BEYOND MADRID'S HEAT

A Deconstruction of Madrid's Urban Heat Crisis

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AR3A010 Research Plan
AR3DC100 Architectural Design Crossovers Graduation Studio

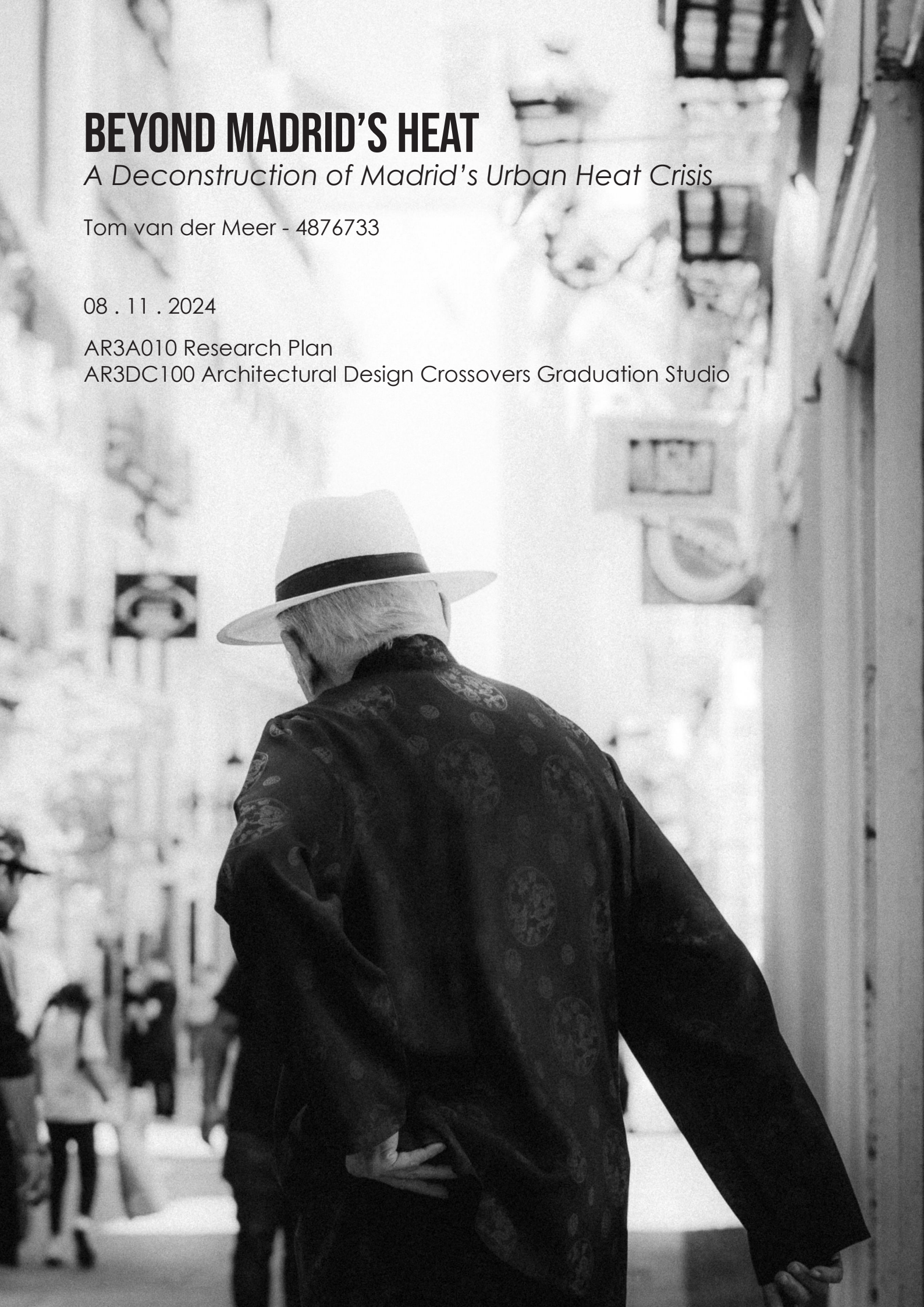

Fig. 1: *An elderly couple seeking shade.* Madrid Street Life by photographer *Lena Ivanova (2019)*

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Baja el avión por fin,	*The plane finally lands,*
estoy bajando a la ciudad de agosto.	*I am descending into the city of August.*
La sombra de las alas deja huellas azules	*The shadow of the wings leaves blue traces*
sobre la tierra seca	*on the dry earth*
y recorre los campos con una vibración	*and travels across the fields with the vibration*
de película antigua.	*of an old film.*
Estoy bajando, llego	*I am descending, I arrive*
a la ciudad tomada por los brazos desnudos,	*at the city taken by bare arms,*
[...]	*[...]*
Estoy en la ciudad del calor soportado,	*I am in the city of endured heat,*
en la ciudad que vive a ritmo de trasbordo.	*in the city that lives at the rhythm of transfers.*
[...]	*[...]*
el caribe metálico de los ventiladores,	*the metallic Caribbean of the fans,*
la sombra de sus aspas en el techo,	*the shadow of their blades on the ceiling,*
o las huellas azules,	*or the blue footprints,*
las alas del avión que vuelve a irse,	*the wings of the plane that leaves again,*
en la ciudad de agosto,	*in the city of August,*
en un piso segundo,	*on a second floor,*
en un rincón del viento.	*in a corner of the wind.*

Part of "La Ciudad de Agosto" with its English translation by *Luis García Montero*

Beyond Madrid's Heat

Keywords
Climate Adaptation
Climate Justice
Urban Climate Resilience
Urban Excessive Heat
Urban Heat Island Effect

A Deconstruction of Madrid's Heat Crisis

When settlements began to form in the region that is now Madrid during the 9th century, the area was characterized by a temperate climate with dry, hot summers and mild, cool winters, classified as a hot-summer Mediterranean climate in the Köppen-Geiger system *(Moreno et al., 2020)*. Over time, increasing human interventions transformed these microclimatic conditions. Natural land cover was replaced with more dense urban development, and anthropogenic activities and energy consumption increased. These changes led to the Urban Heat Island (UHI) effect, where urban areas retain significantly more heat than the rural surroundings. Madrid is a prime example of a city experiencing severe UHI impacts, with temperature differences between the city center and the rural surroundings of up to 8.5 degrees centigrade *(Arup, 2023)*. This has made Madrid one of the most extreme urban heat hotspots globally, with implications for infrastructure, public health, comfort, and social equity. The impacts of the UHI effect are not experienced equally. Marginalized populations are disproportionately affected, facing heightened health risks during heat waves *(López-Bueno et al., 2020)* and increased social isolation. These vulnerabilities are compounded by infrastructural challenges, as systems struggle to address the dual pressures of rising temperatures and growing energy demands. Despite these challenges, opportunities exist. Six neighborhoods, identified as housing relatively higher proportions of marginalized populations, provide potential sites for intervention. These neighborhoods present potential sites for interventions, in terms of physicality (e.g. urban excess heat recovery systems) as well as social (e.g. Barcelona's Climate Shelter Network)

Moreno, H. L., Giancola, E., & Egido, M. N. S. (2020). Evaluation of weather conditions in urban climate studies over different Madrid neighbourhoods: Influence of urban morphologies on the microclimate. Atmosphere, 11(5), 435.

Arup. (2023). Madrid suffers most extreme urban heat island hot spot, new international survey shows. Arup.

López-Bueno, J. A., Díaz, J., Sánchez-Guevara, C., Sánchez-Martínez, G., Franco, M., Gullón, P., Núñez Peiró, M., Valero, I., & Linares, C. (2020). The impact of heat waves on daily mortality in districts in Madrid: The effects of sociodemographic factors. Environmental Research, 190, 109993.

"How can **localized architectural interventions** and **urban infrastructures** address the **vulnerabilities** of **marginalized populations** in response to **Madrid's Urban Heat**?"

Mohtat, N., & Khirfan, L. (2021). The climate justice pillars vis-à-vis urban form adaptation to climate change: A review. Urban Climate, 39, 100951.

This study is framed around the principles of climate justice, specifically the pillars of recognitional, procedural, and distributive justice *(Mohtat & Khirfan, 2021)*. It aims to move beyond merely mitigating urban heat, instead leveraging it as a lens to address systemic inequities. Through a mixed-methods approach, this research will examine how urban infrastructure functions, or fails to function, in the face of extreme heat. The findings will inform the design of more inclusive and resilient urban systems.

"Addressing the **UHI effect** is not solely about reducing temperatures but also about rethinking the **socio-spatial** systems that shape cities, ensuring they are **inclusive**, **resilient**, and **just**."

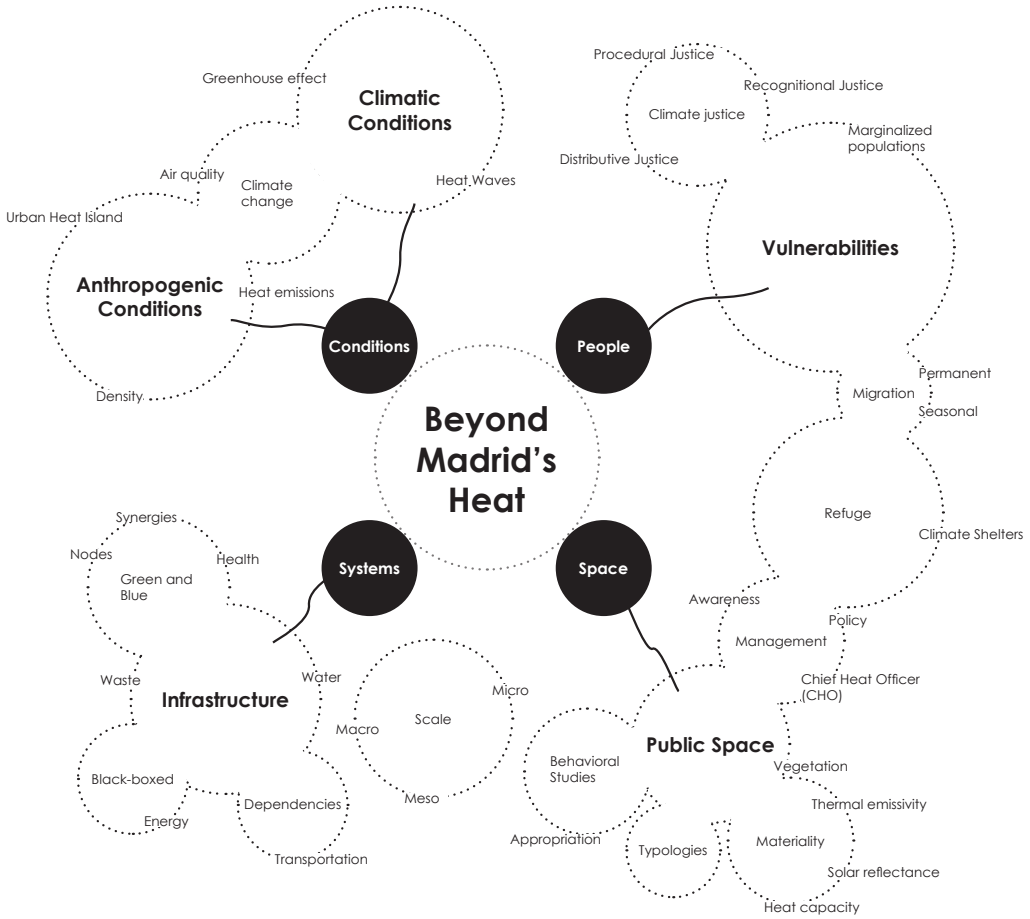


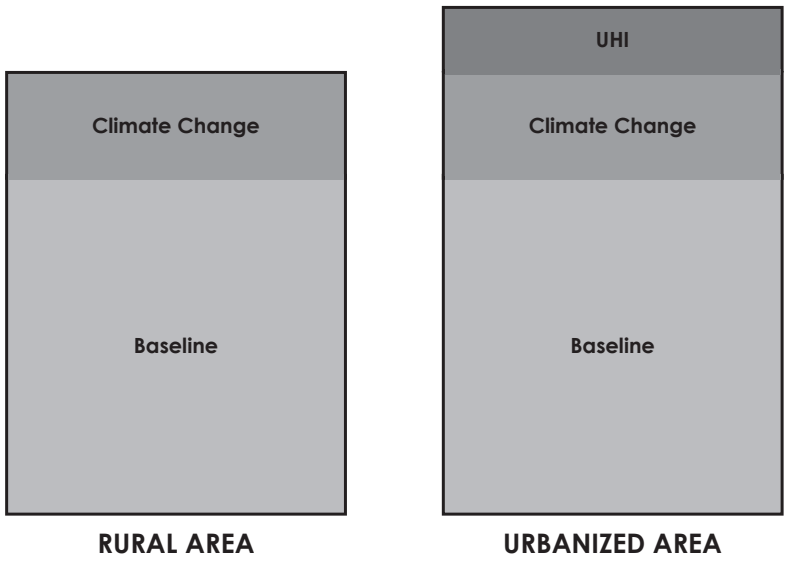
Fig. 2: *Systemic Diagram*, Showcasing the different fields associated with Madrid's Urban Heat by *Author*

Fig. 3: *Modification of Land Surfaces* , a change from cobblestone to tarmac in *Madrid's Lavapiés* by *Madrid No Frills (2023)*

Theoretical Framework

To effectively address the challenge of Urban Heat, it is essential to define and understand its origins and impacts. The "Singapore 2.0" framework *(Philipp & Chow, 2020)* suggests that urban heat is based on an elevated baseline temperature, which has increased due to climate change. These shifts in temperature are globally impactful, demanding worldwide interventions to achieve meaningful mitigation. A particular phenomenon, the Urban Heat Island (UHI) effect, differentiates urban areas

Philipp, C. H., & Chow, W. T. L. (2020). Urban heat vulnerability analysis for Singapore. ETH Zurich.



NUSEnterprise. (2022). Cooling Singapore 2.0 Building a Digital Urban Climate Twin. YouTube.

Fig. 4: *Differences in temperature between urbanized and rural* areas by Cooling Singapore 2.0 *(NUSEnterprise, 2022)*

from rural areas by significantly higher temperatures *(Fig. 4)*, which in the case of the city of Madrid can be as high as 8.5 degrees centigrade *(Arup, 2023)*. As a localized issue, UHI can be mitigated through localized interventions and is primarily driven by three factors: (1) Modification of land surfaces *(Fig 3.)*, (2) Anthropogenic heat sources, and (3) Climatic conditions. Such extreme heat events affect human health and comfort across all demographics, with the most severe consequences disproportionately impacting vulnerable groups. A socio-ethical perspective is needed in examining how marginalized populations *(Fig. 5)* suffer disproportionately from environmental challenges due to socio-economic and demographic disadvantages. For example, Amorim-Maia et al. *(2023)* highlight the role of urban climate

Arup. (2023). Madrid suffers most extreme urban heat island hot spot, new international survey shows. Arup.

Amorim-Maia, A.T., Anguelovski, I., Connolly, J. & Chu, E. (2023). Seeking refuge? The potential of urban climate shelters to address intersecting vulnerabilities. Landscape and Urban Planning, 238, 104836.

shelters in mitigating intersecting vulnerabilities, emphasizing how unequal access to cooling resources contributes to environmental injustice. Mohtat and Khirfan *(2021)* distinguish three pillars of climate justice: (1) Recognitional, (2) Procedural, and (3) Distributive. Recognitional Justice entails acknowledging the unique identities and needs of marginalized communities. Procedural Justice promotes inclusive decision-making processes. Distributive Justice emphasizes fair resource distribution, addressing the socio-economic challenges faced by vulnerable populations, especially in energy-poor neighborhoods *(Martín-Consuegra et al., 2023)*. Such communities in Madrid often lack access to air conditioning or insulation, making them vulnerable to heat stress. High mortality rates during heatwaves, as López-Bueno et al. *(2020)* discuss, often go hand-in-hand with socio-demographic factors, underlining the necessity of more resilient design strategies for these marginalized demographics.
Additionally, extreme urban heat stresses infrastructure and increases energy demands. Urban climate resilience, the capacity of urban systems to adapt and recover from climatic stresses, serves as a framework for understanding how infrastructure deals with heat stress. Graham & Marvin's *(2001)* frame resilience through the lens of networked infrastructures, emphasizing the interdependencies of the infrastructures. Graham's *(2010)* work on infrastructure failure underscores the interdependence of these systems and how disruption in one can cascade into others, intensifying urban vulnerabilities. Moreover, the physical infrastructures rely on workers *(Fig. 6)*, who themselves are vulnerable to extreme heat, further increasing pressures on systems that depend on their labor.

This theoretical framework addresses two primary approaches to managing urban heat: mitigation and adaptation. Urban heat mitigation focuses on reducing heat absorption and enhancing cooling in urban areas. Green infrastructure shade and cool through evapotranspiration, proving highly effective in reducing urban temperatures *(Philipp &*

Mohtat, N., & Khirfan, L. (2021). The climate justice pillars vis-à-vis urban form adaptation to climate change: A review. Urban Climate, 39, 100951

Martín-Consuegra, F., Núñez Peiró, M., Alonso, C., Sánchez-Guevara Sánchez, C., Pérez, G., & Arranz, B. (2023). Targeting the most energy vulnerable: Deprived neighbourhoods at risk of winter fuel poverty and high summer urban heat island intensity. A case study in Madrid (Spain).

López-Bueno, J. A., Díaz, J., Sánchez-Guevara, C., Sánchez-Martínez, G., Franco, M., Gullón, P., Núñez Peiró, M., Valero, I., & Linares, C. (2020). The impact of heat waves on daily mortality in districts in Madrid: The effects of sociodemographic factors. Environmental Research, 190, 109993.

Graham, S., & Marvin, S. (2001). Splintering Urbanism: Networked Infrastructures, Technological Mobilities, and the Urban Condition. Routledge.

Graham, S. (2010). Disrupted cities: When infrastructure fails. New York: Routledge.

Fig. 5: *Vulnerable demographics* **,** Elderly people (>65 years old), Children (<12 years old), People with pre-excisting health conditions (Respiratory and Cardiovascular conditions), People with a migration background & People in low-income areas by *Author*

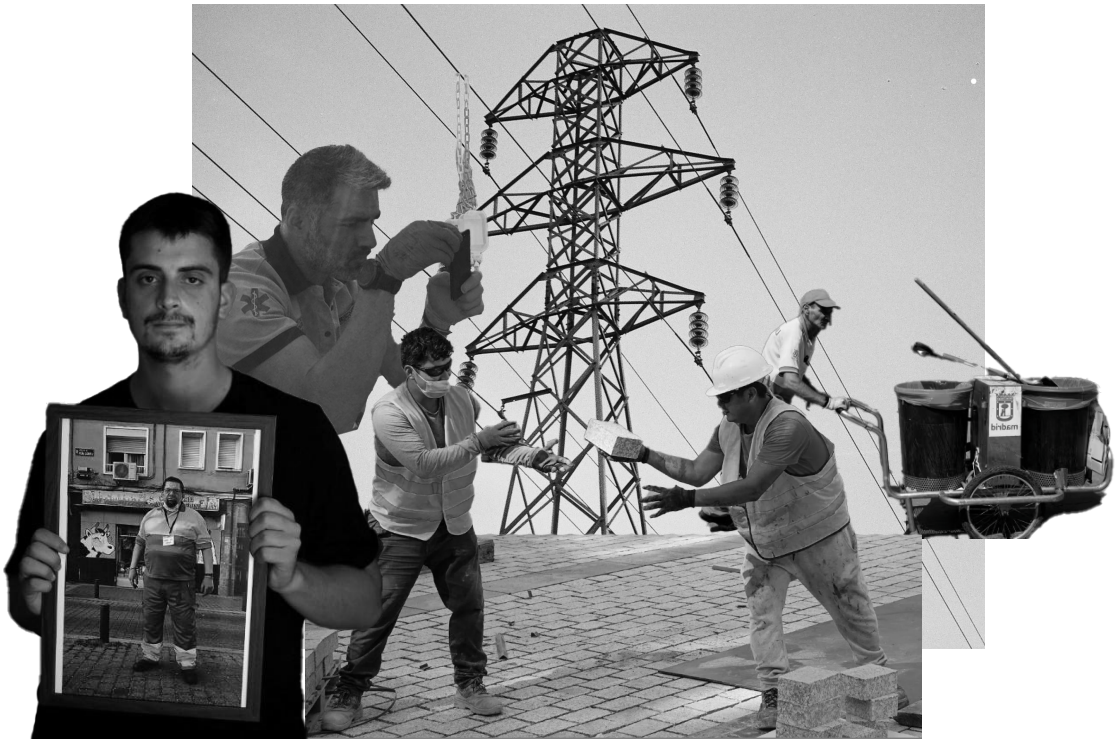


Fig. 6: *Vulnerable workers* **,** Outside workers who keep the urban infrastructures running. (e.g. waste management workers) by *Author*

Chow, 2020). Reflective building materials represent another strategy to decrease heat absorption and improve urban comfort *(Martín-Consuegra et al., 2024)*. Cities similar to Madrid offer multiple relevant mitigation strategies, potentially applicable to Madrid's specific context. In addition, Zhang *(2022)* explores the possibility of harnessing the UHI effect's positive aspects, suggesting that while some heat can be used for energy efficiency, excess heat remains a health hazard and infrastructure challenge. Excess heat in Madrid impacts energy demand *(Garrido-Perez et al., 2021)*, social spaces, and the well-being of Madrileños. Research by Sandvall et al. *(2021)* illustrates the potential of recovering excess heat for district heating, where urban waste heat is repurposed for cooling or heating. This adaptation model could mitigate heat stress in housing, a sector particularly vulnerable to extreme temperatures *(Alonso et al., 2024)*, especially for marginalized populations. The European ReUseHeat project *(Lygnerud et al., 2022)* advocates for integrating renewable energy and heat recovery as fundamental components of urban resilience.

Besides the physical implications, urban heat presents social challenges as well. Understanding how people respond to heat stress informs the eventual intervention. Cresswell and Merriman *(2011)* examine the social practices of mobility and adaptation, suggesting that vulnerability shape peoples' perceptions. These behavioral insights help design targeted interventions in neighborhoods where residents may lack the awareness or resources to effectively use cooling infrastructure *(López-Bueno et al., 2020)*. For example, public awareness campaigns during heatwaves could mitigate risks for vulnerable populations in Madrid, as we see further in one of the Comparative analysisses the "Climate Shelter Network" in Barcelona. Extreme urban heat events can cause populations, particularly vulnerable groups, to stay indoors in order to survive the intense heat *(Fig. 7)*.

Philipp, C. H., & Chow, W. T. L. (2020). Urban heat vulnerability analysis for Singapore. ETH Zurich.

Martín-Consuegra, F., Pérez, G., Montero, I., Herrera, L., Frutos, B., Alonso, C., de Frutos, F., & Martínez, A. (2024). Thermo-optical mapping of urban coating materials: A GIS-based surface renovation tool for passive cooling of cities.

Zhang, J. (2022). Positively using heat island to modify city environment. Global Scientific Research in Environmental Science, 2(1), 1–12.

Garrido-Perez, J. M., Barriopedro, D., García-Herrera, R., & Ordóñez, C. (2021). Impact of climate change on Spanish electricity demand. Climatic Change, 165, Article 50.

Sandvall, A., Hagberg, M. & Lygnerud, K. (2021). Modelling of urban excess heat use in district heating systems. Energy Strategy Reviews, 33, 100594.

Alonso, C., Frutos, F., Martin-Consuega, F., Oteiza, I. & Frutos, B. (2024). Energy consumption and environmental parameters in Madrid social housing. Performance in the face of extreme weather events. Building and Environment, 254, 111354.

Lygnerud K, Nielsen S, Persson U, Wynn H, Wheatcroft E, Antolin-Gutierrez J, Leonte D, Rosebrock O, Ochsner K, Keim C, Perez-Granados P, Romanchenko D, Langer S, Ljung M. (2022). Handbook for increased recovery of urban excess heat.

Cresswell, T., & Merriman, P. (2011). Geographies of mobilities: Practices, spaces, subjects. Ashgate Publishing.

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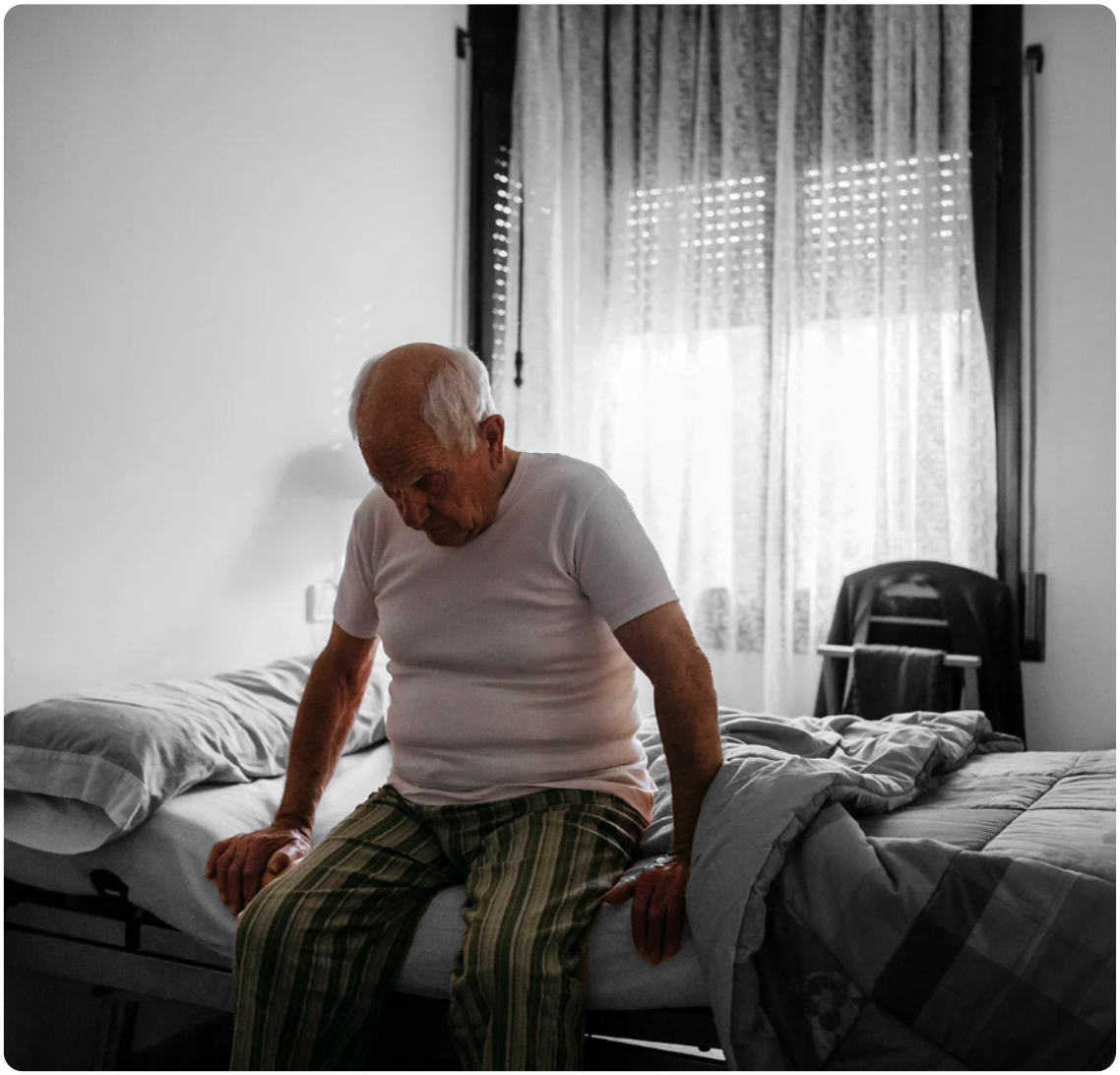


Fig. 7: *Social isolation* , Lonely senior man sitting on bed at home by photographer *Josep M Rovirosa (2021)*

Methodological Framework

The methodology for this research is based on a mixed-methods approach, integrating both quantitative and qualitative research methods to evaluate the problem from social as well as spatial and physical perspectives. Urban heat cannot be fully understood through its physical dimensions alone, as it represents socioeconomic, -demographic, and technical hybrids encompassing interconnected spatial and social components. An analysis of one would be insufficient to understand its systemic functions. Rather than analyzing the separate domains, these methods investigate their interconnections and influences. The key methods are outlined below.

Statistical Data Analysis

A statistical approach will be employed to analyze the quantitative dimensions of the research. This includes identifying six neighborhoods *(Fig. 8)* with a relatively higher concentration of vulnerable populations exposed to urban heat, as determined through statistical data *(Appendix B)*. Moreover, statistical analysis will provide a basis for assessing temperature patterns and projecting future scenarios under various urban interventions, facilitating the evaluation of their effectiveness. It will also support the analysis of building energy efficiency and resilience. Additionally, this data will be applied to examine the performance of infrastructure in vulnerable neighborhoods across Madrid.

GIS Mapping & Remote Sensing Analysis

GIS (Geographic Information System) mapping is a method that captures, stores, analyzes, and visualizes spatial and geographic data. It visualizes relationships, patterns, and trends through maps, integrating layers of data (e.g. demographics, climate, infrastructure).

Remote sensing analysis uses satellite sensors to study Earth's surface (e.g. tracking temperature, vegetation, urban changes) without physical contact.

GIS mapping and Remote sensing analysis will be utilized to map the spatial distribution of infrastructures and urban heat in and around the vulnerable neighborhoods of Madrid, enabling the identification of hotspots and their relation within the vulnerable neighborhoods. This method will also analyze the location and density of green spaces, shading devices, and water features throughout the city, aiding in the visualization of heat intensity and the identification of areas prone to overheating.

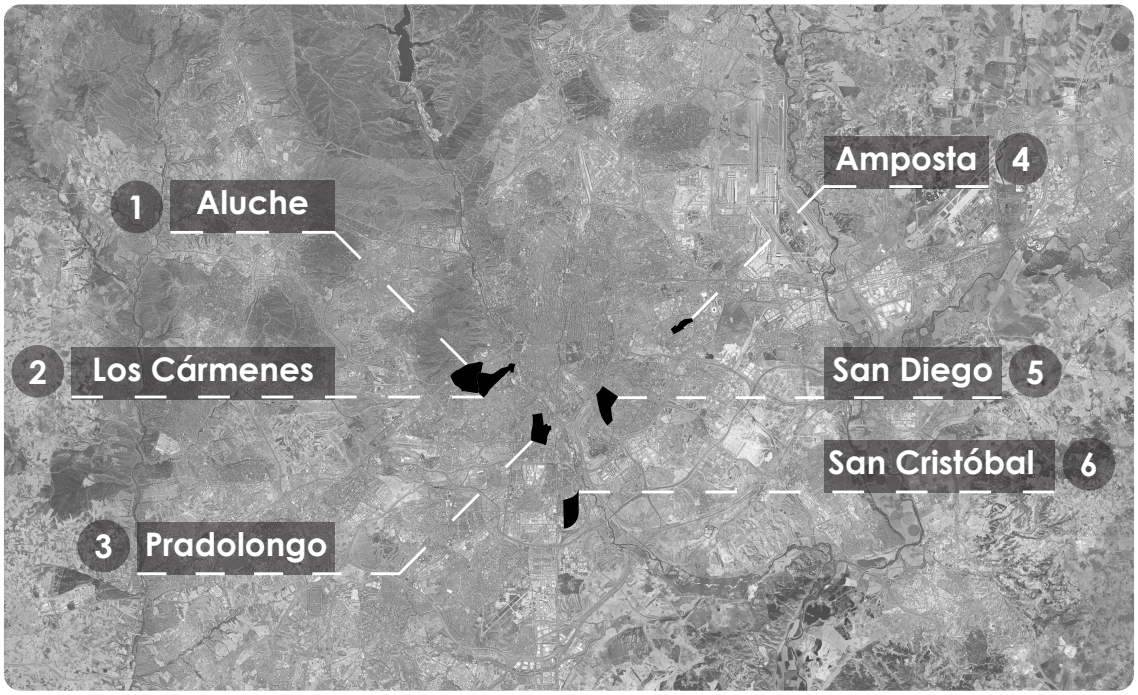


Fig. 8: *Six vulnerable neighborhoods*, The neighborhoods exhibit relatively higher levels of demographic vulnerability by *Author*

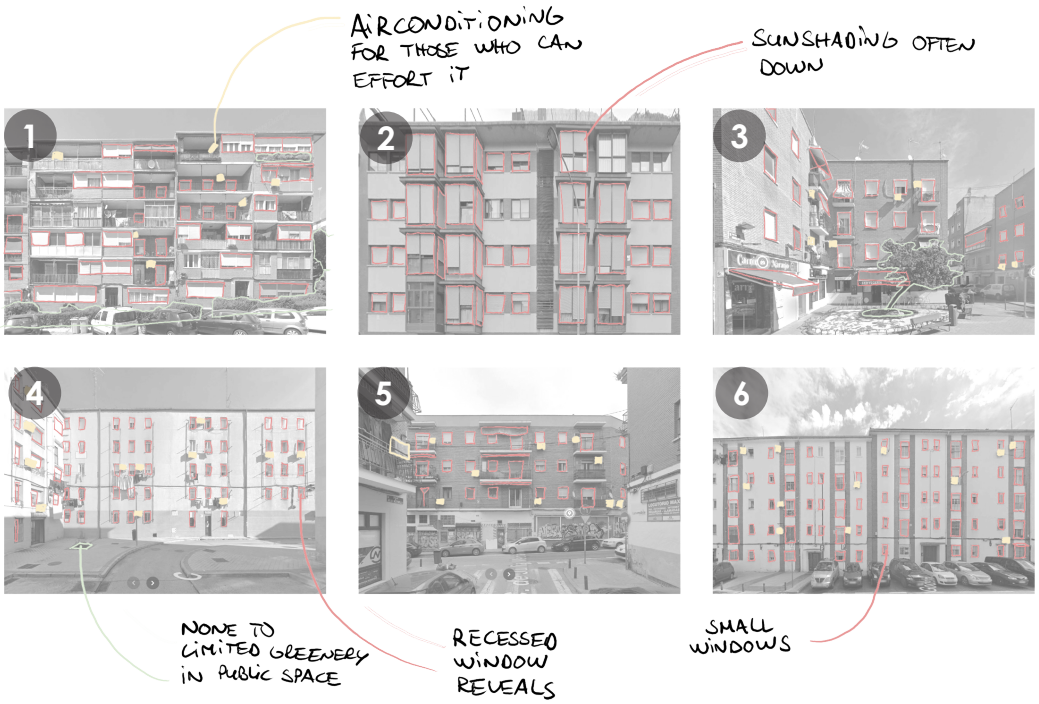


Fig. 9: *Preliminary analysis of neighborhoods*, Recording the factors that contribute to and influence urban heat through Google Maps by *Author*

Digital Modeling

To enhance the understanding of statistical data models, climate modeling serves as a valuable tool. My interest in Digital Twins stems from their potential to analyze the interactions between systems and is a valuable tool regarding the urban heat phenomenon. The *"Cooling Singapore"* project, for instance, employed a *"Digital Urban Climate Twin" (DUCT) (NUSEnterprise, 2022)* as an interactive platform for analyzing the impact of design interventions on urban morphology and climate conditions. In the eventual design phase, the parameters influencing the design will become critical. This approach aligns closely with a research-by-design methodology. Applying this method in this project may require adaptation. Instead of citywide applications, scaling down the concept to an urban block or building level may provide a more manageable and focused scope.

NUSEnterprise. (2022). Cooling Singapore 2.0 Building a Digital Urban Climate Twin. YouTube.

Comparative Analysis

Many cities worldwide face challenges similar to those experienced by Madrid concerning urban heat and its associated vulnerabilities. Several cities have already established frameworks to ad-dress these challenges *(Philipp & Chow, 2020)* and even have implemented various mitigation strategies. Studies like *"Cooling Singapore"* from ETH Singapore, or the *"Climate Shelter Network"* in Barcelona provide relevant strategies that can be relevant and adapted to the unique situation in the vulnerable neighborhoods in Madrid. Comparative analysis enables the evaluation of these frameworks and strategies, providing insights for potential climate adaptation interventions in the city of Madrid. For instance, strategies such as reusing excess heat for infrastructure cooling or developing climate shelters can be relevant for Madrid.

Philipp, C. H., & Chow, W. T. L. (2020). Urban heat vulnerability analysis for Singapore (D 2.4 – Vulnerability Map). ETH Zurich.

Literature review

The literature review serves as the foundation for understanding climate justice, emphasizing frameworks that incorporate equity into climate adaptation strategies. It highlights approaches that address the social dimensions of vulnerability, making it especially relevant for examining the needs of marginalized populations regarding urban heat. The research thusfar has primarily focused on reviewing existing literature, which offers insights into the disproportionate impacts of urban heat on vulnerable groups. The literature review establishes a theoretical framework for analyzing climate justice.

Policy Analysis

Policy analysis will involve the examination of urban heat policies in Madrid. This method aims to understand how past and present strategies have addressed, or often times failed to address, the needs of vulnerable populations regarding urban heat. It provides insights into the priorities and gaps in Madrid's climate adaptation strategies. This method grounds the research in a more critical understanding of institutional responses and policy impacts.

Field research

Building on the preliminary Google Maps analysis of the route through the six neighborhoods *(Fig. 9)*, I will conduct a physical walkthrough of these areas during my field trip to Madrid. During my fieldtrip, I have to account for the seasonal context of November. My investigation will focus on urban infrastructures, including transportation, water systems, green spaces, waste management, energy facilities, shaded areas, and air-conditioned public spaces. I will observe behavioral patterns in public spaces and note climatic conditions, while also evaluating social facilities like community centers, healthcare clinics, and libraries as potential climate shelters. Additionally, I will identify urban nodes with urban excess heat to explore opportunities for heat recovery.

Research Diagramming

Beyond Madrid's Heat

A Deconstruction of Madrid's Heat Crisis

Problem statement

During the summer months, Madrid experiences extreme heat, a challenge intensified by two phenomena: **climate change** and the **urban heat island (UHI)** effect. While climate change is a global crisis, the UHI effect is a specific phenomenon that can be addressed through localized interventions. This phenomenon is driven by modifications in **land surfaces**, **anthropogenic heat** emissions, and specific **climatic conditions**. These high temperatures strain both the **infrastructure** supporting the city and the well-being of its inhabitants, disproportionately impacting **marginalized populations**.

Leading question

"How can **localized architectural interventions** and **urban infrastructures** address the **vulnerabilities** of **marginalized populations** in response to **Madrid's Urban Heat**?"

- *"What are the relationships betw infrastructure syst*
- *"How could urban heat in Ma would benefit the city instead o*
- *"What role can community pa solutions for urban heat o*
- *"How have cities with Urba implemented localized arch interven*

Theoretical framework

Infrastructure Theory

Climate Justice

- Recoanitional Justice
- Procedural Justice
- Distributive Justice

Urban Adaptation

Urban Resilience

Urban Heat Island (UHI) Effect

- Climate Ada
- Climate Justi
- Urban Climat
- Urban Excess
- Urban Heat Isl

Amorim-Maia, A.T., Anguelovski, I., Connolly, J. & Chu, E. (2023). Seeking refuge? The potential of urban climate shelters to address intersecting vulnerabilities. Landscape and Urban Planning, 238, 104836. https://doi.org/10.1016/j.landurbplan.2023.104836

Graham, S., & Marvin, S. (2001). Splintering Urbanism: Networked Infrastructures, Technological Mobilities, and the Urban Condition. Routledge.

Graham, S. (2010). Disrupted cities: When infrastructure fails. New York: Routledge. https://doi.org/10.4324/9780203894484

Cresswell, T., & Merriman, P. (2011). Geographies of mobilities: Practices, spaces, subjects. Ashgate Publishing.

**Theoretical source foundation*

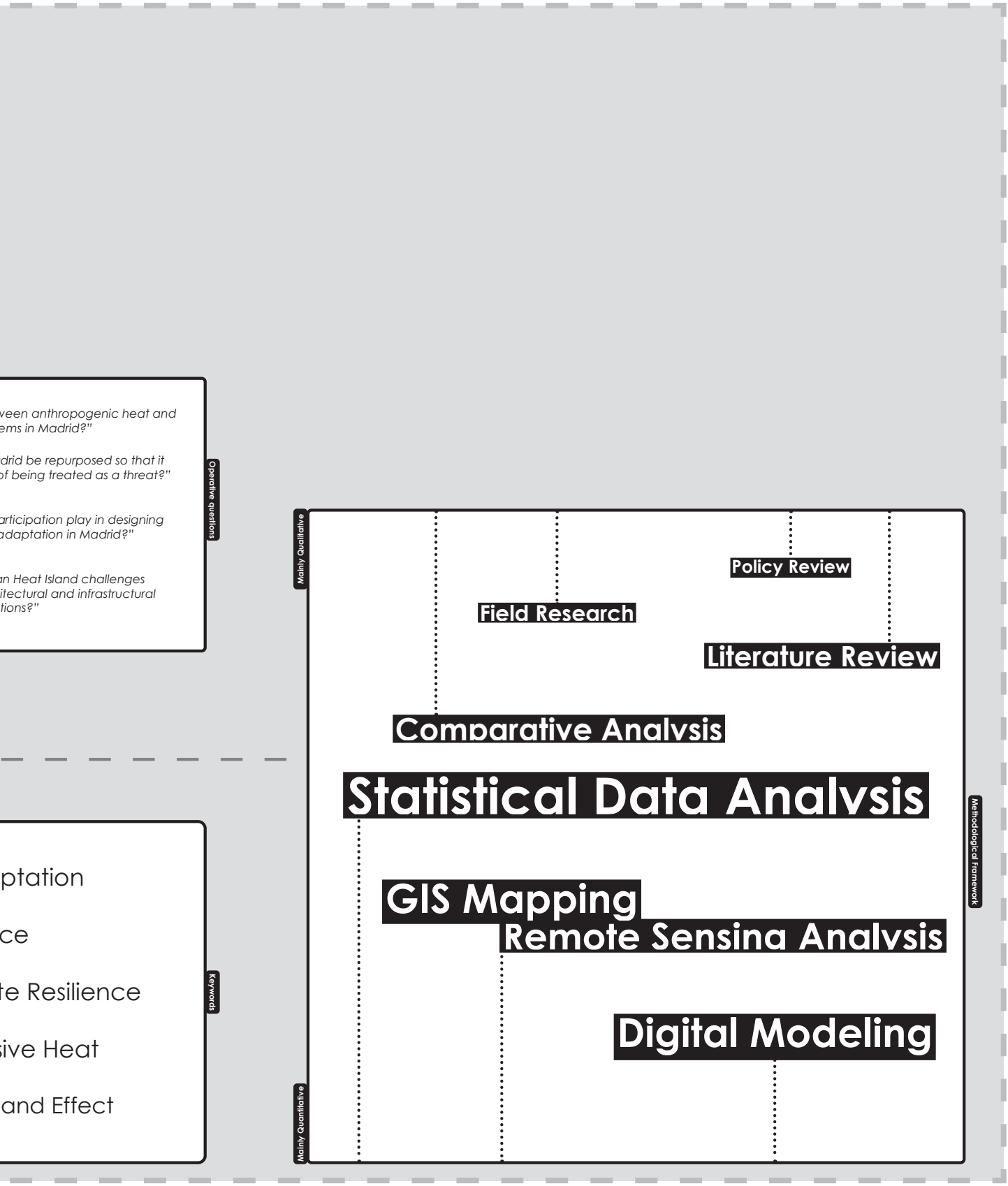


Fig. 10: *Research Diagram* by *Author*

Reflection on Relevance

The urgency of this research is heightened by the recent growing frequency and severity of climate-related disasters worldwide. From evacuations for Hurricane Milton to the recent devastating flood in Spain, these events underscore the critical consequences of inadequate adaptation to a changing climate. No longer isolated incidents, these recurring phenomena disrupt urban systems, threaten public health, and deepen existing social inequalities. In Madrid, the climate-related challenge is the effects of the Urban Heat Island (UHI). Summers have become endurance tests, with heatwaves now a regular occurrence. For many, especially those lacking access to cooling infrastructure or shaded public spaces, navigating the city during such conditions is sometimes impossible.

By prioritizing marginalized populations, the study underscores the social relevance of the challenge. Vulnerable groups face disproportionately higher risks during extreme heat events, making it important to address these inequities as primary considerations rather than secondary. With climate justice as a framework, this research bridges the gap between technical solutions and their socio-spatial impacts, providing a framework for equitable and inclusive design interventions.

Although this study is focused on the city of Madrid, the findings of this research have broader implications for cities worldwide facing similar challenges. The proposed strategies for mitigating and adapting to urban heat can serve as a model for other contexts, offering a framework for cities seeking to address their own challenges regarding urban heat.

Annotated Bibliography

Amorim-Maia, A.T., Anguelovski, I., Connolly, J. & Chu, E. (2023). Seeking refuge? The potential of urban climate shelters to address intersecting vulnerabilities. Landscape and Urban Planning, 238, 104836. https://doi.org/10.1016/j.landurbplan.2023.104836

Urban climate shelters
Vulnerable populations
Adaptive infrastructure
UHI mitigation.

Cresswell, T., & Merriman, P. (2011). Geographies of mobilities: Practices, spaces, subjects. Ashgate Publishing.

Spatial mobility
Vulnerable populations
Spatial dynamics

Graham, S. (2010). Disrupted cities: When infrastructure fails. New York: Routledge. https://doi.org/10.4324/9780203894484

Urban infrastructure failures
Infrastructural vulnerabilities

Graham, S., & Marvin, S. (2001). Splintering Urbanism: Networked Infrastructures, Technological Mobilities, and the Urban Condition. Routledge.

Fragmented infrastructure access
Inequalities

References

Alonso, C., Frutos, F., Martin-Consuega, F., Oteiza, I. & Frutos, B. (2024). Energy consumption and environmental parameters in Madrid social housing. Performance in the face of extreme weather events. Building and Environment, 254, 111354. https://doi.org/10.1016/j.buildenv.2024.111354

Arup. (2023). Madrid suffers most extreme urban heat island hot spot, new international survey shows. Arup. Retrieved 7th of November 2024 from https://www.arup.com/news/madrid-suffers-most-extreme-urban-heat-island-hot-spot--new-international-survey-shows/

Bushenkova, A., Soares, P.M.M., Frederico Johannsen, F. & Lima, D.C.A. (2024). Towards an improved representation of the urban heat island effect: A multi-scale application of XGBoost for Madrid. Urban Climate, 55, 101982. https://doi.org/10.1016/j.uclim.2024.101982

Carbonell, A., Arévalo, G., Lao, J., Vergoñós, L., Montlleó, M., & Casals, P. (2017). Barcelona urban heat island characterization and modeling. 7th Advanced Training Course on Land Remote Sensing, SZIU, Godollo, Hungary.

Garrido-Perez, J. M., Barriopedro, D., García-Herrera, R., & Ordóñez, C. (2021). Impact of climate change on Spanish electricity demand. Climatic Change, 165, Article 50. https://doi.org/10.1007/s10584-021-03086-0

Huia, L., Wilhelm, O.V. & Uejiosc, C. (2019). Assessment of heat exposure in cities: Combining the dynamics of temperature and population. Science of the Total Environment, 655(1-12). https://doi.org/10.1016/j.scitotenv.2018.11.028

López Moreno, H., Giancola, E., Sánchez Egido, M. N., Ferrer Tevar, J. A., & Soutullo Castro, S. (2020). Evaluation of weather conditions in urban climate studies over different Madrid neighbourhoods: Influence of urban morphologies on the microclimate. Proceedings of the International Solar Energy Society EuroSun 2020 Conference. https://doi.org/10.18086/eurosun.2020.09.03

López-Bueno, J. A., Díaz, J., Sánchez-Guevara, C., Sánchez-Martínez, G., Franco, M., Gullón, P., Núñez Peiró, M., Valero, I., & Linares, C. (2020). The impact of heat waves on daily mortality in districts in Madrid: The effects of sociodemographic factors. Environmental Research, 190, 109993. https://doi.org/10.1016/j.envres.2020.109993

Lygnerud, K., & Langer, S. (2022). Urban sustainability: Recovering and utilizing urban excess heat. Energies, 15(24), 9466. https://doi.org/10.3390/en15249466

Lygnerud K, Nielsen S, Persson U, Wynn H, Wheatcroft E, Antolin-Gutierrez J, Leonte D, Rosebrock O, Ochsner K, Keim C, Perez-Granados P, Romanchenko D, Langer S, Ljung M. (2022). Handbook for increased recovery of urban excess heat, 2022, ReUseHeat Project, Grant Agreement 767429, European Commission.

Martilli, A., Krayenhoff, E. S., & Nazarian, N. (2020). Is the Urban Heat Island intensity relevant for heat mitigation studies? Urban Climate, 31, 100541. https://doi.org/10.1016/j.uclim.2019.100541

Martín-Consuegra, F., Gómez Giménez, J. M., Alonso, C., Córdoba Hernández, R., Hernández Aja, A., & Oteiza, I. (2020). Multidimensional index of fuel poverty in deprived neighbourhoods: Case study of Madrid. Energy and Buildings, 110205. https://doi.org/10.1016/j.enbuild.2020.110205

Martín-Consuegra, F., Hernández Aja, A., Oteiza, I., & Alonso, C. (2016). Energy needs and vulnerability estimation at an urban scale for residential neighborhoods in Madrid (Spain). Paper presented at PLEA 2016 Los Angeles - 32nd International Conference on Passive and Low Energy Architecture, Los Angeles, CA.

Martín-Consuegra, F., Núñez Peiró, M., Alonso, C., Sánchez-Guevara Sánchez, C., Pérez, G., & Arranz, B. (2023). Targeting the most energy vulnerable: Deprived neighbourhoods at risk of winter fuel poverty and high summer urban heat island intensity. A case study in Madrid (Spain). Paper presented at PLEA 2022 Santiago - Will Cities Survive?

Martín-Consuegra, F., Pérez, G., Montero, I., Herrera, L., Frutos, B., Alonso, C., de Frutos, F., & Martínez, A. (2024). Thermo-optical mapping of urban coating materials: A GIS-based surface renovation tool for passive cooling of cities. Presented at REHABEND 2024 Congress, Gijon, Spain.

Mohtat, N., & Khirfan, L. (2021). The climate justice pillars vis-à-vis urban form adaptation to climate change: A review. Urban Climate, 39, 100951. https://doi.org/10.1016/j.uclim.2021.100951

, H. L., Giancola, E., & Egido, M. N. S. (2020). Evaluation of weather conditions in urban climate studies over different Madrid neighbourhoods: Influence of urban morphologies on the microclimate. Atmosphere, 11(5), 435.

Núñez Peiró, M., Sánchez-Guevara Sánchez, C., & Neila González, F. J. (2017). Update of the urban heat island of Madrid and its influence on the building's energy simulation. In P. Mercader-Moyano (Ed.), Sustainable Development and Renovation in Architecture, Urbanism and Engineering (pp. 339-350). Springer International Publishing. https://doi.org/10.1007/978-3-319-51442-0_28

Núñez Peiró, M., Sánchez-Guevara Sánchez, C., & Neila González, F. J. (2021). Hourly evolution of intra-urban temperature variability across the local climate zones. The case of Madrid. Urban Climate, 39, 100921. https://doi.org/10.1016/j.uclim.2021.100921

NUSEnterprise. (2022). Cooling Singapore 2.0 Building a Digital Urban Climate Twin. YouTube. Retrieved 7th of November 2024 from https://www.youtube.com/watch?v=URGMpDmJbcw

Oquendo-Di Cosola, V., Sánchez-Reséndiz, J. A., Olivieri, L., & Olivieri, F. (2021). Actions for adaptation and mitigation to climate change: Madrid case study. Revista Facultad de Ingeniería, Universidad de Antioquia, (101), 84-99. https://doi.org/10.17533/udea.redin.20200795

Philipp, C. H., & Chow, W. T. L. (2020). Urban heat vulnerability analysis for Singapore (D 2.4 – Vulnerability Map). ETH Zurich. https://doi.org/10.3929/ethz-b-000419689

Ramly, N., Hod, R., Hassan, M. R., & Jaafar, M. H. (2023). Identifying vulnerable population in urban heat island: A literature review. International Journal of Public Health Research, 13(2), 1678-1693. https://doi.org/10.17576/ijphr.1302.2023.02.07

Sandvall, A., Hagberg, M. & Lygnerud, K. (2021). Modelling of urban excess heat use in district heating systems. Energy Strategy Reviews, 33, 100594. https://doi.org/10.1016/j.esr.2020.100594

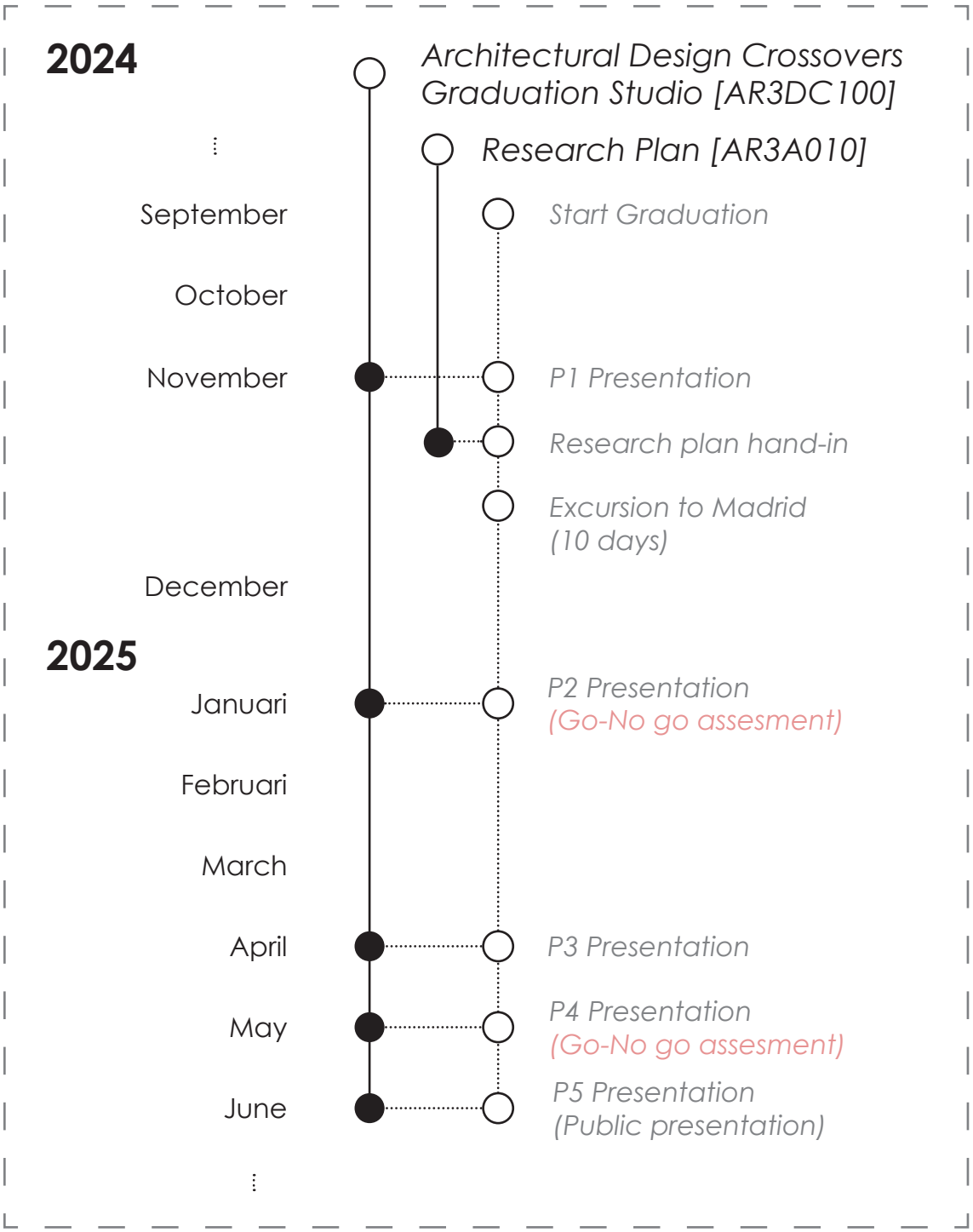
Sánchez-Guevara Sánchez, C., Núñez Peiró, M., & Neila González, F. J. (2017). Urban heat island and vulnerable population: The case of Madrid. In P. Mercader-Moyano (Ed.), Sustainable development and renovation in architecture, urbanism and engineering (pp. 1-13). Springer. https://doi.org/10.1007/978-3-319-51442-0_1

Sobrino, J. A., Oltra-Carrió, R., Sòria, G., Jiménez-Muñoz, J. C., Francha, B., Hidalgo, V., Mattar, C., Julien, Y., Cuenca, J., Romaguera, M., Gómez, J. A., De Miguel, E., Bianchi, R., & Paganini, M. (2013). Evaluation of the surface urban heat island effect in the city of Madrid by thermal remote sensing. International Journal of Remote Sensing, 34(9–10), 3177–3192. https://doi.org/10.1080/01431161.2012.716548

Yildirim, M.A., Bartyzel, F., Vallati, A., Wozniak, M.K. & Oclon, P. (2023). Efficient energy storage in residential buildings integrated with RESHeat system. Applied Energy, 335, 120752. https://doi.org/10.1016/j.apenergy.2023.120752

Zhang, J. (2022). Positively using heat island to modify city environment. Global Scientific Research in Environmental Science, 2(1), 1–12. https://doi.org/10.53902/GSRES.2022.02.000522

Appendix



Appendix A: *Graduation Schedule* , an overview of assignments/ deadlines for the Graduation year.

Websites		
https://idem.madrid.org	Education Statistics	This site provides data on education, including resources for students and educational institutions in Madrid.
https://www.madrid.es	Municipal Services	Offers information on public services, events, and municipal policies affecting the city of Madrid, including environmental data.
https://www.meteoblue.com	Weather Forecast	Provides detailed weather forecasts, climate data, and historical weather information for various locations, including Madrid.
https://geoportal.madrid.es	Geospatial Data	Contains geographic information and maps related to Madrid, including infrastructure, land use, and environmental data.
https://edificioseficientes.gob.es	Energy Efficiency	Offers data on energy-efficient buildings in Spain, including guidelines and statistics on building performance and sustainability.
https://weatherspark.com	Climate Data	Contains detailed climate reports and weather history for different cities, including temperature, precipitation, and wind patterns.
https://www.aemet.es	Meteorological Data	Spain's national weather agency provides real-time weather updates, climate trends, and alerts for natural hazards.
https://map.purpleair.com	Air Quality Monitoring	Displays live air quality data from global monitoring stations, including pollution levels and particulate matter concentration in Madrid.
https://www.windy.com	Wind and Weather Maps	Offers live weather maps with wind, temperature, precipitation, and other environmental conditions globally, including Madrid.
https://www.openstreetmap.org	Open Map Data	A free map resource that offers user-generated, editable maps with extensive details on streets, land use, and geography.
https://widgets.elpais.com/mapbox/renta-ine	Income Distribution	An interactive map showing income distribution and socio-economic data by regions in Spain, including Madrid.
https://datos.comunidad.madrid	Open Data Portal	Madrid's open data portal provides a wide range of datasets, including demographics, health, education, environment, and urban infrastructure.
https://www.statista.com/	Statistical Data	Offers a wide variety of statistics on Madrid, covering topics like population, economy, and living conditions.
http://portalestadistico.com	Statistical Data Platform	A platform providing access to statistical data on various topics, including demographics, economy, and society in Spain.
https://www.ine.es	National Statistics	Spain's national statistical institute offers comprehensive datasets on demographics, economy, housing, and labor.
https://www.elconfidencial.com/	Political Data (2019)	Provides political news and analysis, with articles and reports on Spanish and Madrid-specific elections and policies.
https://www.numbeo.com	Cost of Living Data	A crowdsourced database offering data on the cost of living, crime, healthcare, and quality of life in cities worldwide, including Madrid.
https://www.who.int/	World Health Organisation	
https://onebillionresilient.org/	Chief Heat Officer Network	
https://unhabitat.org/	Chief Heat Officer Network	Eleni Myrivili
https://www.technologyreview.com/2021/07/10/1028172/climate-change-human-body-extreme-heat-survival/	Human body tolerances when it comes to heat	

Appendix B: *Preliminary data collection* **,** An overview of different sources for data on Madrid.

During my ten-day excursion in Madrid, I have developed a preliminary itinerary to guide my activities and field research. Prior to the visit, I identified six neighborhoods with relatively high concentrations of marginalized populations regarding urban heat. While visiting these areas, I will use a range of methods, trying to capture the impact of urban heat on these communities. Given that the excursion takes place in November, during autumn, I will interpret my findings with **seasonal context** in mind. My research will begin with an **examination of urban infrastructures** within and surrounding these neighborhoods, focusing on elements such as transportation networks, water systems, green spaces, waste management, energy facilities, shaded areas, and air-conditioned public spaces. I will also observe **behavioral patterns in public spaces** to gain insights into how people use these areas, simultaneously noting down the climatic conditions. Additionally, I will **assess the social facilities**, including community centers, healthcare clinics, and libraries, which could serve as potential climate shelters for vulnerable populations. Finally, I will **identify urban nodes experiencing excess heat** to evaluate their suitability for potential heat recovery (and potential integration into district heating or cooling systems). This way I hope to get a better view in what ways these urban infrastructures **support or fail to support** the residents of these neighborhoods.

Itenerary	
6/11/2024	Research plan
7/11/2024	Research plan
	Plaza Juan Pujol (UHI Hotspot)
	La Bicicleta
8/11/2024	Research plan
	Padel lesson at 17:00 (Arena Rio Padel)
	Madrid Rio Parque
	Círculo de Bellas Artes
9/11/2024	Pradolongo
	C. de Nicolás Sánchez, 113
	12 de Octubre University Hospital
	Parque de Pradolongo
10/11/2024	Aluche
	Depósito 8 Metro Madrid
	Parque de Aluche
	Los Carmenes
	C. del Concejal Francisco José Jiménez Martín
11/11/2024	Amposta (Tutors in Madrid)
	Centro de Servicios Sociales Luz Casanova
	Arturo Soria Plaza
	Centro comercial Alcalá Norte
	Parque El Paraíso
12/11/2024	San Diego (Tutors in Madrid)
	Centro de Servicios Sociales San Diego
	Paque Nautilus
13/11/2024	San Cristobal (Tutors in Madrid)
	Casa San Cristobal de la Montemadrid Foundation
	Puente de Colores
	Hospital de dia Madrid Sur
	Health Center San Cristobal de los Angeles
14/11/2024	Check-in at Downtown Hostel Madrid
	Segovia / Toledo
15/11/2024	Museo Nacional Centro de Arte Reina Sofía
	Museo del Prado
16/11/2024	Arturo Soria Plaza
	Estadio Santiago Bernabéu
	Hospital Universitario Ramón y Cajal

Apendix C: *Itenerary Excursion Madrid* **,** An (preliminary planned) overview of activities during the 10 day excursion to Madrid.

TU Delft
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and the Built Environment