

Implementation of a solar model and shadow plotting in the context of a 2D ${\sf GIS}$

Challenges and applications for the cooling effect of tree-covered based greening solutions in urban public spaces

Thomas Leduc, Xenia Stavropulos-Laffaille, Ignacio Requena-Ruiz

{thomas.leduc, xenia.laffaille, ignacio.requena}@crenau.archi.fr



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Solar model and shadow plotting

Urban cooling strategies

- Urban bioclimatic specific response (Sobstyl et al., 2018)
 - Overheating amplification
 - Mitigation and adaptation strategies (Aram et al., 2019)
 - Vegetative cover
 - Stack night ventilation
 - Water bodies
 - Modification of surface albedos
 - "Shading is a key measure to improve OTC¹ and mitigate UHI²" (Ruefenacht and Acero, 2017), (Aleksandrowicz et al., 2020)
 - incoming solar radiation interception, evapotranspiration, etc.
- The Coolscapes research program (ANR-18-CE22-0003)
 - An interdisciplinary approach to understand the manifold phenomena influencing citizens' thermal perception

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¹OTC: outdoor thermal comfort ²UHI: urban heat island

Sunlight exposure in streets is directly linked to design decisions

- The strictly geometric aspects of shading is essential in answering simple questions like:
 - Where are located the "shadow fences" generated by the urban environment at a given date and time?
 - How much space of a predefined study area is in shade for a given date and time?
 - What is the tree canopy contribution to the total shade cover?
 - What is the evolution of this contribution over the summer period, the crown remaining unchanged?
 - What areas are shaded for at least 3 hours on a hot summer day?
 - What areas are shaded for at least 3 consecutive hours on a hot summer day?
 - Do these areas guarantee spatial continuity in order to allow comfortable pedestrian mobility?

Reference tools

- Numerical modeling of the urban climate: several softwares are designed to calculate radiation and thermal comfort conditions
 - CAAD-based
 - Townscope
 - Heliodon 2
 - Solene
 - etc.
 - Grid-based
 - RayMan
 - Solweig → UMEP (QGIS plugin)
 - CityComfort+ (Rhino, Radiance, raster layer in ArcMap 10)
 - Ladybug/Honeybee (Rhino, Dynamo, Radiance, EnergyPlus, etc.)
 - ENVI-met
 - TUF-3D (3-D raster structure)
 - etc.

Technical solution implemented

• Geopandas (pandas + shapely), Pysolar, etc.



 3D Management: buildings as right prisms, spherical/ cylindrical/ conical trees



Shadow overlaps through contour network polygonization

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Case study: Cours Cambronne (Nantes, France)



- Graslin district: 13.6 ha, 293 buildings (floor area: 6.4 ha), 98 trees
- Cours Cambronne: a public walkway lined with buildings and 64 trees, 180m × 50m



Case study: Shade contribution of the tree canopy



- On 21st July at 12 am (UTC), the 293 buildings and 98 trees produce a ground shade of approx.
 2.8 ha, i.e. approx. 20% of the district total area
- The shade produced by the tree canopy represents about 16% of the total shade on the ground

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Case study: Shade ratio evolution over the summer period





- The tree-shades cover on average one third of the courtyard
- This contribution is almost systematically higher than that of the surrounding buildings (×6 at 2 pm UTC)

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Case study: Delineation of shaded areas over several hours



- Try to delineate potential cool spots during a heat wave event
- Although the central strip situated halfway between the two rows of trees is finally fairly exposed, the tree roots are very well protected

Delineation of shaded areas over several consecutive hours



- Handling temporal continuity beyond spatial continuity
- Delineate areas that are permanently in the shade (to design and deploy appropriate street furniture)
- The overall fragmentation decreases, patterns that guarantee a certain spatial continuity emerge

Image: A math a math

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Discussion: pros

- Pros: beyond descriptive analysis, shadow as a design object
 - While it is possible to vectorise the raster shadows obtained via UMEP, the underlying pixelisation is nevertheless problematic when seeking to use shadows for the design of urban spaces as given, for example, in the solar envelope concept (Knowles, 2003)



- Vector shadows enable to delineate potential cool-paths and urban oases or cools spots in the urban fabric
- Simple and automatique method based on standard urban data. On the shelf, easy and fast to apply to a big study area

Discussion

Discussion: contras

- Contras: need for an energy-based approach
 - ► The current method is not based on DEMs → the interactions between the topography and the sun path model are not considered
 - The simplified and strictly geometric approach is not sufficient to properly inform the complex notion of pedestrian thermal comfort in heterogeneous urban spaces
 - Particular building geometries (e.g., walkways, porches, steep rooftops) are not considered
 - Thermal comfort simulation tools such as ENVI-met allow studying the spatial distribution of thermal comfort indexes by integrating an energy-based approach
 - Using a more representative geometric approach, based on 3D city models (ex. CityGML (Biljecki et al., 2018)) and a thermo-radiative (or even aeraulic) model would make it possible to transform this prototype into a more relevant tool for city designers

Conclusion

- An overlay to Geopandas which benefits from the combined power of the pandas and shapely libraries in particular, but also from a highly developed ecosystem (notebooks in particular)
- To assist urban designers with GIS&T solutions that make it possible to distinguish the respective shadow contributions, their annual evolution and potential spatial or temporal continuities
- To go beyond the calculation and descriptive analysis of the shadows cast in the urban space and to use them as standard polygonal shapes

Perspectives for extension

- Development of thermal comfort indicators for outdoor spaces
- Implementation of computationally-efficient radiation exchanges in an Urban Canopy Model with trees
- GIS&T Body of Knowledge domain applications by UCGIS
 - Architecture
 - Climate Studies & Atmospheric Science
 - Environmental Science & Management
- GdR MAGIS 2022-2026: Action de Recherche *Géomatique, Ville, Climat et Pollution*, A. Ruas (Univ. Eiffel) and T. Leduc
 - To better identify, structure and develop geomatics for urban climate and pollution studies

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Conclusion

t4gpd

- https://github.com/crenau/t4gpd
- https://t4gpd-docs.readthedocs.io

