Multiscale Factors of Urban Heat Islands using Geomatics: Implications for Civil Engineering Education and practices for Mitigation of urban heat islands

Fabiola D. Yépez-Rincón, Andrea N. Escobedo Tamez, Milena Mesa Lavista, José Luis Brúster Flores, Ivone G. Zapata Wah, Gerardo J. Fajardo San Miguel, José L. González Abreu

Faculty of Civil Engineering, Universidad Autónoma de Nuevo León, San Nicolás de los Garza, C.P.64455, Nuevo León, México; fabiola.yepezrn@uanl.edu.mx, andrea.escobedo@uanl.edu.mx, mmesal@uanl.edu.mx, jose.brusterflr@uanl.edu.mx, guadalupe.zapatawh@uanl.edu.mx, gerardo.fajardosn@uanl.edu.mx, gonzalezab@uanl.edu.mx

Keywords: Sustainable Practices, Urban Planning, Remote Sensing, Urban Heat Islands

Abstract

Urban Heat Islands (UHIs) are a significant urban climate phenomenon, exacerbating energy demand, air pollution, and public health issues. This research highlights the relevance of this approach for civil engineering education, emphasizing the importance of incorporating sustainable studies into curricula. For civil engineers, learning about UHI is not just about understanding the science behind these phenomena but it's about applying their expertise to create solutions that lead to sustainable, resilient, and livable cities. By integrating UHI mitigation strategies into their projects, civil engineers with their actions and decisions can potentially contribute to reducing the negative impacts of urbanization and climate change. This study employs the knowledge of the Junior Students from the Civil Engineer Program from the Universidad Autónoma de Nuevo León, to apply the Local Climate Zones (LCZ) framework at a Level 1 and a multiscale approach to examine UHI dynamics across various spatial building scales, that go from microscale (building and street level) to mesoscale (neighborhood and city level) and/or regional scales. The findings underscore the potential for Civil Engineers Junior Students to design climate-resilient infrastructures that address UHI impacts, fostering sustainable urban development and better climate adaptation strategies.

1. Introduction

Only three years ago, November 15, 2022, Earth reached 8 billion people, and it is estimated that by 2050, over 70% of people will live in cities (CEPAL, 2022). The rapid growth of population and industry has led to disorderly urban expansion over the past decades, causing degrading processes that modify the environment (UN, 2018). Although cities occupy only 2-3% of the surface of Earth, they are responsible for consuming between 60% and 80% of global energy, nearly 75% of natural resources, and producing at least 75% of greenhouse gases (Pérez, 2021).

Urban development causes drastic changes to the natural city landscape (Mantilla Baquero, 2022). Which originally consisted of water, soil, and vegetation, turning it into an artificial landscape with constructions and building materials such as concrete, asphalt, and metal (Manna & Sarkar, 2025; Bullock & Gregory, 2009). The conventional materials used to build up cities are heat-absorbing and accumulating materials, although technology has advanced and now there are different options such as the cool pavements (Malik & Kumar, 2025). This "external envelope," as non-structural facades surrounding a block space are called, traps heat in its molecules and releases it slowly through heat liberation or radiation occurring at night (Palau Flórez, 2016), the building materials releases heat energy into its surroundings, causing the temperature to decrease (Amani, et al. 2025), but heating up the city comparatively to the rural areas; then essentially heat absorption is the opposite of heat liberation (Parihar & Birman, 2024).

To understand the process of urban warming, it is essential to first comprehend the warming process of Earth (Barboza Lizano, 2013). The Sun supplies virtually all the energy received by the Earth this energy is necessary for life to exist because dives the process of photosynthesis, heating of the soil, heating the air, evaporation or the mechanisms that drive the weather (Rosenberg et al. 1983; Roldán Voloria, 2013). Once in the atmosphere a natural mechanism occurs together with the gases that comprise it. The heat is received, retained and then a proportion of it is returned to space. This mechanism, however, works differently in cities rather than in the natural ecosystems, because of the buildup materials and form. The heat is trapped in the air (Du et al, 2024) and retained in the building and construction materials (Paramita, 2025), like as pavements (Li & Wu, 2025). In addition to the shape of the city and the different materials used, the heat could increase or decrease depending on the activities carried out and their gas emissions by block or group of blocks, and this is due to the small microclimates in very localized areas within the city. That is, UHI effect is directly related to the urban pollution (Cichowicz & Bochenek, 2024).

UHI's represent localized areas in urban environments that can suffer significantly higher temperatures than the more rural surrounding environments (Chakrabortty et a., 2024), driven by factors such as anthropogenic heat, altered land surfaces, and dense infrastructure (Oke, et al., 2017; Oke, 1982). These temperature differentials pose critical challenges to urban sustainability, influencing energy demand, air quality, human health, and overall livability (Santamouris, 2014). Understanding the temperature, humidity and other climatic dynamics of urban areas across multiple spatial scales—from the mesoscale, which addresses large-scale urban heat patterns, to the microscale, which examines finer variations at the street or building level—is essential for effective urban planning and heat adaptation and mitigation strategies (Xu et al. 2022).

1.1 Civil Engineering Students and their learning on sustainability

The generations of Civil Engineering bachelors can contribute to minimizing the UHI phenomenon through their influence in: (1) Sustainable urban planning by incorporating green roofs (Sun & Ni, 2016), urban parks (Xu, et al., 2022), and vegetation into urban design to increase shading and evapotranspiration (Aboelata & Sodoudi, 2019), or designing cities more compact with mixed-use spaces (Jamei et al., 2020) and efficient layouts to reduce urban sprawl and heat intensity (Gago, et al., 2013). (2) Sustainable buildings with reflective and permeable materials (i.e. permeable pavements according to Li et al., 2013) to reduce heat absorption and improve water retention. (3) Design water

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
https://doi.org/10.5194/isprs-annals-X-3-W3-2025-135-2026

systems for climate resilience that utilize stormwater, reduce runoff, and integrate blue infrastructure (Siehr et al., 2022). (4) Education and Capacity building, thoroughly educating the community (Cui et al., 2024; Akkose et al., 2021), first to create awareness of people, stakeholders and residents about the importance of these sustainable practices and collaborate with policymakers to develop strategies to prioritize UHI mitigation. For the WHO (2020), a priority is to educate people about risk and threat reduction measures and strategies for urban heat mitigation.

1.2 Geomatics and Artificial Intelligence

Geomatics, integrates geographic information systems (GIS), remote sensing, and spatial analysis, and constantly offers a comprehensive approach to studying UHI phenomena across scales as mentioned by Fadhil Ali (2023) cited by (Hamood, 2023). At the mesoscale, remote sensing data from satellites or airborne platforms can capture urban heat variations over large geographic areas (Milesi & Churkina, 2020), allowing researchers to analyze and comprehend the influence of urbanization, land cover changes, and atmospheric conditions on regional thermal patterns (Zhou et al., 2018). At the microscale, sensing urban build up environment has been studied by Hou & Zhang (2024) with Geospatial Artifical Intelligence (GeoAI) and street-level imagery, which is ultra-high-resolution spatial data—often derived from unmanned aerial systems (UAS) (Chen et al., 2021), street-level temperature sensors (Middel et al., 2022), or detailed land cover maps—can provide insights into the fine-grained interactions between urban features such as buildings, vegetation, and human activity (Zong, 2024).

Artificial intelligence (AI) has the ability to process thousands of raw satellite images (Meoni et al., 2024). The application of AI onboard satellite venture highlights its potential to directly handle multispectral or thermal infrared data through the techniques of machine learning (Danielsen et al., 2021) and deep learning (Giuffrida et al., 2021). Google has AI and Machine Learning (ML) powered tools, particularly its cloud-based engine and advanced algorithms, which provide a robust platform for analyzing landscape studies such as land use cover change or UHI at various scales (Junaid, 2024). By leveraging large-scale satellite data and geographic information system (GIS) technologies, Google's AI engine can identify patterns of land surface temperature across urban landscapes (Hasan et al., 2024). For instance, Google Earth Engine (GEE) offers powerful geospatial analysis capabilities (Yang et al., 2022), enabling researchers to monitor UHI variations over time and space, incorporating high-resolution remote sensing imagery, climate data, and ML models (Gorelick et al., 2017). The engine allows for real-time data processing, providing actionable insights into how urban heat is distributed across cities and the factors contributing to its intensity.

This integration of AI into UHI research not only enhances the precision and rate of processing and analyses data, but also opens avenues for predictive modeling, where ML algorithms can forecast future UHI trends based on historical data and environmental variables (Zhang et al., 2020). By coupling AI with UHI studies, city planners, environmental scientists, and policymakers can better understand the dynamics of urban heat, predict its impacts, and design targeted interventions aimed at reducing its negative effects, such as through the use of green roofs, urban forests, or reflective materials (Zhou et al., 2018).
This study aims to reduce the gap between microscale and mesoscale perspectives on urban heat by utilizing advanced geomatic technologies and AI in Google to analyze the spatiotemporal variability of UHI effects. By combining remote sensing, GIS-based modeling, and localized thermal measurements, we seek to enhance the understanding in civil engineering students of how urban morphology and environmental factors interact to shape urban heat patterns. The AI is used to process thousands of satellite images with thermal infrared bands at a spatial resolution of 30 m per pixel. This knowledge is crucial to sensibilize students and to develop targeted interventions that mitigate UHI effects and promote climate resilience in urban areas (Stone & Rodgers, 2001). This is a project being developed at the Faculty of Civil Engineering at Autonomous University of Nuevo León, Mexico.

2. Methodology

2.1 Characteristics of the curricula

From the Civil Engineering curricular program (2019) in the School of Civil Engineering at Autonomous University of Nuevo León, Mexico there are two Geomatics classes, the Basic given in the fourth semester and which has the Topography I course as an obligatory requirement and the Advanced Geomatics which is given during the sixth semester of the carrier, by then the civil engineer student is considered a "Junior Student" and can understand the types of buildings, materials and geometries. These experimental Geomatics applications focused on Sustainable practices and have been implemented each semester since 2019 in around 25-30 students per semester. The scope of the experiment ranges from just the delivery of an interactive learning product, in which they are given a grade for the quality of the work evaluated with a rubric, to the participation of the group in work teams at national and international conferences that are held available during the semester. The motivation to achieve a higher academic goal is mainly due to the interest of the students, but when this participation becomes outstanding, the professors manage a scholarship with the university for the students with the best achievements.

2.2 Geomatics Class Plan

The class program is divided in three phases and distributed in 75 class hours or 19 class weeks. Phase 1: Fundamentals of Advanced Geomatics, Phase 2: Integration of AI and BigData, and Phase 3: Apply knowledge in Geomatics and AI to solve complex problems.

2.3 Data collection and preparation

Multiscale Factors of Urban Heat Islands: Implications for Civil Engineering Sustainability Learnings and Good Practices is implemented during a full semester in three classes with three different professors. Professors agree with the methodology and study areas and have meetings every two weeks to adjust and share experiences. Data collection and preparation are divided and made by each professor part, then shared via a Google Drive folder with all the editor share permissions. In the same folder are also allocated references, methodological material, or scripts. Each student has access to a Lab computer with QGIS, and the Internet, and has their own GEE account.

2.3.1 Experimental study case: To embark on this exercise it was decided to use the Monterrey Metropolitan Area (MMA) located at approximately 25.6700° N latitude, 100.3100° W longitude and 550 meters above sea level (Figure 1). It is situated in the northeastern part of Mexico, in the Nuevo León state, surrounded by the Sierra Madre Oriental Mountain range. The methodology, however, could be applied to any country in the world, with similar build-up characteristics and access to the Google Street View survey services.

MMA is one of the major urban centers in northern Mexico, known for its industrial significance and rapid urbanization. In 2020 MMA's population was 5,341,177 inhabitants, representing 92% of the total state population of Nuevo Leon (INEGI, 2020). Urban sprawl developed fast and disordered over the past few decades, as a result of lack of planning, population increase, costs of land, and industrial expansion. The most important industries playing a dominant role in its economy are manufacturing, steel, and cement. The urban city sprawl has led to a significant increase in impervious surfaces, including concrete, asphalt, and steel, which absorb and store heat, contributing to UHI formation (Figure 1).

Geographically, Monterrey is situated in a basin surrounded by mountainous terrain, such as the Sierra Madre Oriental to the east. This natural topography restricts air flow and increases the likelihood of temperature inversions, which can trap heat and exacerbate UHI effects. The climate of Monterrey is semi-arid, with hot summers and mild winters. The region experiences long periods of intense sunshine, and rainfall is relatively scarce, which further limits the fresher and cooling effect of vegetation and water bodies. The combination of these factors—high levels of urbanization, topographical constraints, and climate—makes the study of UHIs in Monterrey particularly important.

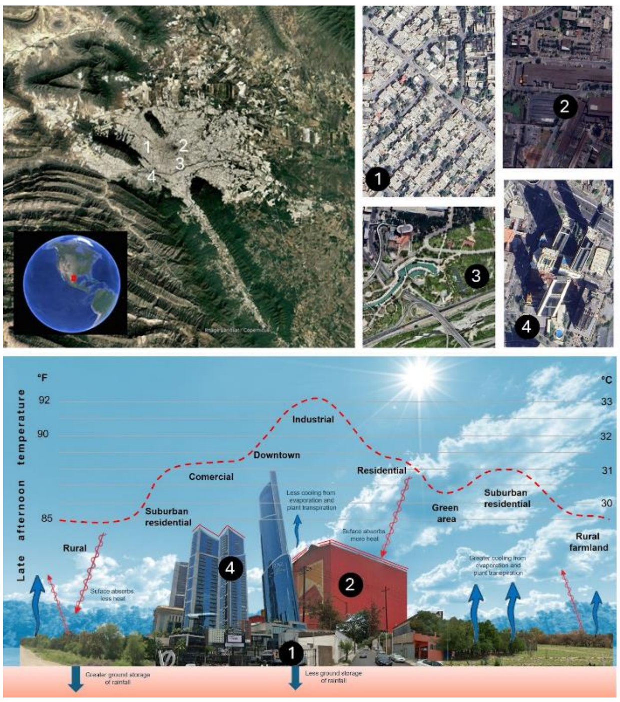


Figure 1. Monterrey Metropolitan Area, different build up areas and the heat island effect. Source: Own creation with Google Street View and goodfon.com

In recent years, research has indicated that the UHI effect in Monterrey is significant, particularly in the densely built-up urban core. The city's high density of industrial zones, commercial districts, and residential areas, combined with limited green spaces, results in a higher concentration of heat in urban areas compared to the surrounding rural zones. Heat can be considered a high-risk factor for public health and safety (McMichael et al., 2010).

Several studies have shown that Monterrey's urban core experiences substantial temperature differences when compared to its surrounding rural and suburban areas (Jauregui, 1987; Manzanilla Quiñones, 2022; Lemoine-Rodriguez et al., 2024; Rivera-Rivera, 2012). Temperature differences can reach up to 4-5°C or more during the summer months, particularly during the day (Zapata-Wah et al., 2024). This heat accumulation in cities leads to increased energy consumption for air conditioning, heightened air pollution (Sigh et al., 2020), and negative health impacts, especially among vulnerable populations (Ahmadalipour et al., 2019).

2.4 Survey design and methodology

A survey was administered to students enrolled in the Advanced Geomatics course, targeting those from the fifth to the eighth semester (Figure 2). The total population comprised 130 students, and the sample size was determined using Cochran's finite population formula (Eq. 1) (1977) at a 95% confidence level and a 5% estimation error.

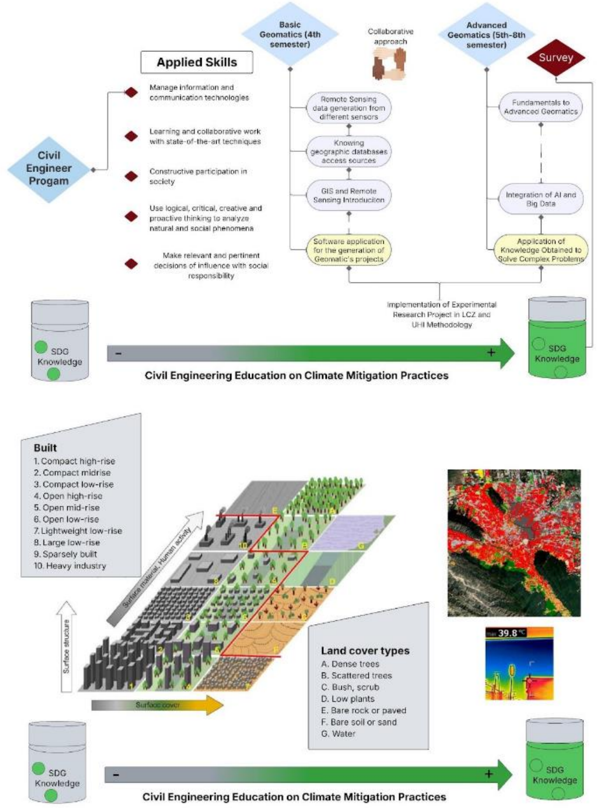
$$n= N * Za2 \; * p * qe2 \; (N\text{-}1) + \; Za2 \; * p *q$$

Where:
n sample number
N population
Za statistical parameter that depends on the confidence level
p probability of statistical events occurring
q probability of the statistical event not occurring
e maximum accepted estimation error

This calculation yielded a representative sample of 40 students (approximately 30% of the population). The questionnaire was designed to address two primary areas: student engagement and pedagogical improvements. Its structure included the following sections:

1. Demography: Students specified when they completed the course (semester and year) and named their respective professors, allowing for analysis across four academic years.
2. Previous knowledge: Respondents evaluated their initial familiarity with key concepts—like heat islands and building types—and identified any gaps in their understanding from beginning of request.
3. Knowledge acquired: Students assessed if the Practical Exercise improved their understanding of how heat islands and building types affect the urban environment.
4. Perception of Geomatics tools: The survey probed how the exercise influenced their valuation of geomatics in civil engineering, as well as changes in their perspectives on heat islands, building types, urban planning, and sustainability.
5. Recommendations for improvement: Participants provided suggestions for refining the exercise, including whether they would recommend it to future students.

Note: The use of digital formats for the survey forms was essential to the success of this work. The Forms application enabled us to efficiently distribute the survey to former students by contacting them through email or through WhatsApp groups created specifically for their class cohorts. This approach was justified, as it allowed us to gather valuable insights into the social and perceptual dimensions of urban heat islands (UHIs) and to assess the impact of the applied methodology. All participants were informed about the survey, and their consent was properly requested and obtained.



2.4 The understanding of new sustainable concepts

2.5.1 Urban envelope: The built environment was classified following the criteria of (Betchel et al. 2019), and it was complemented through direct observation at the block level. A hybrid model is currently under development. The model integrates the World Urban Database and Access Portal Tools (WUDAPT) methodology. The methodology was explained to the students using the Google Street View Platform and by comparing several examples of build-up types.

Urban climate scales can be represented at the Monterrey Metropolitan Area (MMA) level and its surrounding buffer as mesoscale, within the city at a local level, and at street level as microscale (Figure 3). The study currently being conducted in the Geomatics Department aims to characterize all scales of urban heat islands. Part of the analysis is based on building types.

2.5.2 Multiscale: Figure 3 exemplifies the complexity and multifaceted nature of the need for solutions that take into account the several scales of effect of urban climate issues, as acknowledged by a multiscale climate city approach (Bi & Little, 2022). Joshi et al. (2024) examined three decades of studies about impacts of climate on cities from the micro to the global scales. Their review highlights the lack of literature about the heat waves and the built environment relationship, such as the heat wave impacts on buildings, energy, inhabitants' health, and infrastructure and mitigation measures. Zermoglio et al. (2005) recognizes the benefits of a multiscale approach for human wellbeing, as Urban Climate Studies are the holistic understanding of climate systems. These complex interactions between the different levels of urban environments and climate systems have been reported by authors such as McPearson et al., (2016). For example, Schiano-Phan (2015) highlights the mitigating potential of urban environments and their microclimate features (e.g., green roofs) may have broader impacts on city-wide or regional climate patterns. The multiscale approach can also tailor adaptation and mitigation strategies and develop more precise and targeted solutions as addressed by Budzik et al., (2025) in a review of spatial data and sustainable planning optimization methods for mitigating UHI. Authors such as Roelich & Giesekam (2019) or Khan et al. (2018) underline better informed decision-making, enhancing resilience and sustainability practices, and protecting public health.

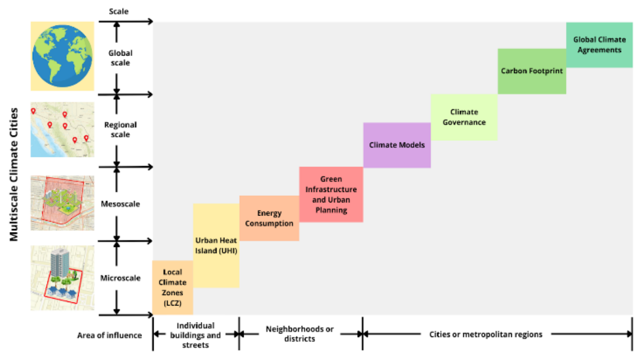


Figure 3. Multiscale Climate Cities and areas of influence.

2.5.3 Local Climate Zones: The shape and function of urban structures create unique microclimates that impact the quality of life of their inhabitants. Building Types considering the Local Climate Zone (LCZ) methodology by Bechtel & Daneke (2012) categorizes urban areas into distinct classes based on physical characteristics such as land cover, surface materials, and building types (see Figure 4). Among the LCZ classes, several building type categories are relevant for understanding urban heat dynamics, particularly in terms of their impact on temperature and microclimatic conditions.

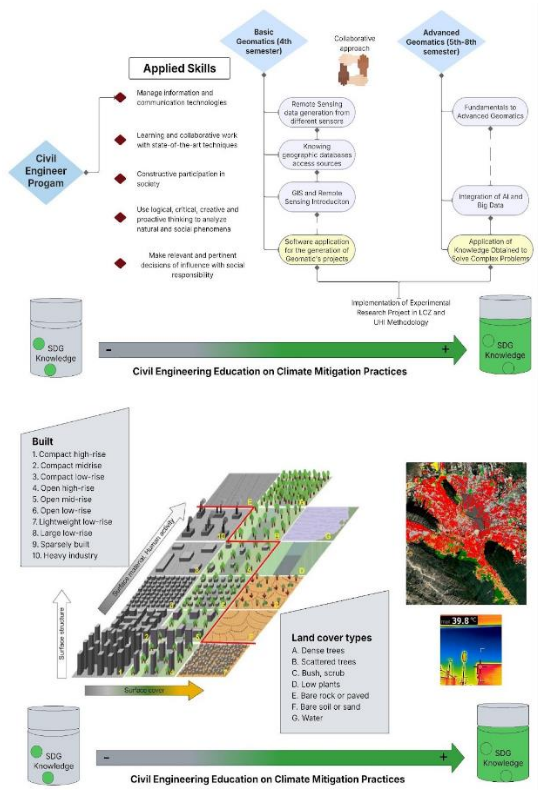


Figure 4. The 17 standard LCZs. Modified from Stewart & Oke (2012) by Sida, et al. (2021).

Each of these building types plays a distinct role in urban heat dynamics. Denser zones, particularly those with more compact building arrangements, tend to absorb and retain more heat, exacerbating UHI effects. In contrast, areas with more open spaces or lighter construction materials allow for better ventilation and cooling, mitigating some of the heat buildup. Understanding these distinctions is essential for urban planners and researchers in designing effective strategies to combat urban heat islands, improve climate resilience, and enhance urban living conditions.

2.5.4 Mesoscale: The surface temperature is studied at the mesoscale level using a series of hundreds or thousands of satellite images from different periods. The adapted formula for Land Surface Temperature was applied (Ermida, 2020; 2022). GEE is an open-access program that can process historical libraries of satellite images and spatial datasets related to climate from all over the planet using artificial intelligence, particularly in developing countries (Vijayakumar et al., 2024).

3. Results

3.1 Urban envelope

The built environment was classified according to the criteria of (Betchel et al. 2019), but it was done through direct observation at the block level.

A hybrid model is currently under development. The model integrates the World Urban Database and Access Portal Tools (WUDAPT) methodology (see Figure 2). To date, it is known that at least 47% of the urban envelope is represented by two types of construction in MMA: (a) Type 3 with 32.18 % and (b) Type 8 with 14.78 %, as is shown in Figure 5.

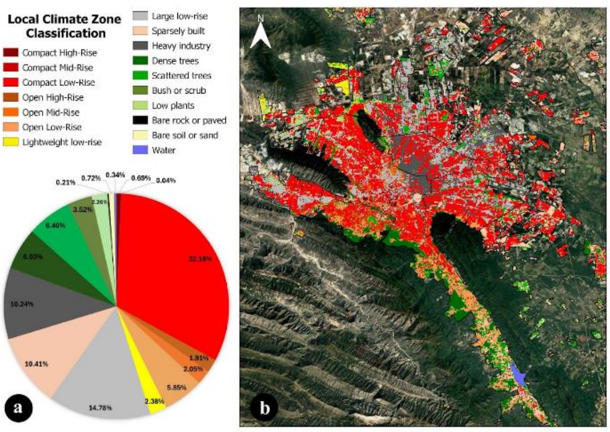


Figure 5. Local Climate Zone Classification of the MMA, a) Representative percentages and b) distribution of the types of construction.

3.2 Microscale

In a city with a population of one million, temperature increases can range from 1 to 12°C higher compared to surrounding rural areas (EPA, 2022). The rise in heat leads to a decrease in thermal comfort, with streets feeling extremely hot when walking during the summer (Figure 6), and even at night, it is noticeable how heat radiates from the ground or the buildings themselves. Using thermal sensors students measure and evaluate temperatures between 12 and 14 hours, finding surfaces that exceed the 45.7°C.

Figure 6. Geomatics students used a thermal sensor in a microscale capture, a) testing the sensor over various materials, b) in urban green areas, c) RGB visible light sensor and d) a thermal image.

As expected, they found thermal differences between the distinct environments. The most striking data were the thermal differences found in buildings favored by the shade of trees. In parks or green urban areas (green infrastructure), temperatures are reduced by up to 8°C on average, but in vegetated areas near rivers (blue/green infrastructure) they could even drop to 13°C.

3.3 Mesoscale

Figure 7 shows the cartography corresponding to the 2013-2022 period, created with 258 Landsat 8 images from April to August. The images were processed using Google Earth Engine. City temperatures are higher in areas where industry is concentrated and where there are extensive commercial zones. Students realized how the heat concentrates in the areas where commerce or industrial processes are happening.

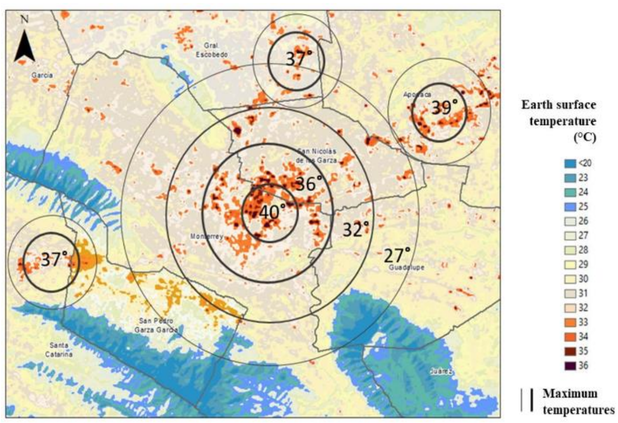


Figure 7. The map of MMA heat islands 2013-2022 period.

3.4 Surveyed Students

From the survey carried out, the students were divided by semester and professor. Figure 8 presents the students who participated in the survey, along with the percentage they represent of the total sample and the total number of students for each professor. Where the majority of surveyed students were from the sixth semester (72.5%).

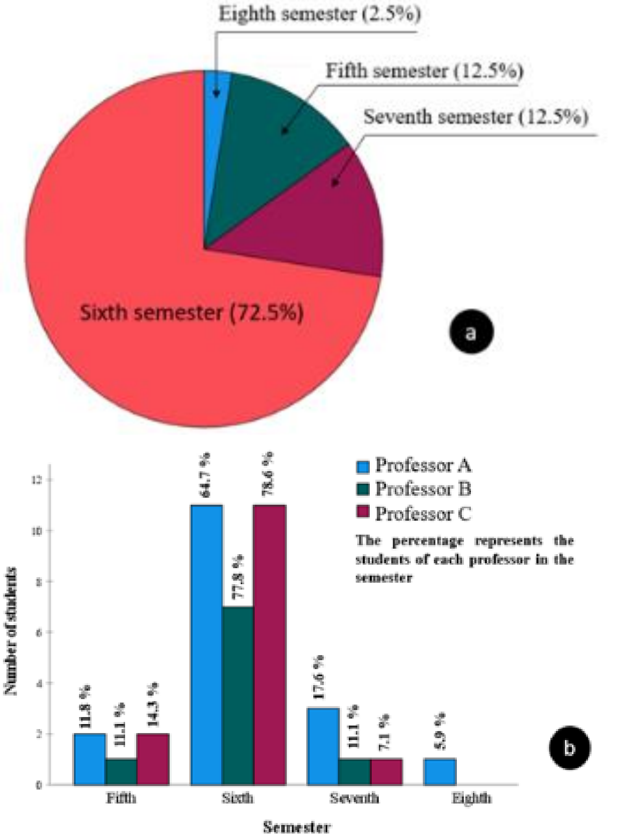


Figure 8. Distribution of students that participate in the survey, a) Distribution of percentage by semester, b) Percentage of students by professors.

Analysis of the survey responses revealed several key insights regarding student engagement and the effectiveness of the course.

The most relevant questions for learning and engagement were:

1. How would you rate your experience in terms of practical learning with Geomatics tools?

2. How challenging was the Practical Exercise?

3. How familiar were you with the concepts of heat islands and building types before taking this exercise?

4. Do you think Practical Exercise helped you better understand the impact of heat islands and building types on the urban environment?

5. To what extent did it change your perspective on heat islands?

6. To what extent did it change your perspective on building types?

7. To what extent did it change your perspective on urban planning? and,

8. To what extent did it change your perspective on sustainability?

The responses to these questions are presented in Figure 9, which shows that most students were not familiar with the concepts of heat islands and building types before the exercise. For the masses, the activity was challenging and over 65% reported having a positive experience with hands-on learning. As a result, students gained a better understanding of Geomatics, and most experienced a positive change in their perception of heat islands, building types, sustainability, and urban planning.

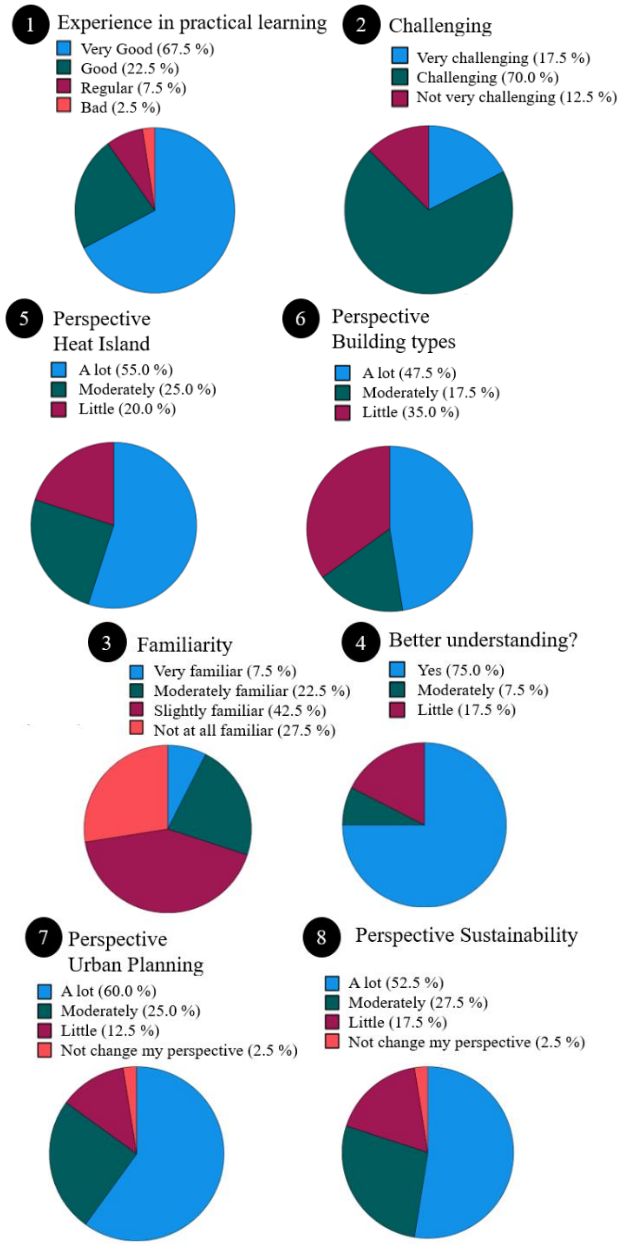


Figure 9. Responses of the survey students, taking into account their experiences.

The most relevant questions for the objective focused on identifying suggestions for pedagogical improvements were the following: (1) What aspects of the Practical Exercise do you think could be improved? (2) How do you think those aspects could be improved? (3) Would you recommend the Practical Exercise to future students of Advanced Geomatics? and (4) Do you have any other comments or suggestions?

Analyzing the results related to this second objective, some students suggested applying the exercise to real-world problems rather than relying solely on academic examples. The possibility of simplifying the explanatory videos and adding more examples was also mentioned. Most participants would recommend the

exercise to future students, and some positive comments highlighted the quality of teaching and the relevance of the course.
Overall, the most valuable aspects they learned were: analyzing data and creating urban heat island maps (37.5%), the importance of civil engineering in planning and managing sustainable cities (30.0%), and the impact of construction types and materials on urban design (25.0%). Future research could integrate these perceptual findings with temporal climate datasets to develop hybrid models that combine human-centric insights with AI-based predictive analytics for a more holistic understanding of UHIs.

4. Conclusions

According to climate change scenario projections in several regions of the world, extreme temperatures (>35°C) will cover more spatial and temporal areas, meaning that more days of the year will exceed historical annual averages and will continue to increase in the coming decades. Civil engineering curricula should consider the incorporation of sustainability and climate change mitigation practices.

This study bridges the gap between future microscale and mesoscale civil engineers' perspectives on urban heat by using advanced geomatics technologies and artificial intelligence to analyze the spatiotemporal variability of urban heat island (UHI) effects. The methodology integrated remote sensing, GIS-based modeling, and localized thermal measurements to enhance civil engineering students' understanding of UHI phenomena.

The survey revealed that most students were unfamiliar with the concepts of heat islands and building types before the class, but over 65% had a positive experience, improving their understanding of Geomatics and their perception of urban planning, sustainability, and construction materials, highlighting its relevance in civil engineering education.

This new applied knowledge is essential to foster awareness among students and young professionals and develop interventions to mitigate UHI effects and promote climate resilience in urban areas. It is important to study heat waves and the distribution of urban heat islands to focus on social and economic adaptation programs that help reduce thermal discomfort. The types of exterior building envelopes should consider the use of materials that allow for heat absorption, and if possible, develop new technologies for its harvesting.
The authors believe that this exercise will enhance the teaching practice by integrating the survey results into their instructional approach. Additionally, it provides valuable insights for redesigning the educational program, particularly incorporating content that addresses the integration of the Sustainable Development Goals into the professional practice of civil engineers.

5. Acknowledgements

The authors thank the Secretariat of Science, Humanities, Technology, and Innovation (Secihti) and the PRONAII 2024-35 project for awarding scholarships to our bachelor students of the Faculty of Civil Engineering, and students of the Master of Science in Environmental Engineering and Doctorate in Engineering with a focus on Environmental Engineering—at the Autonomous University of Nuevo León. We also acknowledge the Department of Geomatics at the Institute of Civil Engineering providing the tools and resources necessary to carry out this research.

6. References

Aboelata, A., & Sodoudi, S. (2019). Evaluating urban vegetation scenarios to mitigate urban heat island and reduce buildings' energy in dense built-up areas in Cairo. *Building and environment,* 166, 106407.

Ahmadalipour, A., Moradkhani, H., & Kumar, M. (2019). Mortality risk from heat stress expected to hit poorest nations the hardest. *Climatic Change,* 152, 569-579.

Akkose, G., Akgul, C. M., & Dino, I. G. (2021). Educational building retrofit under climate change and urban heat island effect. *Journal of Building Engineering*, 40, 102294.

Amani, M. J., Tanzadeh, R., Moghadas Nejad, F., Kabiri Nasrabad, M. M., Chalabii, J., & Movahedi Rad, M. (2025). Urban Sustainability Through Pavement Technologies: Reducing Urban Heat Islands with Cool Pavements. *Buildings,* 15(3), 504.

Barboza Lizano, Ó. (2013). Calentamiento Global:"la máxima expresión de la civilización petrofósil". Revista del CESLA. *International Latin American Studies Review*, (16), 35-68.

Bechtel, B., & Daneke, C. (2012). Classification of local climate zones based on multiple earth observation data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 5(4), 1191-1202.

Bechtel, B., Alexander, P. J., Beck, C., Böhner, J., Brousse, O., Ching, J., ... & Xu, Y. (2019). Generating WUDAPT Level 0 data–Current status of production and evaluation. *Urban climate,* 27, 24-45.

Bi, C., & Little, J. C. (2022). Integrated assessment across building and urban scales: A review and proposal for a more holistic, multi-scale, system-of-systems approach. *Sustainable Cities and Society*, 82, 103915.

Budzik, G., Sylla, M., & Kowalczyk, T. (2025). UnderstandingUrban Cooling of Blue–Green Infrastructure: A Review of Spatial Data and Sustainable Planning Optimization Methods for Mitigating Urban Heat Islands. *Sustainability*, 17(1), 142.

Bullock, P., & Gregory, P. J. (Eds.). (2009). Soils in the urban environment. John Wiley & Sons.

CEPAL. 2022. El mundo alcanza los 8 mil millones de habitantes, de los cuales 662 millones viven en América Latina y el Caribe. https://www.cepal.org/es/noticias/mundo-alcanza-8-mil-millones-habitantes-cuales-662-millones-viven-america-latina-caribe

Cichowicz, R., & Bochenek, A. D. (2024). Assessing the effects of urban heat islands and air pollution on human quality of life. *Anthropocene,* 100433.

Cui, Y., Yin, M., Cheng, X., Tang, J., & He, B. J. (2024). Towards cool cities and communities: Preparing for an increasingly hot future by the development of heat-resilient infrastructure and urban heat management plan. *Environmental Technology & Innovation*, 34, 103568.

Chakrabortty, R., Pramanik, M., Hasan, M. M., Halder, B., Pande, C. B., Moharir, K. N., & Zhran, M. (2024). Mitigating Urban Heat Islands in the Global South: Data-driven Approach for Effective Cooling Strategies. *Earth Systems and Environment*, 1-28.

Chen, B., Xu, B., & Gong, P. (2021). Mapping essential urbanland use categories (EULUC) using geospatial big data: Progress, challenges, and opportunities. Big Earth Data, 5(3),410-441.

Danielsen, A. S., Johansen, T. A., & Garrett, J. L. (2021). Self-organizing maps for clustering hyperspectral images on-board a cubesat. *Remote Sensing*, 13(20), 4174.

Du, R., Liu, C. H., Li, X., & Lin, C. Y. (2024). Interaction among local flows, UHI, coastal winds, and complex terrain: Effect on urban-scale temperature and building energy consumption during heatwaves. *Energy and Buildings,* 303, 113763.

EPA. 2022. Las islas de calor. Agencia de Protección Ambiental de Estados Unidos. https://espanol.epa.gov/la-energia-y-el-medioambiente/las-islas-de-calor

Ermida, S. L., Soares, P., Mantas, V., Göttsche, F. M., & Trigo, I. F. (2020). Google earth engine open-source code for land surface temperature estimation from the landsat series. *Remote Sensing*, 12(9), 1471.

Ermida, S.L. 2022. Landsat Land Surface Temperature, update to use collection 2. https://github.com/sofiaermida/Landsat_SMW_LST/blob/master/modules/Landsat_LST.js

Gago, E. J., Roldan, J., Pacheco-Torres, R., & Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable and sustainable energy reviews*, 25, 749-758.

García, J.E., Chávez, J.H., Terán, B.T., Álvarez, J., & Hermosillo, R. (2019). Metodología para el estudio experimental del comportamiento histeretico de una union viga-columna de concreto reforzado con fibras de acero adicionada. Paper presented at the XXII Congreso Nacional de Ingeniería Sísmica, Nuevo Léon, México.

Giuffrida, G., Fanucci, L., Meoni, G., Batič, M., Buckley, L., Dunne, A., ... & Aschbacher, J. (2021). The Φ-Sat-1 mission: The first on-board deep neural network demonstrator for satellite earth observation. *IEEE Transactions on Geoscience and Remote Sensing,* 60, 1-14.

Hamoodi, M. N. (2023). Study Urban Heat Island and Its Effects on Clamite of Al-Kut City Using Geomatics Techniques. University of Technology: Baghdad, Iraq.

Hasan, M. M., Pramanik, M., Alam, I., Kumar, A., Avtar, R., & Zhran, M. (2024). Assessing the efficacy of artificial intelligence based city-scale blue green infrastructure mapping using Google Earth Engine in the Bangkok metropolitan region. *Journal of Urban Management.*

Hou, C., Li, Y., & Zhang, F. (2024). Sensing Urban Physical Environment with GeoAI and Street-Level Imagery. In *Handbook of Geospatial Approaches to Sustainable Cities* (pp. 3-30). CRC Press.

INEGI. (2020). Censo poblacional de México. Instituto Nacional de Geoestadistica Informatica

Jamei, E., Ossen, D. R., Seyedmahmoudian, M., Sandanayake, M., Stojcevski, A., & Horan, B. (2020). Urban design parameters for heat mitigation in tropics. *Renewable and sustainable energy reviews*, 134, 110362.

Jauregui, E. (1987). Urban heat island development in medium and large urban areas in Mexico. *Erdkunde*, 48-51.

Joshi, K., Khan, A., Anand, P., & Sen, J. (2024). Understanding the synergy between heat waves and the built environment: a three-decade systematic review informing policies for mitigating urban heat island in cities. *Sustainable Earth Reviews*, 7(1), 25.

Junaid, S. M. (2024). The Classification of Land Use and Land Cover was conducted using the Manual Method in ArcGIS and using AI/ML in the Google Earth Engine for Salem District, Tamilnadu, India.

Khan, Y., O’Sullivan, T., Brown, A., Tracey, S., Gibson, J., Généreux, M., ... & Schwartz, B. (2018). Public health emergency preparedness: a framework to promote resilience. *BMC public health*, 18, 1-16.

Li, H., Harvey, J. T., Holland, T. J., & Kayhanian, M. (2013).The use of reflective and permeable pavements as a potential practice for heat island mitigation and stormwater management. *Environmental Research Letters,* 8(1), 015023.

Li, Z., & Wu, S. (2025). Research on the heat conduction, physical and rheological properties of asphalt binder modified with boron nitride. *Construction and Building Materials,* 462, 139937.

Malik, A., & Kumar, R. (2025). Cool Pavements and Their Role in Enhancing Urban Thermal Comfort. *Baltic Multidisciplinary Research Letters Journal*, 2(1), 77-86.

Manna, H., & Sarkar, S. (2025). Quantifying urban Land SurfaceTemperature (LST) dynamics in an industrial and mining hub of Eastern India using remote sensing and geospatial analysis. *Theoretical and Applied Climatology*, 156(3), 151.

Mantilla Baquero, J. D. Elementos de innovación en la vivienda agrupada, Conjunto residencial Los Cedros, Bucaramanga 1970.

McMichael, A., McMichael, C., Berry, H., & Bowen, K. (2010). Climate-related displacement: health risks and responses. Climate Change and Population Displacement: Multidisciplinary Perspectives. Oxford, England: Hart Publishing Ltd.

McPhearson, T., Haase, D., Kabisch, N., & Gren, Å. (2016).Advancing understanding of the complex nature of urban systems. Ecological indicators, 70, 566-573. https://doi.org/10.1016/j.ecolind.2016.03.054

Middel, A., Nazarian, N., Demuzere, M., & Bechtel, B. (2022). Urban climate informatics: An emerging research field. *Frontiers in Environmental Science,* 10, 867434.

Milesi, C., & Churkina, G. (2020). Measuring and monitoring urban impacts on climate change from space. *Remote Sensing*, 12(21), 3494.

McMichael, A.J.; Wilkinson, P.; Kovats, R.S.; Pattenden, S.; Hajat, S.; Armstrong, B.; Vajanapoom, N.; Niciu, E.M.; Mahomed, H.; Kingkeow, C.; et al. International study of temperature, heat and urban mortality: the 'ISOTHURM' project. Int. J. Epidemiol. 2008, 37, 1121–1131, doi:10.1093/ije/dyn086.

ONU. 2018. Las ciudades seguirán creciendo, sobre todo en lospaíses en desarrollo. https://www.un.org/development/desa/es/news/population/2018-world-urbanization-prospects.html

Palau Flórez, D. (2016). Estudio de alternativas de una envolvente urbana que permita mitigar el efecto isla de calor y su incidencia sobre el confort y el medio ambiente.

Paramita, B. (2025). Building climate resilience in Indonesia: The role of cool roofs. Field Actions Science Reports. *The journal of field actions*, (Special Issue 27), 112-122.

Parihar, J., & Birman, S. (2024). Heat Resilience in Urban Environments: Strategies for Sustainable City Climate Management. In The Climate-Health-Sustainability Nexus: Understanding the Interconnected Impact on Populations and the Environment (pp. 305-324). Cham: Springer Nature Switzerland.

Pérez, I. 2020. Olas de calor, cada vez más frecuentes en México. https://ciencia.unam.mx/leer/1018/las-olas-de-calor-cada-vez-mas-frecuentes-en-mexico

Pérez, N. R. 2021. Renaturalizar las ciudades: una estrategia de planeación para la sustentabilidad urbana. Paisaje, ordenamiento y sustentabilidad, 147.

Ríos Lizcano, A. K. (2019). Ecosistemas urbanos: Un servicio ambiental para el municipio de Monterrey (Doctoral dissertation, Universidad Autónoma de Nuevo León).

Rivera Rivera, A. L. (2012). Urban heat islands in Monterrey, Mexico using remote sensing imagery and geographic information systems analysis.

Roelich, K., & Giesekam, J. (2019). Decision making under uncertainty in climate change mitigation: introducing multiple actor motivations, agency and influence. *Climate policy*, 19(2), 175-188.

Roldán Viloria, J. (2013). Energías renovables. Lo que hay que saber. Ediciones Paraninfo, SA.

Rosenberg, N. J., Blad, B. L., & Verma, S. B. (1983). *Microclimate: the biological environment.* John Wiley & Sons.

Schiano-Phan, R., Weber, F., & Santamouris, M. (2015). The mitigative potential of urban environments and their microclimates. *Buildings,* 5(3), 783-801.

Santamouris, M. (2014). On the energy impact of urban heat island and global warming on buildings. *Energy and buildings*, 82, 100-113. doi: 10.1016/j.enbuild.2014.07.022

Sida, J., Huang, F., Zhan, W., Bechtel, B., Liu, Z., Demuzere, M., Zhang, X., 2021: Mapping Local Climate Zones: A Bibliometric Meta-Analysis and Systematic Review. doi.org/10.31219/osf.io/c2bez

Siehr, S. A., Sun, M., & Aranda Nucamendi, J. L. (2022). Blue-green infrastructure for climate resilience and urban multifunctionality in Chinese cities. *Wiley Interdisciplinary Reviews: Energy and Environment*, 11(5), e447.

Singh, N., Singh, S., & Mall, R. K. (2020). Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus. In *Urban ecology* (pp. 317-334). Elsevier.

Stone Jr, B., & Rodgers, M. O. (2001). Urban form and thermal efficiency: how the design of cities influences the urban heat island effect. American Planning Association. *Journal of the American Planning Association,* 67(2), 186.doi: 10.1080/01944360108976228

Sun, T., Grimmond, C. S. B., & Ni, G. H. (2016). How do green roofs mitigate urban thermal stress under heat waves?. *Journal of Geophysical Research: Atmospheres,* 121(10), 5320-5335.

Voogt, J. (2007, July). How researchers measure urban heat islands. In United States Environmental Protection Agency (EPA), State and Local Climate and Energy Program, Heat Island Effect, Urban Heat Island Webcasts and Conference Calls.

Xu, C., Chen, G., Huang, Q., Su, M., Rong, Q., Yue, W., & Haase, D. (2022). Can improving the spatial equity of urban green space mitigate the effect of urban heat islands? An empirical study. *Science of The Total Environment,* 841, 156687.

Xu, X., Qiu, W., Li, W., Huang, D., Li, X., & Yang, S. (2022). Comparing satellite image and GIS data classified local climate zones to assess urban heat island: A case study of Guangzhou. *Frontiers in Environmental Science*, 10, 1029445. doi: 10.3389/fenvs.2022.1029445

Yang, L., Driscol, J., Sarigai, S., Wu, Q., Chen, H., & Lippitt, C. D. (2022). Google Earth Engine and artificial intelligence (AI): a comprehensive review. *Remote Sensing,* 14(14), 3253.

Zapata Wah, I. G., Yépez Rincón, F. D., & Huerta-García, R. E. (2024). Analyzing Monterrey blue/green infrastructure for the mitigation of heat islands using Earth Observation and WUDAPT method. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 10, 439-444.

Zermoglio, M. F., Van Jaarsveld, A., Reid, W., Romm, J., Biggs, O., Yue, T. X., & Vicente, L. (2005). The multiscale approach. Millennium Ecosystem Assessment, Ecosystems and Human Wellbeing: multi-scale assessment, 4, 61-84.

Zong, H. (2024). Odor Monitoring and Modeling at an Urban Waterfront and Landfill Site in Hong Kong (Doctoral dissertation, Hong Kong University of Science and Technology (Hong Kong)). https://www.proquest.com/openview/158d7f8e73954e89fe80c2517e7b04b7/1?pq-origsite=gscholar&cbl=2026366&diss=yOke, T. R. (1982). The energetic basis of the urban heat island. Quarterly journal of the royal meteorological society, 108(455), 1-24. https://patarnott.com/pdf/Oake1982_UHI.pdf

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., ... & Sobrino, J. A. (2018). Satellite remote sensing of surface urban heat is-lands: Progress, challenges, and perspec-tives. *Remote Sensing*, 11(1), 48.doi: 10.3390/rs11010048