimized arrangement with the existing situation except for receptor four, as shown in (Figure 57). A comparison between the geometric equidistant arrangement and the optimized arrangement showed no variation in the average PET value. Notably, receptor R3 showed the highest increase in PET value, with an observed difference of 1.8 °C. Slight increases in PET value were also observed for receptors R1, R2, and R5, with differences of 0.3, 0.3, and 0.2°C, respectively. Conversely, the PET value for receptor R4 decreased by 0.6°C. However, this change in the PET value did not affect the thermal sensation of the users, as it kept the user feeling slightly warm.

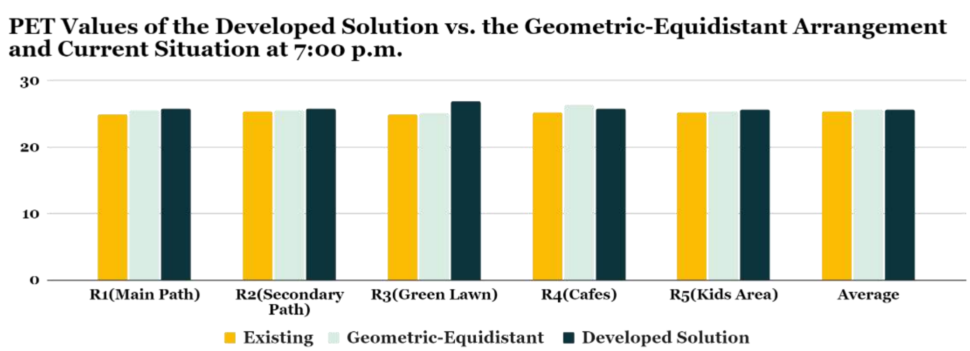

Figure *57*: PET Values of the Developed Solution vs. the Geometric-Equidistant Arrangement and Current Situation at 7:00 p.m. (Source: Author)

6.1.4. Outcomes

The integration of participants with diverse backgrounds leads to facilitating the co-production of the knowledge process. This collaborative process yields a more practical application in real-life scenarios.

Hard System Outcome

Utilizing simulation as a hard system tool proved valuable in assessing the thermal performance of Abdeen Square. It became evident that the thermal sensation experienced in Abdeen Square was very hot. The geometric equidistant arrangement emerged as the optimal solution for improving thermal performance.

Soft System Outcome

Conducting an on-site survey and interview as a soft systems approach provided a comprehensive understanding of the current situation of Abdeen Square.

It became apparent that users mainly occupy the green lawns and the main path. Moreover, Abdeen users strongly prefer comfortable outdoor spaces that provide relaxation, boast large green areas, and offer diverse activities. The survey results also indicated that users need to improve the thermal performance of Abdeen Square. Users suggested increasing shading and incorporating more green elements to enhance the Square's overall quality. Additionally, users desired more green elements in their preferred zones, emphasizing the importance of incorporating green spaces for aesthetic purposes and providing a sense of comfort. Interestingly, users favored a geometric-equidistant arrangement, as they found it to be organized, fitting with the context, and enhancing the thermal performance of Abdeen Square.

The Developed Solution Outcome

Relying solely on the simulation did not comprehensively understand Abdeen Square's situation. Therefore, conducting an on-site survey and semi-structured interviews became crucial in obtaining a complete picture. This comprehensive approach led to the developing of a simulated solution that demonstrated similar enhancements in thermal sensation as the geometric equidistant arrangement. Furthermore, this solution improved thermal sensation in the most utilized areas of Abdeen Square.

6.2. Discussion: The Correlates: A Co-produced Knowledge

From the preceding field work, the co-exploration phase identified the issues regarding thermal performance from the provider and recipient sides. The co-develop phase identified the area of improvement of the thermal performance from both sides, and the cafe managers' preference was investigated.

The discussion aims to fulfill the research objective, highlighting the impact of co-produced knowledge in optimizing the trees' spatial arrangement to enhance the outdoor thermal performance of Abdeen Square. This section will correlate the findings previously discussed through the two approaches: the soft system and the hard system, within the context of the seven characteristics of knowledge co-production. Finally, these correlations will colligate to deduce the hard and soft systems integration as a methodological approach and its contribution to obtaining coproduced knowledge.

However, while conducting the research, some limitations were encountered as follows:

1. The on-site survey of the co-explore phase and the co-develop phase was conducted during the co-develop phase to investigate the user needs regarding the current situation and their preference regarding the

proposed solutions for optimizations to ensure reaching the same users who will contribute to the onsite survey, and due to the thesis time limitation.

2. Trees were selected as the micro-climate landscape element that will be used for optimization due to the time limitation, as trees are known as the most effective landscape element in enhancing the thermal performance of outdoor spaces (Chen *et al.*, 2022).
3. Envi-Met is known for giving a better result for the impact of trees on enhancing the outdoor thermal performance of outdoor spaces; however, the simulation time takes a long time. Accordingly, and due to the limitation of time, the Grasshopper tool and its plugins were used as they have an acceptable accuracy in assessing outdoor thermal comfort (Yazıcıoğlu and Dino, 2021), and its simulation period is limited compared to other tools, such as ENVI-met (Pacifici and Nieto-Tolosa, 2021).
4. The methodological approach of the research can be generalized to other contexts. However, the results of the co-produced knowledge of the case study could not be generalized as the results are context-related to Abdeen Square.

6.2.1. The Thermal Performance of the Current Situation and Space Usability Correlate

During the co-exploring phase, it became apparent that Abdeen Square experienced significant heat stress, as indicated by the PET value as shown previously (Figure 34). Consequently, gaining a deeper understanding of how users utilize the space was crucial. The onsite survey findings revealed several key insights. Firstly, users visit Abdeen Square in the afternoons to avoid direct exposure to solar radiation. The green lawns and main path zones were identified as the most frequently utilized areas. Additionally, sitting emerged as the primary activity undertaken by users in Abdeen Square.

The findings highlighted users' need for affordable zones, suggesting that social class plays a role in the space's usability. Moreover, users desired to sit in areas offering a favorable view of the most active routes. This aligned with Gehl's (2011) argument that the corresponding trend regarding the user preference towards using square zones is sitting on places that provide views to the most trafficked pedestrian route.

This finding further highlights the importance of integrating the knowledge gained of the current situation of thermal performance and usability of a space to enhance the usability of outdoor space. Previous discussions on knowledge coproduction have emphasized the significance of inclusivity in developing context-based products. By involving diverse groups with different types of knowledge, inclusivity enriches the understanding of challenges (Norström et al., 2020) and leads to products that cater to the diverse needs of various groups (O'Connor et al., 2019; Norström et al., 2020).

6.2.2. The Thermal Performance of the Current Situation and Recipients Needs Correlate

The second correlation between the thermal performance of the current situation and the user needs during the co-explore phase revealed similar requirements from both the provider and the recipients. The provider determined that Abdeen Square experienced significant heat stress, while the users' survey responses indicated their desire to improve the Square's thermal performance.

The findings of this part of the survey found that first, users need to enhance the thermal performance by suggesting an increase in the percentage of green areas and shading capacity as a priority to increase the quality of Abdeen Square, as shown previously (Figure 44), which aligned with Vukmirovic, Gavrilovic, and Stojanovic (2019) and Gehl (2010) who argued that thermal comfort is an influential factor affecting the usability of outdoor spaces. Second, users also need an outdoor space that provides comfort and aesthetic value by providing landscape elements, which aligns with Gehl’s (2010) argument.

Users mentioned the main features they prefer in the outdoor spaces they visited, where the two main features are relaxation and the presence of green elements. They found that the percentage of green elements needs to be increased in Abdeen Square, and they suggested increasing these elements on the most usable zones mentioned previously, which are the green lawns and the main path (Figure 46).

During this phase, it became clear through an interview with Abdeen's manager that not all types of trees could be used for the simulation and that edible trees needed to be planted instead. As a result, the initial tree suggestions from the provider were modified to maintain the same thermal performance while also meeting the manager's requirements.

The correlation findings revealed that the coproduction of knowledge through a collaborative process led to the developing of a process-based product. This product aimed to facilitate the identification of priorities by addressing the identified needs. It became apparent from this correlation that improving the thermal performance of the frequently used spaces, as mentioned by the users, became crucial in enhancing the coproduced product. Also, using specific types of trees became apparent according to the manager's requirement.

This aligns with Vincent et al. (2018) and Loeffler (2021), that understand that the coproduction of knowledge is a collaborative process that enhances the relevance and credibility of the generated knowledge. As a result, the process-based coproduced product emerged aims to define priorities from various perspectives to ensure the sustained usability of the product (Wall, Meadow and Horganic, 2017; Vincent *et al.*, 2018).

6.2.3. The Thermal Performance of the Optimized Solutions and Recipients' Preference Correlate

The involvement of Abdeen Square users has been invaluable in developing a contextual, co-produced climate service. By presenting proposed solutions to the users and requesting their preferences, they were actively engaged and provided valuable insights into their preferences, reasoning, and areas for improvement.

Most of the users selected the geometric-equidistant arrangement, as shown in (Figure 51), which also demonstrated the optimum average reduction of thermal sensation, transitioning from feeling very hot to feeling hot, as illustrated before in (Figure 47).

Presenting the differences between the four proposed solutions using 3d visuals before user selection instilled a sense of trust and curiosity among the users, prompting them to ask additional questions to gain a deeper understanding of each solution before making their preference known. This aligns with Wall, Meadow, and Horganic (2017) and Vincent et al. (2018) arguments that the co-producing knowledge process is collaborative, aiming to reach a process-based outcome that requires active communication and continuous knowledge exchange and learning that enables trust between different stakeholders.

However, to accommodate the needs mentioned before and the preferences of users regarding the trees' arrangements, their desire for increased green elements in their preferable zones (Figure 46), the green lawns, and the main path, as well as the constraints set by the cafes' manager' regarding the trees in front of the cafes (Figure 52), a solution has been developed. Knowledge co-production is a collaborative process that aims to reach a context-based solution through the continuous exchange of knowledge, which help in identifying where such refinement is required, as mentioned by (Vincent *et al.*, 2018; Zurba *et al.*, 2021).

6.2.4. The Hard System and Soft System Approach Correlate

The research highlighted the significant value of weaving between soft and hard systems in enriching the knowledge coproduction process. By integrating knowledge from both systems, a more contextual outcome was achieved. This value was realized when each stakeholder brought their expertise to the table. Therefore, it was crucial first to map out the competent stakeholders involved. This aligns with Vincent *et al.*, (2021) discussion on the importance of identifying the stakeholders who will be impacted by a decision and have the authority to enable or constrain action. By understanding their roles and perspectives, more comprehensive and inclusive coproduced knowledge can be attained. Also, it was crucial to manage the time boundaries of the two phases to reach the value of the integration between the recipients and providers through the process. This management ensures that the co-produced knowledge is timely managed through the process cycle (Wall, Meadow and Horganic, 2017).

To sustain the value of knowledge co-production, choosing a language that all users could comprehend before undertaking the empirical study was essential. This ensures effective communication and collaboration among stakeholders, promoting a more robust and meaningful knowledge coproduction process.

The integration of Grasshopper in assessing the thermal performance of the current situation and the optimized and developed solutions for Abdeen Square offered valuable insights despite its limitations. By conducting an onsite survey and utilizing 3D visuals (Figure 32), the results became more comprehensible and accessible to a wider audience. Also, the value added from both systems was sustained by using more easily understandable language instead of technical jargon.

Using contextual language that is easily understood is crucial to ensure the understanding of key concepts. Integrating users' participation using different mobilizing tools, such as on-site surveys, is essential, as mentioned by Vincent et al. (2021) and Korhonen-Kurki et al. (2022), to sustain contextual co-produced knowledge. These findings demonstrate that the combination of both systems optimizes the thermal performance of Abdeen Square. This optimization improves its thermal performance and emphasizes its value and potential utilization.

Also, the tangling between the epistemological and ontological background of users in the context of Abdeen Square has resulted in the emergence of new co-produced knowledge. This integration and collaboration between the provider and recipients fostered a comprehensive understanding of the situation, therefore, a new co-produced knowledge. The importance of bringing diverse participants with different epistemological and ontological backgrounds was argued by Vincent *et al.* (2021) as essential to ensure the inclusivity of the co-produced knowledge.

6.2.5. The Co-produced Knowledge between Thermal Performance and User Suitability

The intertwining of different backgrounds has led to a new spatial arrangement of trees in Abdeen Square to optimize its thermal performance. This innovative solution (Figure 53), driven by co-produced knowledge, is more thermally optimum and more applicable to the diverse stakeholders involved. As a result, the outcome is more contextual and tailored to meet the needs of all parties involved. The solution showed its effectiveness regarding thermal performance by comparing it to the optimum solution resulting from the simulation (Figure

54). It also considered the user suitability regarding the preferred spaces' thermal performance, specifically the green lawns and the main path, and the concerns for specific trees’ spatial location. This highlights that the co-production process is a flexible process leading to more tailored contextual and goal-oriented co-produced knowledge where flexibility means opening to change plans (Fazey et al., 2014) by being more problem-focused (Norström et al., 2020) according to the specific context and needs (O’Connor et al., 2019; Norström et al., 2020).

This new co-produced knowledge gave a new insight regarding the term "optimization," as previously, the concept of "optimization" was limited to a one-way process achieved through simulation. However, through this collaborative effort, the meaning of optimization has expanded. It now encompasses not only the thermal performance of Abdeen Square but also the optimum solution for diverse users, which is applicable in real-life situations.

Chapter 7: Conclusion: Towards a Co-produced Knowledge for Outdoor Space Thermal Performance.

This study aims to reduce the gap between climate service providers and recipients while designing or developing outdoor spaces. It advocates for a more inclusive and collaborative process between the climate service provider and recipients to ensure the integration of different knowledge and expertise, aiming to reach an optimum solution for the outdoor space landscape setting, considering thermal performance and user suitability.

Based on the wide-ranging literature reviewed, Thermal comfort is considered one of the most fundamental qualities affecting outdoor space utilization. It also showed different climate scientists' and urban designers' previous works to optimize the thermal performance of the outdoor space setting to enhance its utilization. Co-production of Knowledge is a process that ensures collaboration between climate providers and different stakeholders to sustain an ongoing negotiation, resulting in more reliable knowledge that can be used in real-life situations. This study investigates the co-produced knowledge impact in optimizing the tree spatial arrangement to enhance the outdoor thermal performance of Abdeen Square.

A methodological approach was used to achieve this objective that integrates hard system and soft system tools to ensure the presence of knowledge from the climate service provider and consumer during the empirical study. As a research initiation, the simulation and recipients profile toolkit were investigated to determine the tools and methods used throughout the study.

The methodological approach then divided the empirical study into two sequential phases. The first phase, "Co-Explore the Needs," aimed to assess the current thermal performance of Abdeen Square and, on the other hand, the user suitability regarding the recipients' needs.
The second phase, "Co-Develop Solution," aimed to assess the thermal performance of the optimized solution and, on the other hand, the recipient's preference regarding the user preference concerning the optimized solution, also the applicability of applying the optimized solutions on Abdeen Square. Finally, a developed solution resulting from the co-produced knowledge was assessed to investigate its impact on the thermal performance of Abdeen Square and user suitability.

The discussion then colligated both phases to identify the impact of co-produced knowledge on optimizing the spatial arrangement of trees and enhancing outdoor space utilization.

The analyzed findings found that the interrelation between the diverse knowledge of the provider and recipients resulted in new co-produced knowledge that was more contextual and usable in real-life situations. The finding also highlighted the significant value of weaving between soft and hard systems to enrich the knowledge coproduction process and reach a more contextual and goal-oriented outcome. It was found that the provider gave technical insights regarding the thermal performance of Abdeen Square, ways of optimizing it, and the optimum solution regarding the thermal performance. While these insights were enriched by the recipients, who put new knowledge into the process regarding the users' suitability by giving new insights regarding the space usability, their needs, and their preferences regarding the optimized solution and the knowledge from the managers regarding their needs and preferences. This resulted in a developed solution that is more contextual and sustains the thermal performance and the user suitability, thus enhance the utilization of Abdeen's Square.

Based on these research findings, a set of implications and recommendations for future research and urban design practices for outdoor space design are outlined:

1. The thermal performance of outdoor spaces is a critical factor that significantly influences their utilization. As such, it is crucial to establish comprehensive guidelines incorporating microclimate-responsive landscape design principles into the design and redevelopment of outdoor spaces. Such guidelines will enable the creation of outdoor environments that enhance their utilization. Also, ensuring the participation of various stakeholders while designing or redeveloping outdoor spaces is included in those guidelines to ensure the design's suitability.

2. Strengthen the linkage between thermal performance and user suitability through the ongoing negotiations and continuous transferability of knowledge between the climate provider and the various stakeholders to ensure the creation of optimum solutions for the

utilization of outdoor spaces. The absence of diverse stakeholders in designing or developing outdoor spaces can lead to non-contextual solutions suitable for the needs and expectations of the community. Consequently, it is crucial to prioritize integrating diverse stakeholders throughout these processes to create optimum solutions for utilizing outdoor spaces.

3. The methodological approach can be applied in future similar research as it proved to be very efficient in integrating the two systems to reach more reliable co-produced knowledge that can be applied in real-life situations. At the same time, the hard system approach through simulation provides technical knowledge regarding thermal performance by allowing for comparative measurements of the thermal performance of outdoor space. On the other hand, the soft system approach through the on-site survey and structured interview provides a deeper understanding of user suitability by understanding the recipients' needs and views, verifying or negating the optimized solutions that the simulation alone would not demonstrate.

4. The grasshopper tool and its plugins have acceptable accuracy in assessing outdoor thermal comfort (Yazıcıoğlu and Dino, 2021). It was used due to the time limitation, as its simulation period is limited compared to other tools, such as ENVI-met (Pacifici and Nieto-Tolosa, 2021); however, given the limitation mentioned previously about the grasshopper's ability to assess the thermal performance of the tree. The study encourages conducting this study later using the Envi-Met tool for a more acceptable result.

5. The study encourages a comparative study within the same country to show how co-produced knowledge is unique in itself by its context

specifications. The study encourages investigating the impact of co-produced knowledge in different outdoor space contexts, showing the different results in trees' spatial arrangement optimization to enhance the outdoor thermal performance according to a specific context. The co-produced knowledge resulting in this study is very particular to Abdeen's Square context-specific setting regarding the chosen trees, user needs and perceptions, and the stakeholders involved in the process, which represents a substantial urge for application in other contexts. These studies can be carried out in outdoor spaces of other typologies as new urban communities to contrast the urban structures and social fabric in co-producing different knowledge specific to the context.

In conclusion, outdoor spaces offer their users diverse activities which enhance their well-being; however, space utilization is directly affected by the thermal performance of the outdoor space and its suitability for the user. The thermal performance of outdoor spaces must be addressed while designing or developing an outdoor space. Hence optimizing the micro-climatic landscape setting while designing outdoor spaces is crucial to enhance its thermal performance and user suitability. To achieve this optimization, the integration of diverse stakeholder knowledge is crucial. An optimized solution in our complex world could not be reached through technical knowledge only while neglecting real-life knowledge and vice versa. Optimizing a setting is not only about reaching a setting from a one-way approach, but it is more about reaching out to new co-produced knowledge which is more contextual and goal-oriented, resulting in a recipient acceptance and an optimum experience while utilizing the outdoor space.

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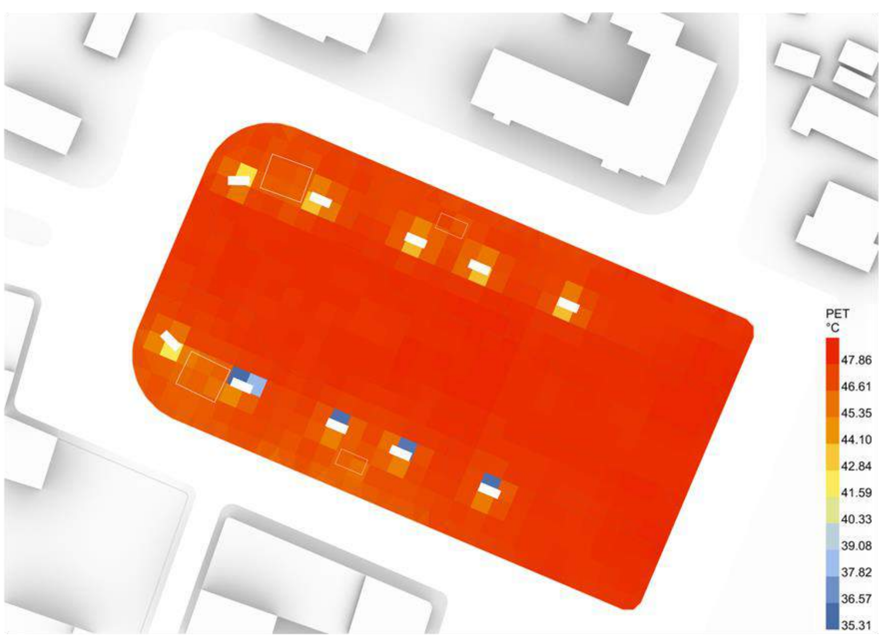
Appendix 1

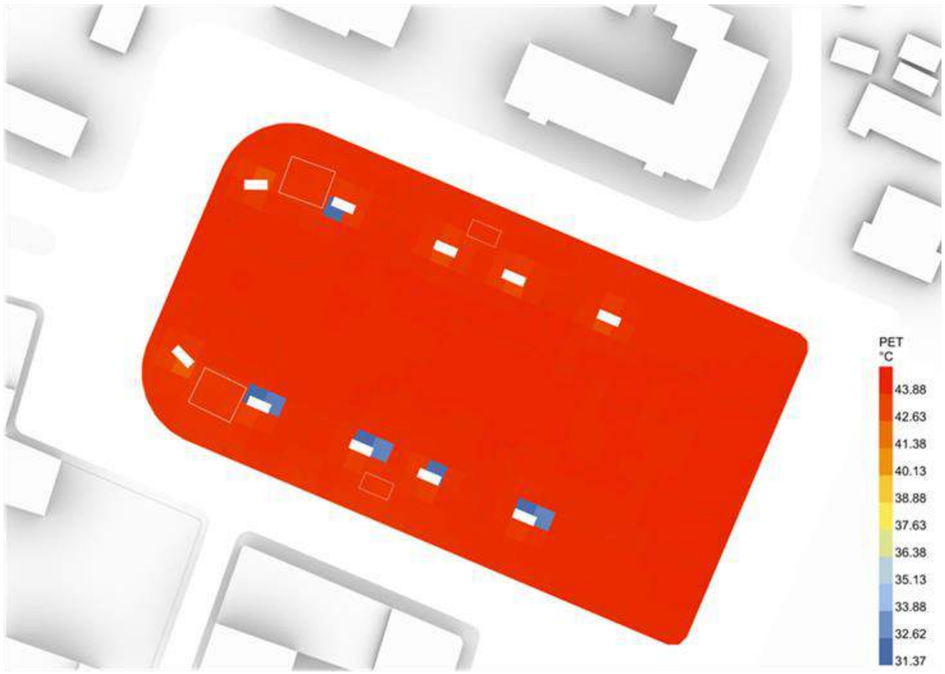
PET Values of the No Vegetation Scenario (°C)

At 12:00 pm

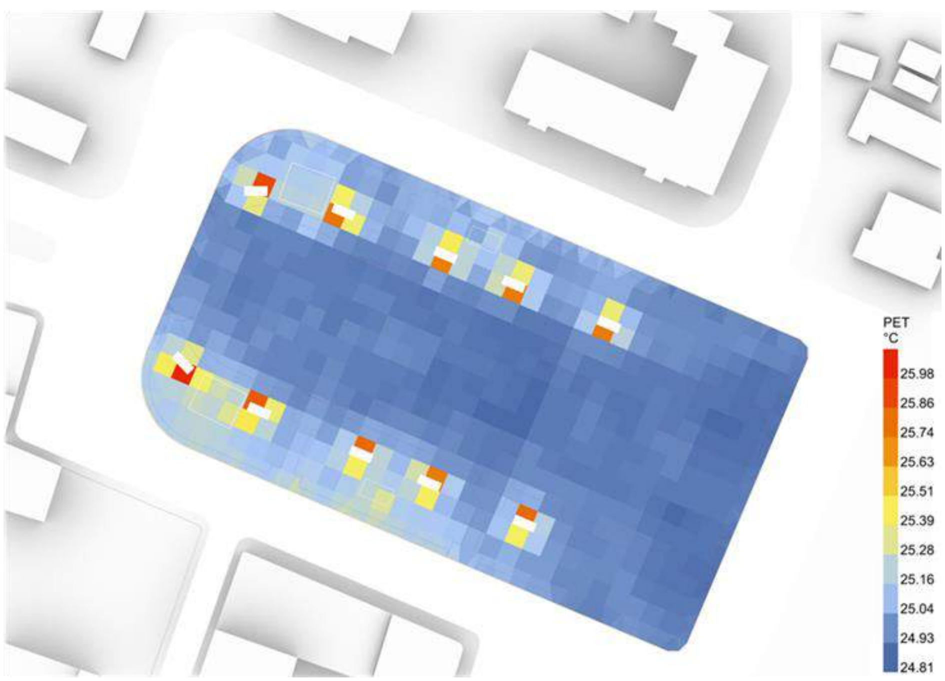


At 2:00 pm

PET Values of the No Vegetation Scenario (°C)



At 4:00 pm



At 7:00 pm

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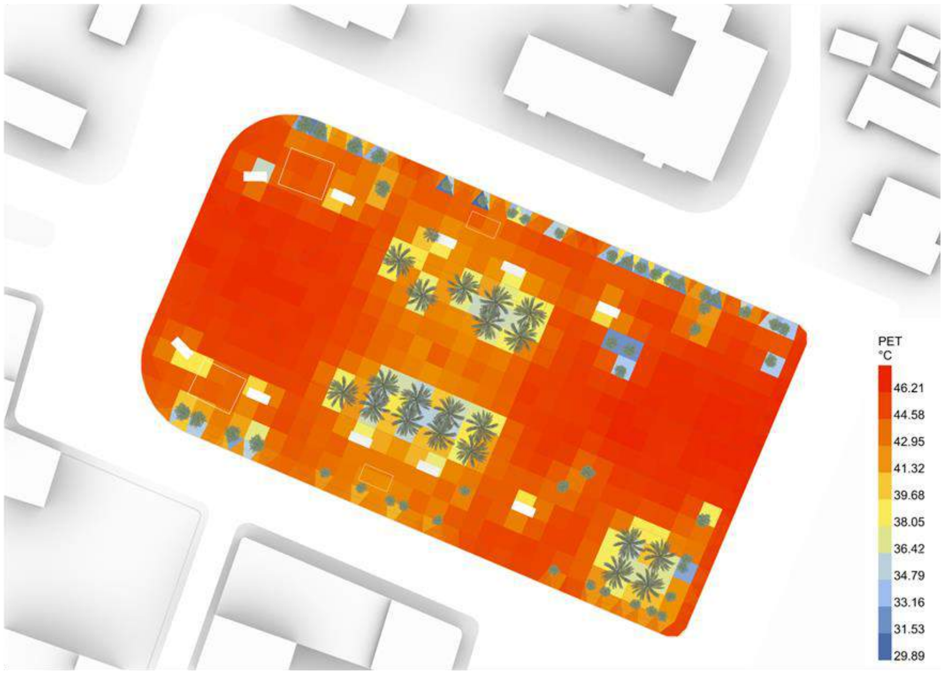

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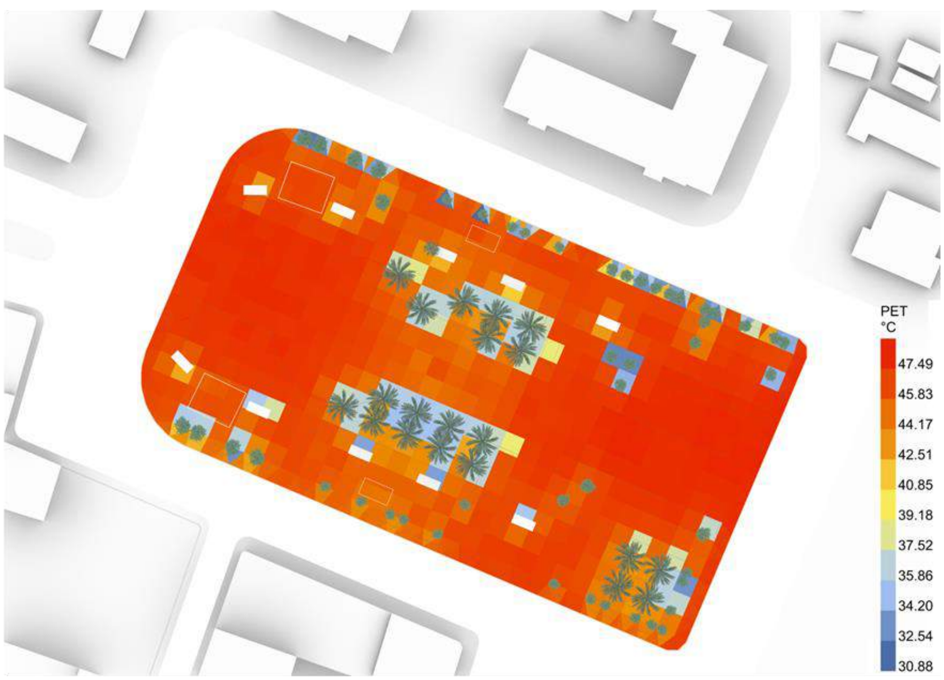

At 2:00 pm

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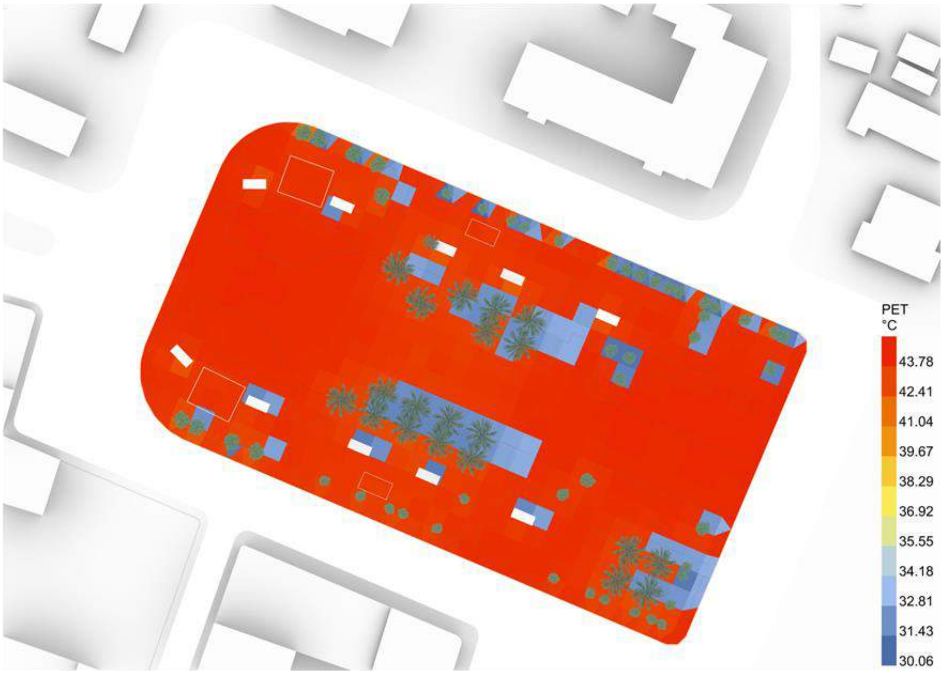

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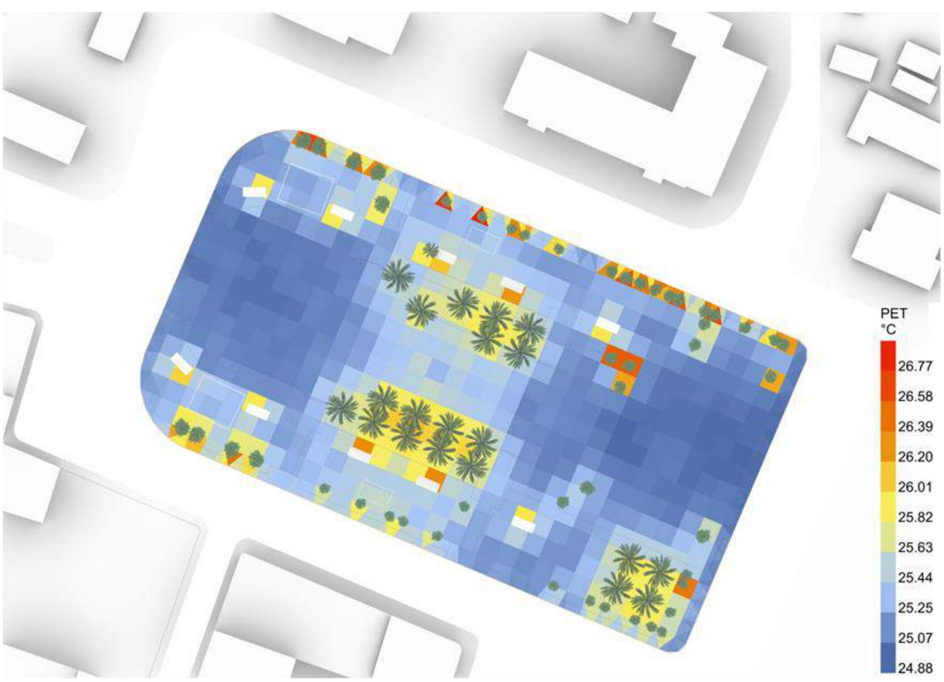

At 7:00 pm

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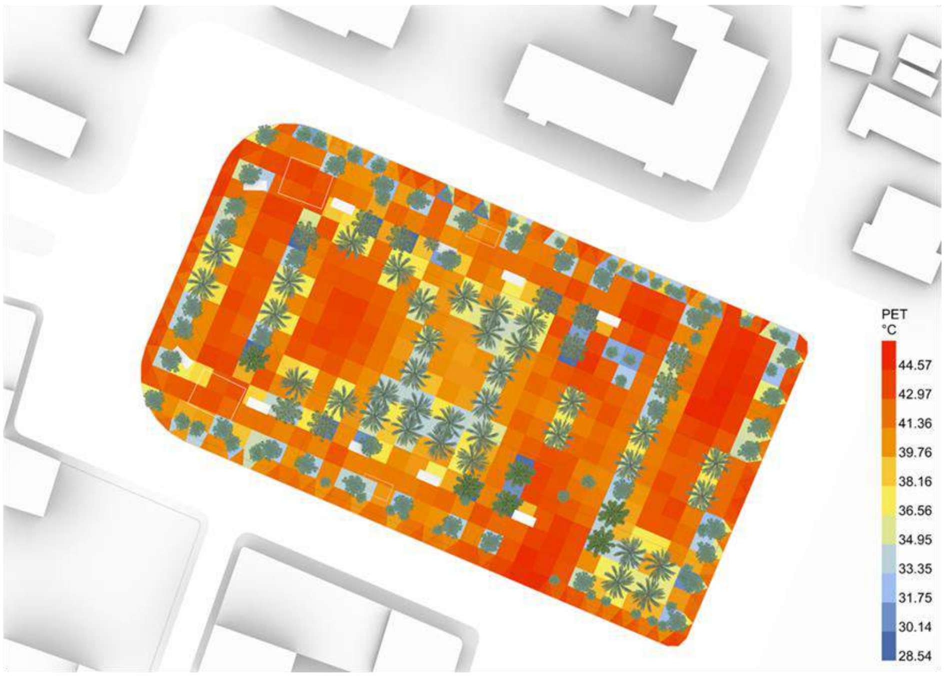

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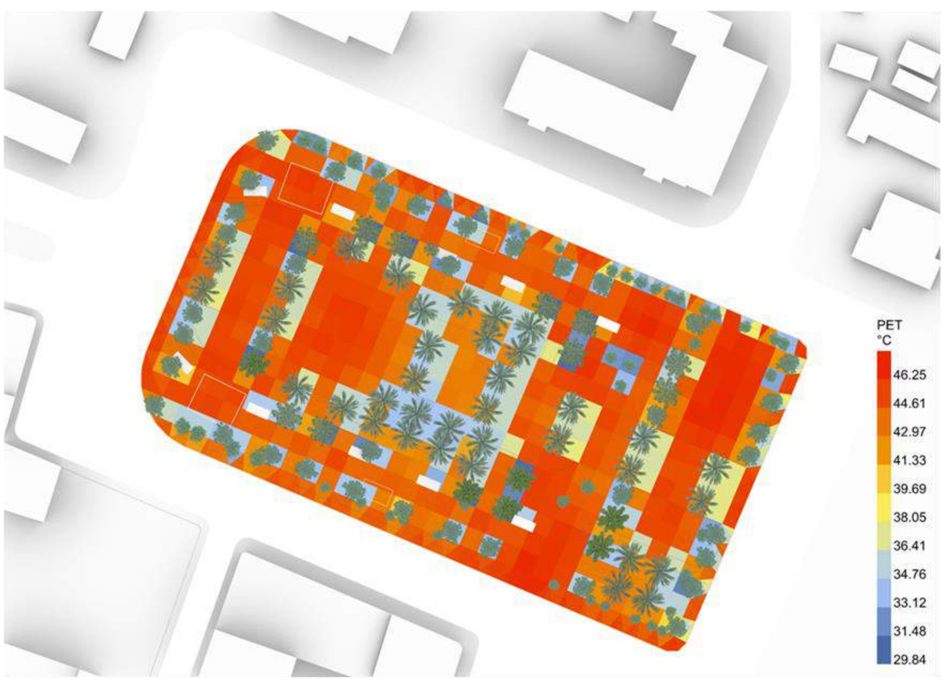

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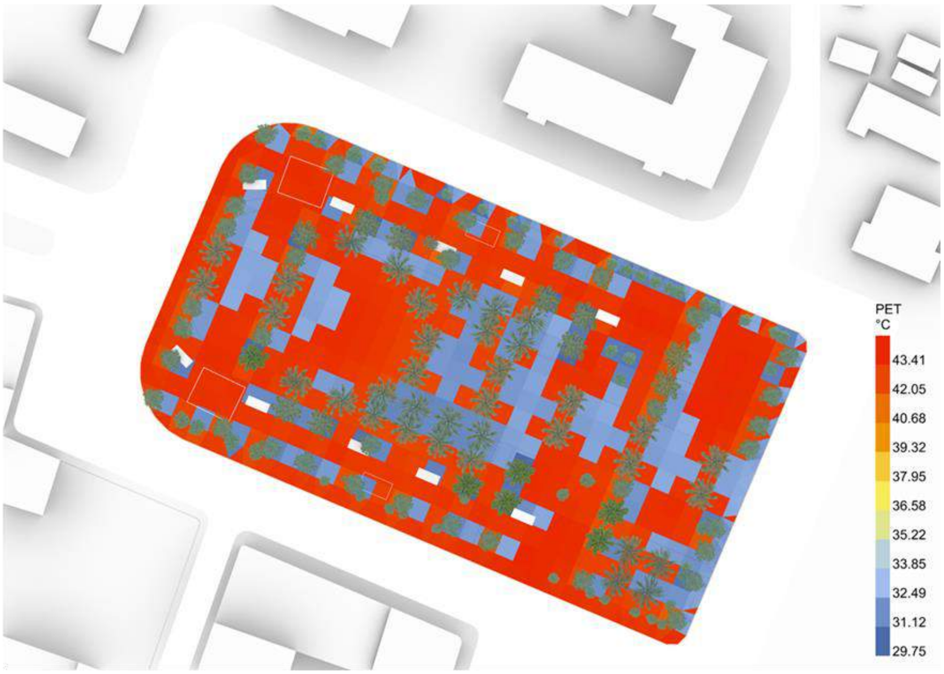

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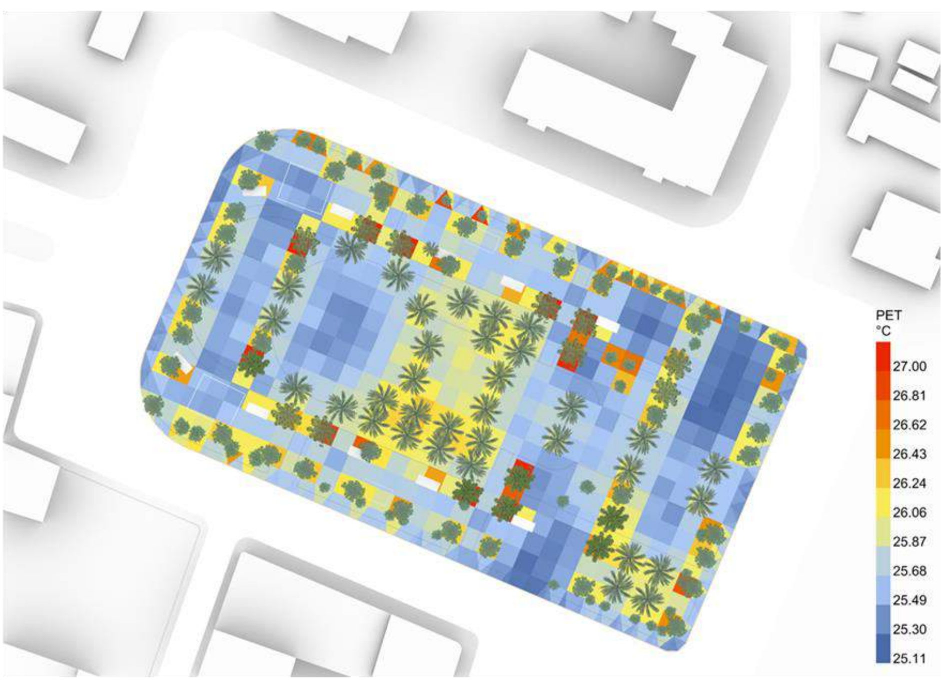

At 7:00 pm

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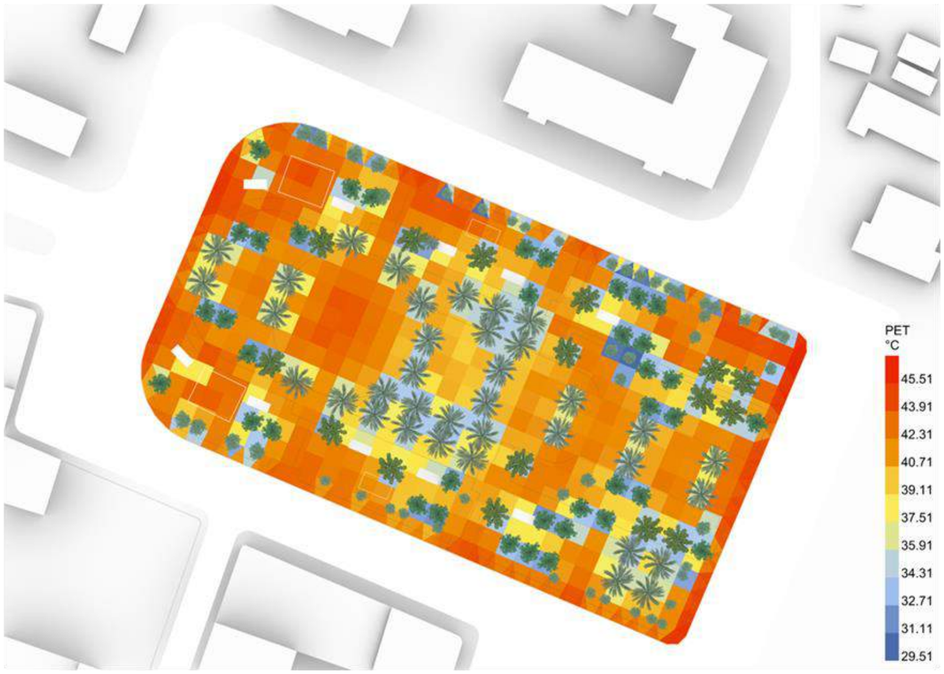

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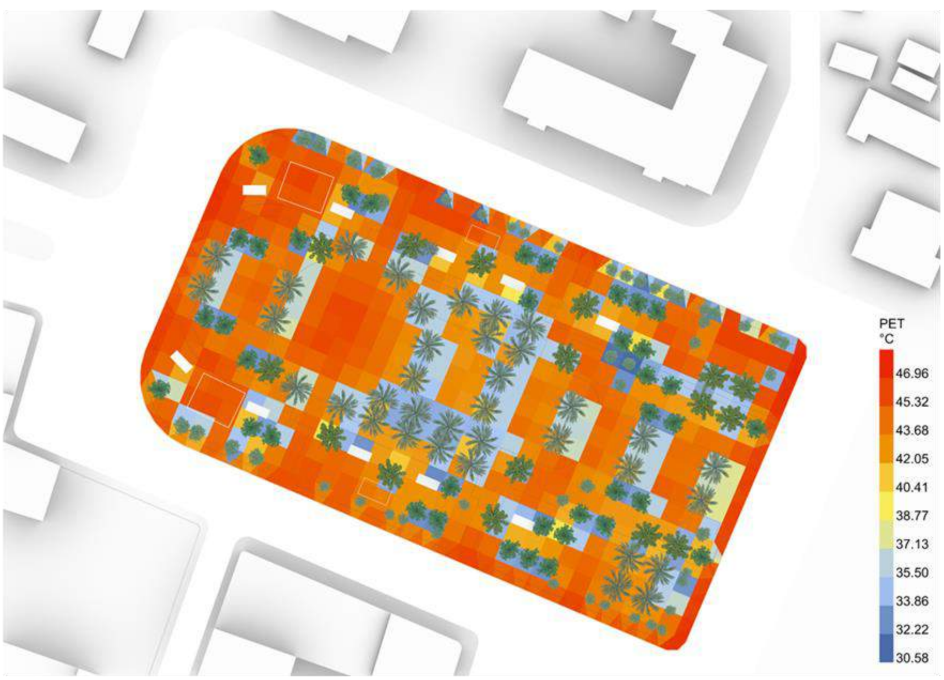

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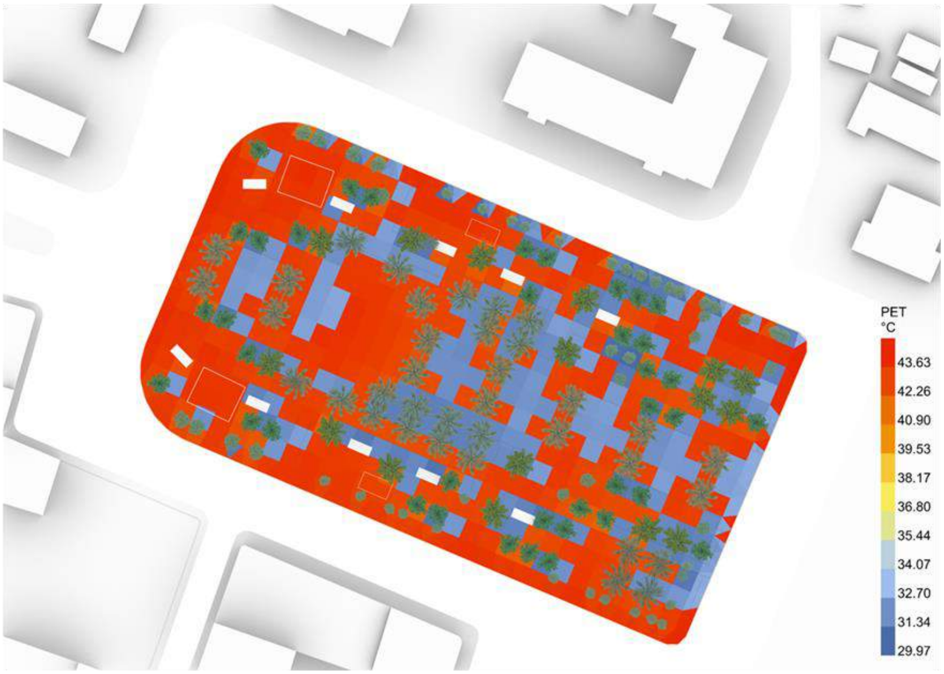

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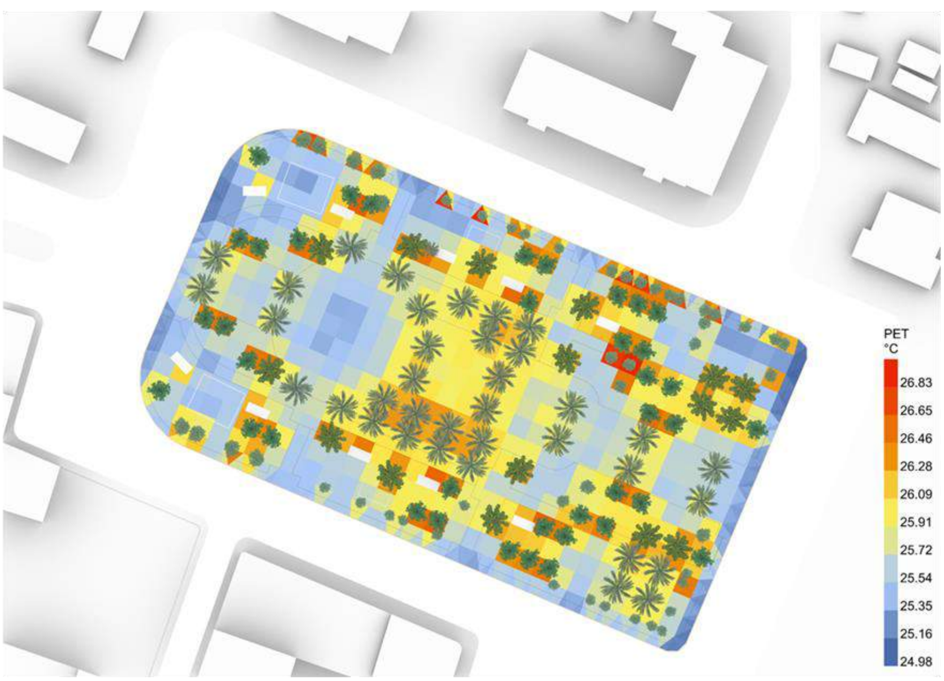

At 7:00 pm

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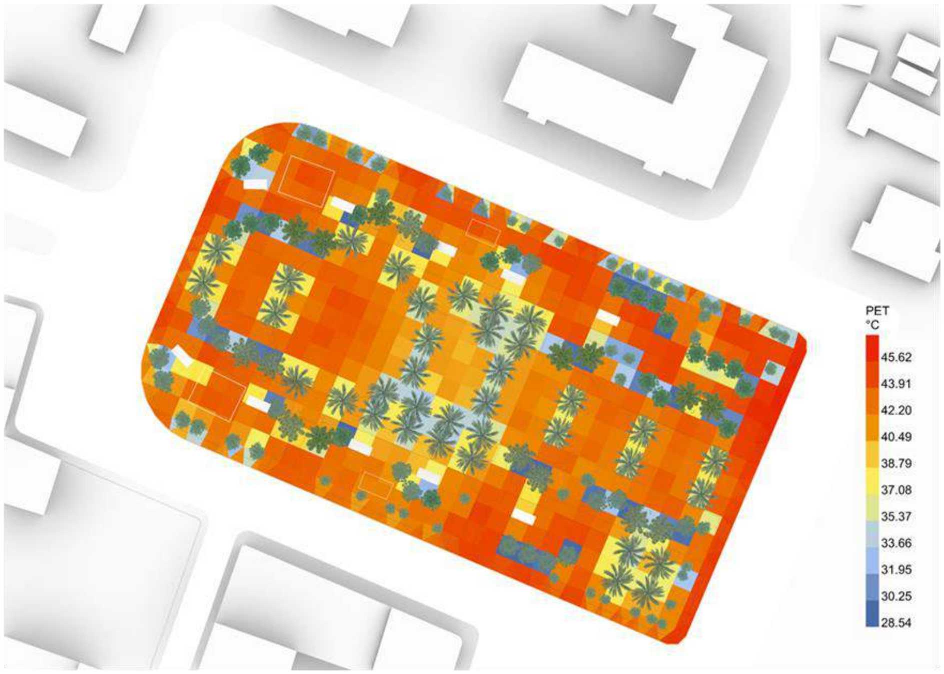

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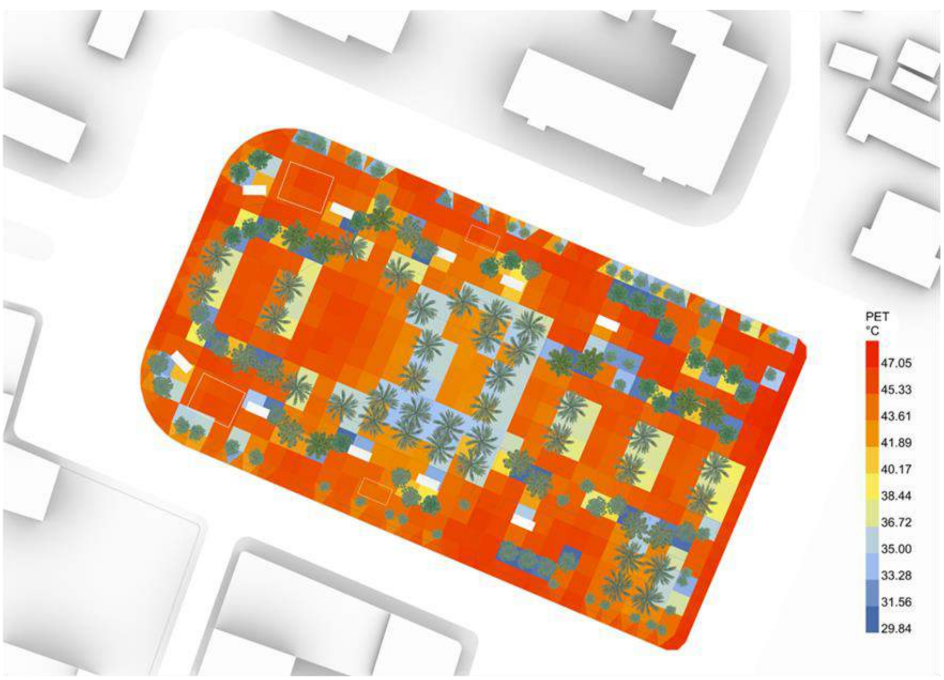

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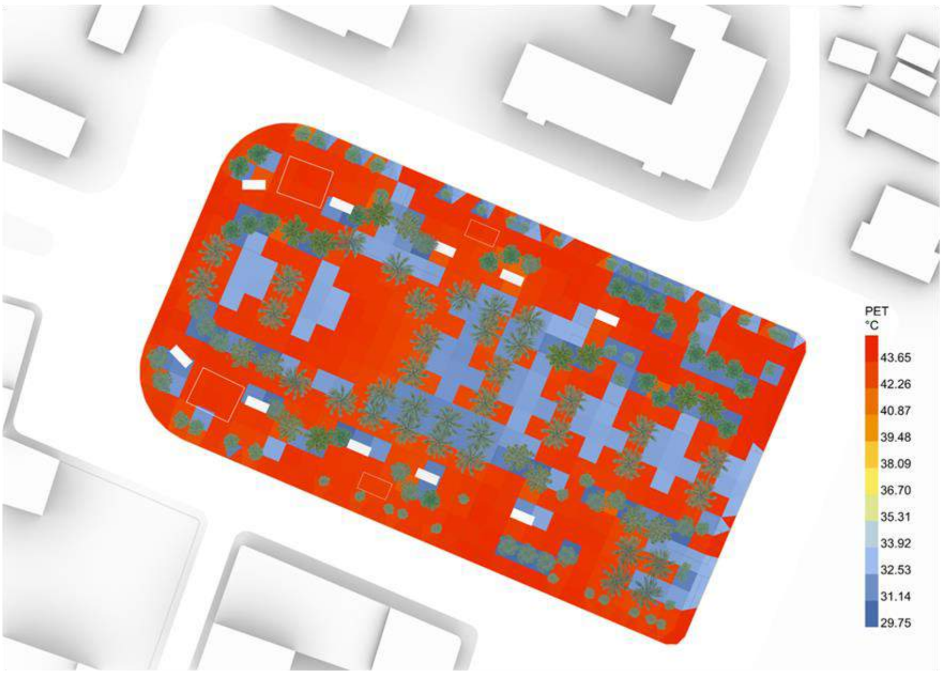

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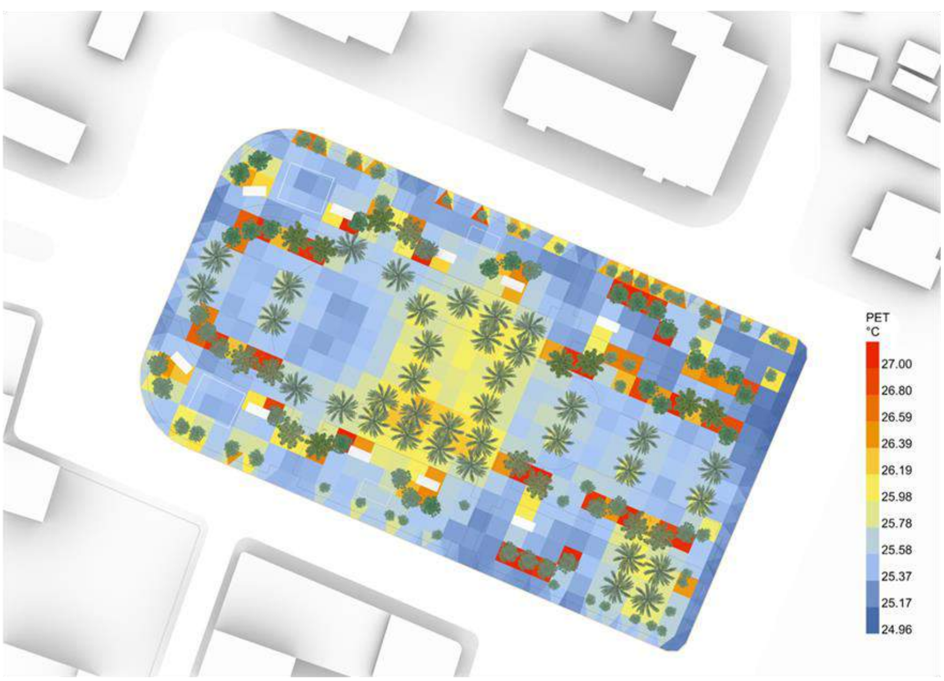
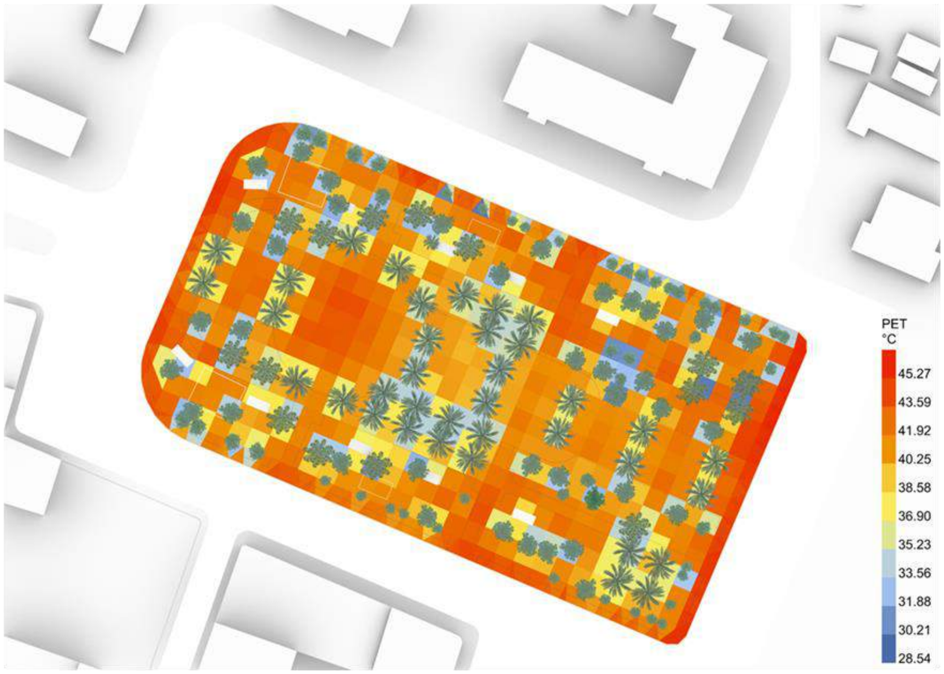


At 7:00 pm

PET Values of the Random Scenario (°C)



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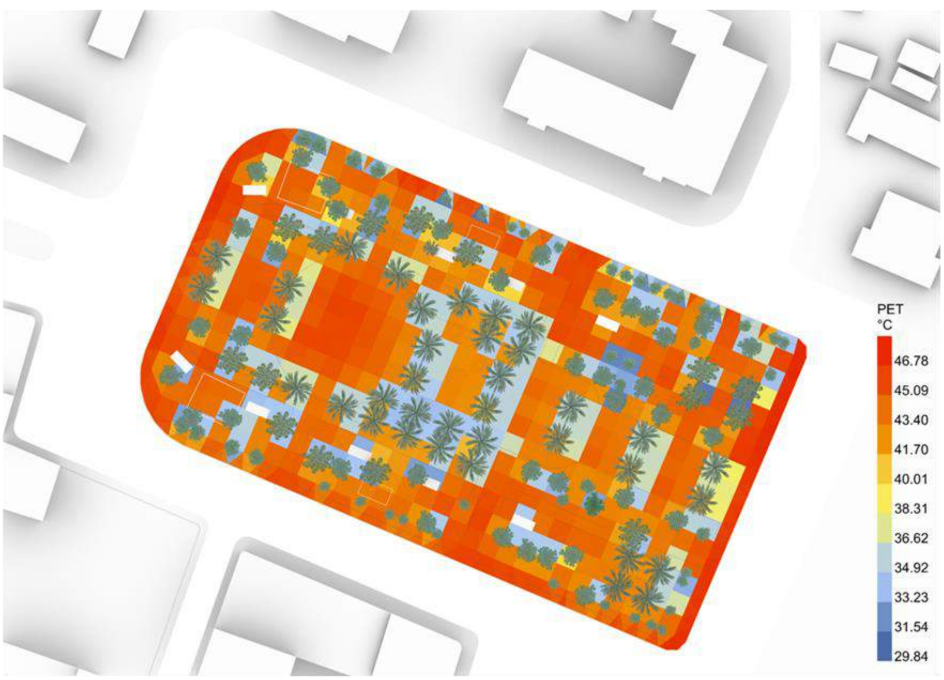

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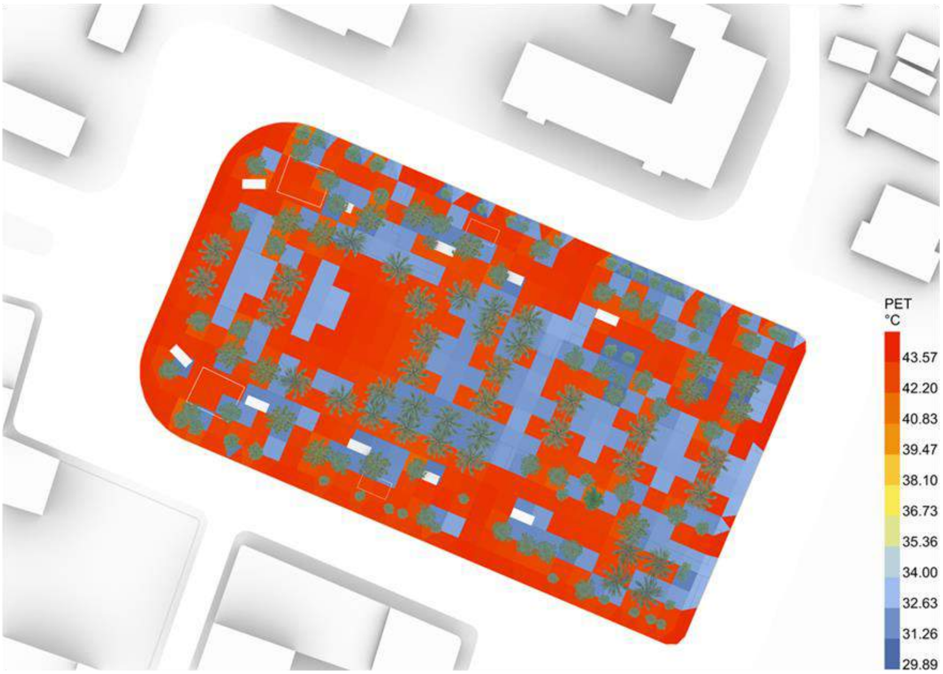

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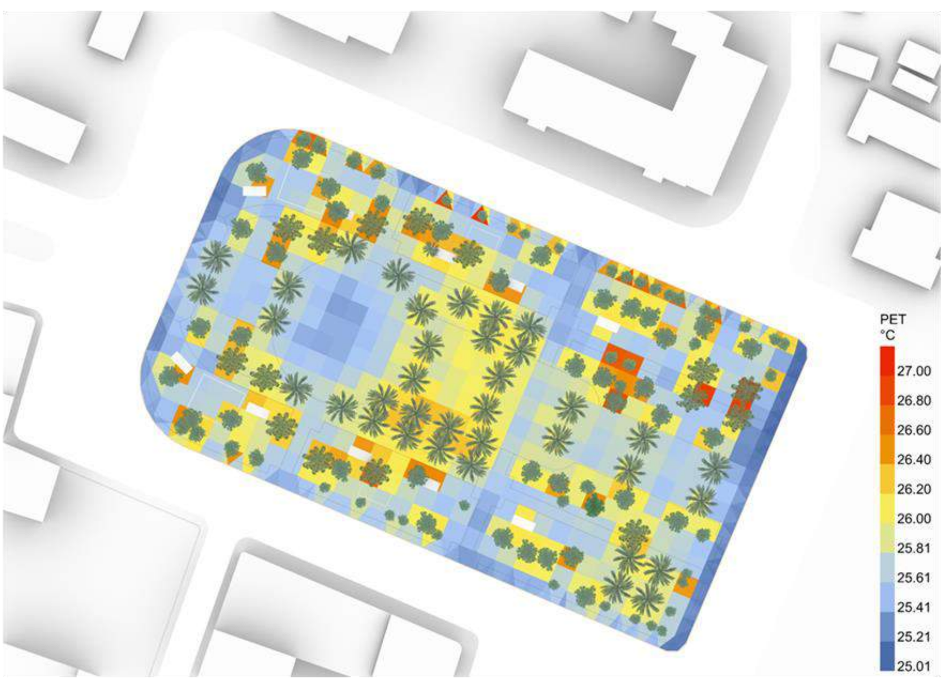
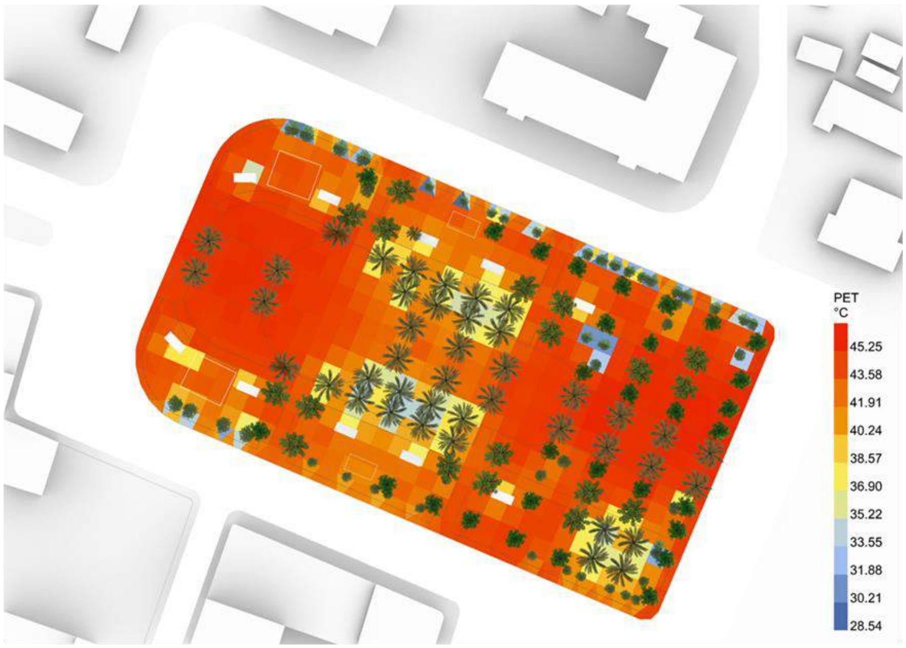


At 7:00 pm

PET Values of the Developed Scenario (°C)



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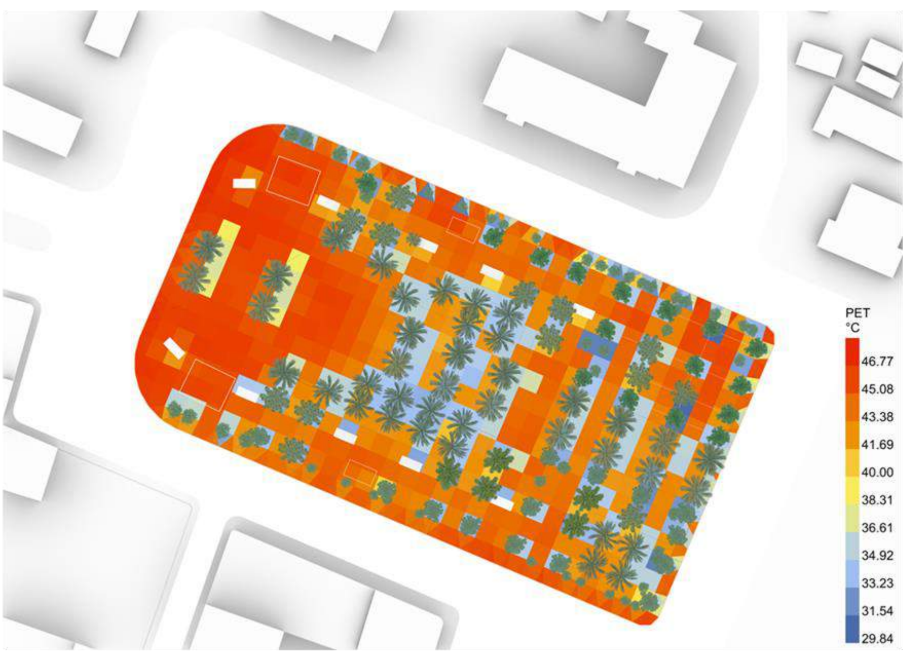

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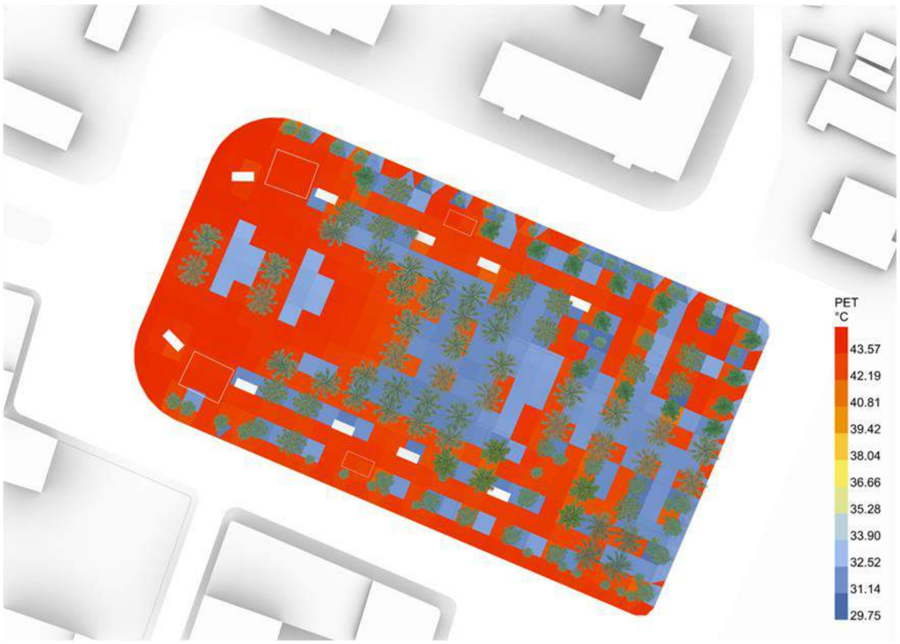

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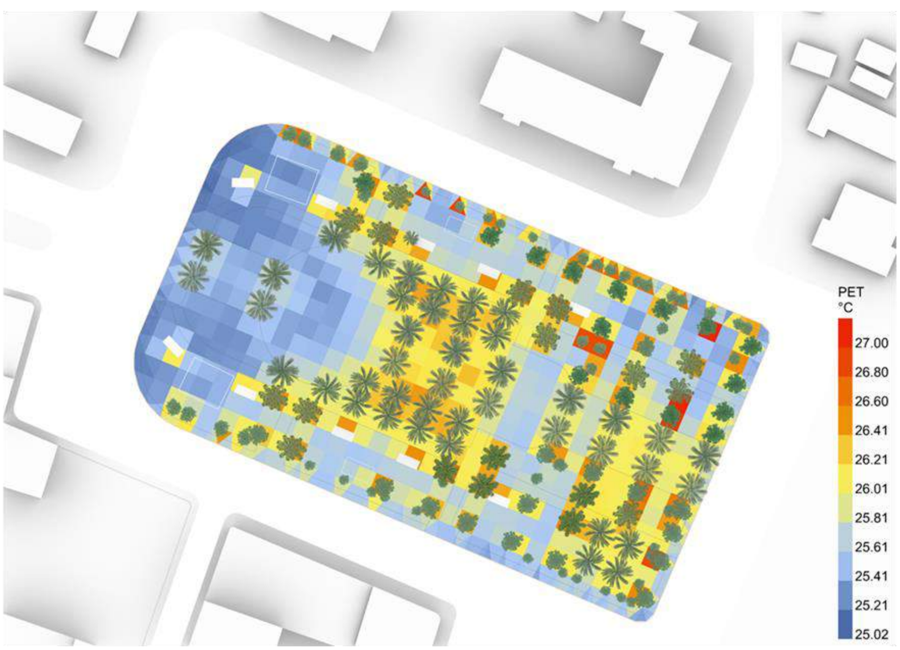


At 7:00 pm

Appendix B

On-Site Survey Questions	
Section 1: Getting to know the user	
Question 1: Age	
Younger than 13	13-19
20-30	31-44
45-60	Over 60
Question 2: Gender	
Male	Female
Question 3: Are you from?	
Employee at Abdeen square	Visitor of Abdeen sqaure
Section 2 :Space Usability & User Needs	
Question 4: What are the reasons you visit Abdeen square?	
Relaxation	Social interaction
Doing exercises	Enjoying nature
Work/Study	Other
Question 5: What activities do you prefer to do in Abdeen square?	
Sitting	Eating
Playing	Taking photos
Jogging	Other
Question 6: What is your favorite time to visit Abdeen Square?	
(6:00 am to 12:00 pm)	(12:00 pm to 6:00 pm)
(4:00 pm to 7:00 pm)	(7:00 pm to 12:00 am)

Question 7: Where do you prefer to stay in Abdeen Square?	
 Cafes	 Secondary path
 Main path	 Kids area
 Green lawns	

Question 8: How do you rate the level of attractiveness of the place?
(5) indicates that the quality of the place is very good, and (1) indicates that the quality of the place is very bad

1	2	3	4	5

Question 9: Which factors do you consider to increase the attractiveness of the square?	
Increase proportion of green elements	Increase shading
More seating capacity	Facilities (cafes - shops - kids area - etc.)
Other	
Question 10: Do you think the percentage of green areas and trees is enough?	
Yes	No
Question 11: **If your answer is no, In your opinion, what are the places that need an increase in the percentage of green elements?**	
 Cafes	 Secondary path
 Main path	 Kids area

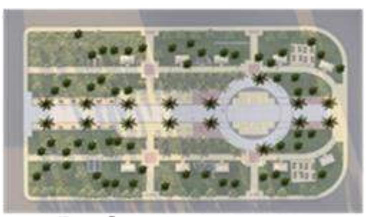
Green lawns

Question 12: What other outdoor spaces do you prefer to visit? Why?

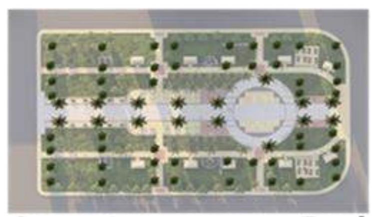
Section 3: Users' Preference

Question 13: Which arrangement of the trees do you prefer?

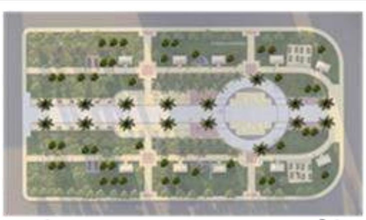
Question 14: What is your arrangement for the following proposals to increase the thermal comfort of Abdeen Square?



Random Arrangement



Geometric arrangement - Equal Interval



Geometric arrangement - unequal interval

Clustered arrangement

Question 15: What is the reason for your preference for the chosen proposal?

Question 16: Do you have any suggestions to improve the proposal you have chosen?

Question 17: If your answer is yes, what are these suggestions?

نبذة

كيف يمكن استخدام عناصر المناظر الطبيعية للمناخ الصغير لتحسين الأداء الحراري للفراغ الخارجي؟ كيف يستخدم المستخدمون الفراغ الخارجي؟ هل هذا الحل الأمثل مناسب من حيث السياق للمستهلكين الذين يستخدمون المساحة الخارجية؟ يجب طرح الأسئلة من قبل كل مقدم خدمة مناخ ومصمم حضري أثناء تصميم أو تطوير الفراغات الخارجية، خاصة في عصر تغير المناخ .تهدف هذه الدراسة إلى تقليل الفجوة بين مقدمي خدمات المناخ والمستهلكين أثناء تصميم أو تطوير المساحات الخارجية .وهي تدعو إلى عملية أكثر شمولاً تهدف إلى الوصول إلى حل مثالي للمناظر الطبيعية للفضاء الخارجي على وجه التحديد الترتيب المكاني للأشجار، لتعزيز الأداء الحراري للمساحة الخارجية .عملية الإنتاج المشترك تهدف إلى تحقيق حل سياقي أكثر من خلال دمج المعارف والخبرات المتنوعة للموردين والمستهلكين . أجريت الدراسة في ساحة عابدين، وهو فراغ خارجي تم تطويره مؤخرًا .تبحث الدراسة في تأثير المعرفة المنتجة بشكل مشترك في تحسين الترتيب المكاني للأشجار لتحسين الأداء الحراري الخارجي لساحة عابدين .نتيجة لذلك، تم استخدام منهجية متكاملة لضمان وجود معرفة متنوعة أثناء الدراسة التجريبية .تم تقسيم الدراسة إلى مرحلتين متتاليتين، حيث تم استخدام" جراسهوبر "كأداة محاكاة لتقييم الأداء الحراري . بينما تم استخدام استطلاع رأى ميداني ومقابلة شبه منظمة للتحقق من مدى ملاءمة المستخدم .نتيجة لذلك، تم العثور على مجموعة من النتائج المتعلقة بالأداء الحراري لساحة عابدين وملاءمة المستخدم، والتي تم تحديدها ثم ربطها .نتج عن العلاقة المتبادلة بين المعرفة المتنوعة في ميدان عابدين معرفة جديدة منتجة بشكل مشترك والتي كانت أكثر سياقية وقابلة للاستخدام في الحياة الواقعية، مما أدى إلى تحسين الترتيب المكاني للأشجار مع مراعاة الأداء الحراري وملاءمة المستخدم، وبالتالي تعزيز الاستفادة من ساحة عابدين .في هذا السياق، يجب أن يكون تصميم أو تطوير المساحات الخارجية مصحوبًا بإعطاء الأولوية لإدماج أصحاب المصلحة المتنوعين الذين لديهم معرفة وخبرات مختلفة في جميع مراحل هذه العمليات لضمان إنشاء المزيد من الحلول المناسبة للسياق والأمثل لأستخدام المساحات الخارجية .

الكلمات الرئيسية: الإنتاج المشترك - الأداء الحراري - ملاءمة المستخدم - استخدام الفراغ الخارجي - الترتيب المكاني للأشجار

إقرار

هذه الرسالة مقدمة في جامعة عين شمس للحصول على درجة العمران المتكامل والتصميم المستدام. إن العمل الذي تحويه هذه الرسالة قد تم إنجازه بمعرفة الباحث سنة 2023

هذا ويقر الباحث أن العمل المقدم هو خلاصة بحثه الشخصي وأنه قد اتبع الإسلوب العلمي السليم في الإشارة إلى المواد المؤخوذه من المراجع العلمية كلٌ في مكانه في مختلف أجزاء الرسالة..

وهذا إقرار مني بذلك،،،

التوقيع:

الباحث: باترشيا جمال

التاريخ:19/07/2023

استخدام الفراغ الخارجي من خلال نهج التصميم المستجيب للمناخ المحلي

الإنتاج المشترك للمعرفة في ساحة عابدين

مقدمة للحصول على درجة الماجستير في العمران المتكامل والتصميم المستدام

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أستاذ..............
جامعة ....

التوقيع

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أستاذ..............
جامعة ....

أ.د. ....
أستاذ..............
جامعة ....

تاريخ المناقشة:...............

الدراسات العليا

ختم الإجازة

موافقة مجلس الكلية .../.../...

أجيزت الرسالة بتاريخ:.............

موافقة مجلس الجامعة .../.../...

جامعة عين شـــــمس

MM/DD/YYYY

جامعة عين شمس

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يونيو ٢٠٢٣