Irradiated Shade

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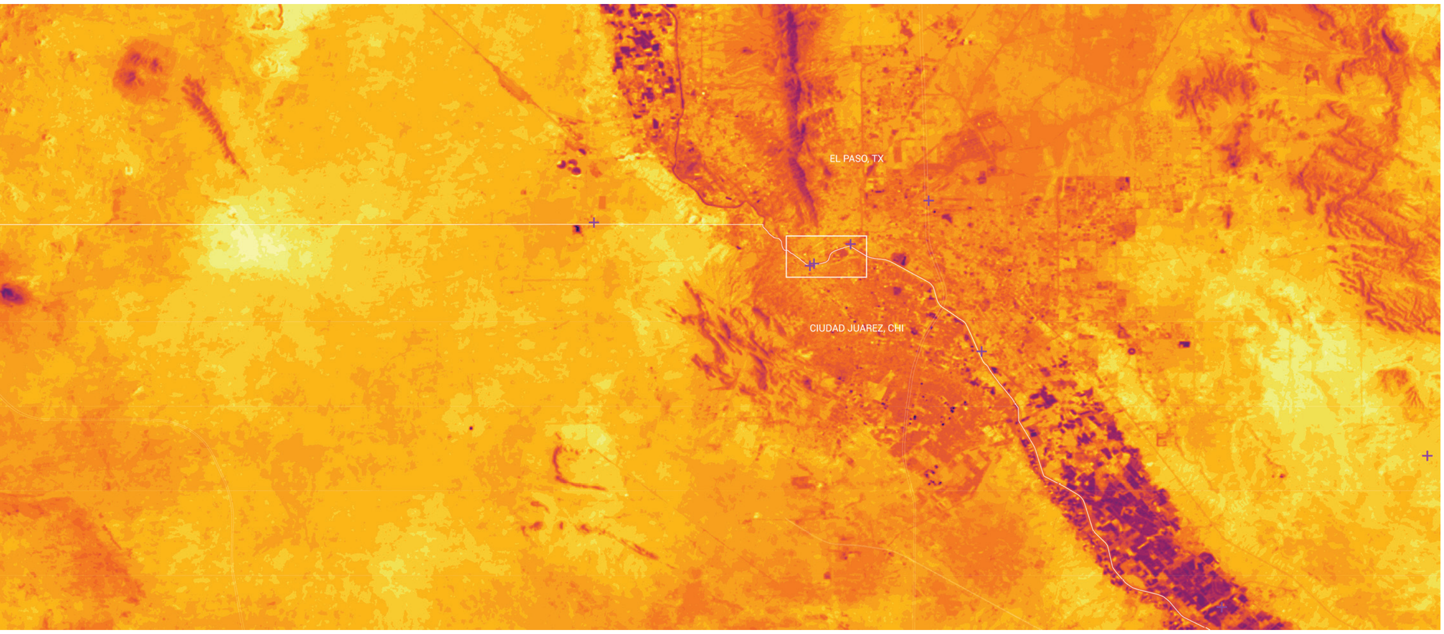
Mapping, Modeling, and Measuring Urban UVB Exposure



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1 Land surface temperature map, El Paso/Ciudad Juárez Metroplex.

ABSTRACT

The paper details computational mapping and modeling techniques from an ongoing design research project titled Irradiated Shade, which endeavors to develop and calibrate a computational toolset to uncover, represent, and design for the unseen dangers of ultraviolet radiation, a growing yet underexplored threat to cities, buildings, and the bodies that inhabit them. While increased shade in public spaces has been advocated as a strategy for "mitigation [of] climate change" (Kapelos and Patterson 2014), it is not a panacea to the threat. Even in apparent shade, the body is still exposed to harmful, ambient, or "scattered" UVB radiation. The study region is a binational metroplex, a territory in which significant atmospheric pollution and the effects of climate change (reduced cloud cover and more "still days" of stagnant air) amplify the "scatter" of ultraviolet wavelengths and UV exposure within shade, which exacerbates urban conditions of shade as an "index of inequality" (Bloch 2019) and threatens public health. Exposure to indirect radiation correlates to the amount of sky visible from the position of an observer (Gies and Mackay 2004). The overall size of a shade structure, as well as the design of openings along its sides, can greatly impact the UV protection factor (UPF) (Turnbull and Parisi 2005). Shade, therefore, is more complex than ubiquitous urban and architectural "sun" and "shadow studies" are capable of representing, as such analyses flatten the three-dimensional nature of radiation exposure and are "blind" to the ultraviolet spectrum. "Safe shade" is contingent on the nuances of the surrounding built environment, and designers must be empowered to observe and respond to a wider context than current representational tools allow.

INTRODUCTION

The project seeks to expand the architect's toolkit in simulating and representing the impact of ultraviolet radiation on sites and bodies, through the production of custom representational tools, drawings, and shade structure designs. This paper will focus primarily on the challenges and efforts to conduct analyses at the urban scale within the study area to identify areas where solar radiation poses a high risk to populations despite apparent shade. This paper will describe the challenges of mapping solar radiation at an urban scale within a binational urban context; proposed approaches, computational tools, and workflows across geographic information system (GIS) and design software platforms to overcome these challenges, including a spherical projection algorithm developed specifically for this application; and the emerging representational outcomes.

CHALLENGES

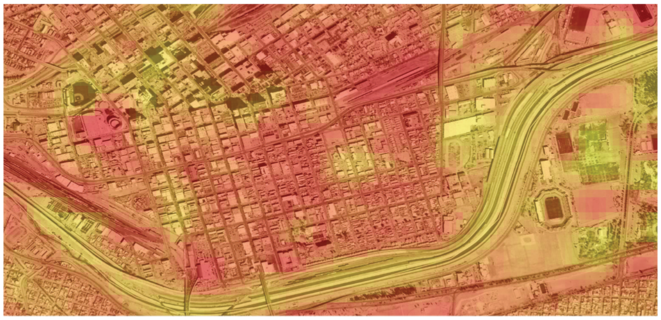
The study focuses on applications within the El Paso/Ciudad Juárez metroplex, a binational territory defined by the inequitable distribution of public shade, where significant atmospheric pollution amplifies the "scatter" of ultraviolet wavelengths and UV exposure within public space. The metroplex spans the US-Mexico border and is characterized by a fragmented multijurisdictional datascape at the intersection of two nations and three states, a complex patchwork of disparate municipal, county, and regulatory domains (Kripa and Mueller 2021). These multiple regulatory boundaries divide the political administration of the territory while also imposing artificial divisions in the collection and distribution of geospatial data relevant to otherwise continuous, transboundary environmental phenomena, including urban UV exposure. As substantial portions of the metroplex population fluidly inhabit multiple jurisdictions on a daily or weekly basis, they cross territories with substantially changing capacities, standards, and protocols for urban environmental assessment. Shared, cross-border environmental and urban planning efforts capable of addressing environmental health risks and promoting environmental justice in the region are limited by both the technical challenges to overcome differences in data gathering and reporting methods across multiple jurisdictions, as well as changing attitudes toward international cooperation at the federal level.[1] Without complete, contiguous, and comparable data describing ultraviolet solar radiation exposure, the disparities and asymmetries in threats to public health across multiple and interrelated jurisdictions remain hidden and difficult to address.

An urban solar radiation analysis in the borderland capable of spanning multiple jurisdictional divisions currently relies on one of two distinct approaches. The first approach would entail a process of data assemblage. That is, researchers could gather discontinuous data from multiple domains and attempt to forge continuities and comparative analyses across the boundaries by addressing the discrepancies in the geographic or environmental data provided. Alternatively, investigators could seek out transboundary datasets that bypass the various data divides. In the study area, this approach would entail the collection of transboundary satellite data or open-source urban-level data. The data assemblage approach in the binational study area faces unique challenges, including the different languages, units of measurement, reporting frequencies, and methods of data collection between the US and Mexico. The alternative approach—to rely on already-contiguous transboundary datasets—faces its own challenges. Contiguous satellite data and imagery in the region is mostly available at a resolution unsuitable for urban-level analysis. High-resolution satellite data and imagery is available from national sources in the US and Mexico and faces a similar challenge to create comparable and contiguous analyses. Open-source urban-level data in the region, including physical and urban geographic features, is relatively incomplete.

In addition to these context-specific challenges, urban-scale solar radiation analysis in any context faces particular difficulties. First is the complexity of the phenomenon (Mueller 2021). Solar radiation levels in an urban environment are dependent on multiple physical and environmental conditions. Physical features (including both topographic elements and elements of the built environment that can impact shade, shadow, and reflectivity) and changing environmental factors (including solar angle, cloud cover, and amount of airborne particulate) can mitigate or amplify ultraviolet radiation exposure in an urban environment. Both direct and diffuse radiation can impact the relative risk of ultraviolet exposure, and each type impacts each site differently at different times of day. Second is the limited availability and application of tools, workflows, and representational methods for urban planners and designers to produce comparative analyses of urban sites incorporating these multiple factors to determine exposure risk and to evaluate proposed solutions to mitigate exposure.

METHODS

To address these challenges, the project takes a composite approach, leveraging readily available cross-border satellite data to begin with a continuous transboundary assessment, while selectively augmenting the relatively low resolution of the dataset with a series of higher-resolution overlays and computational mapping and modeling



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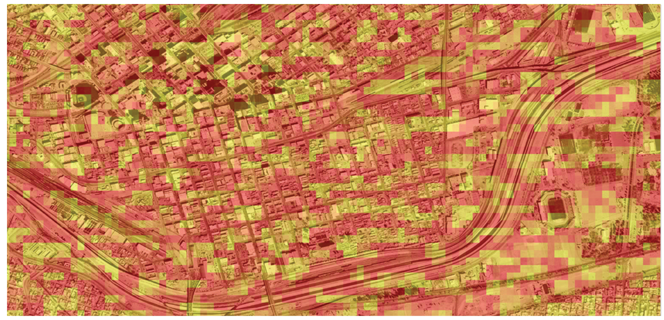

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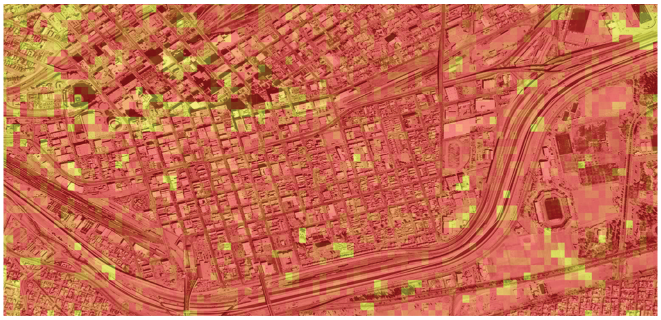

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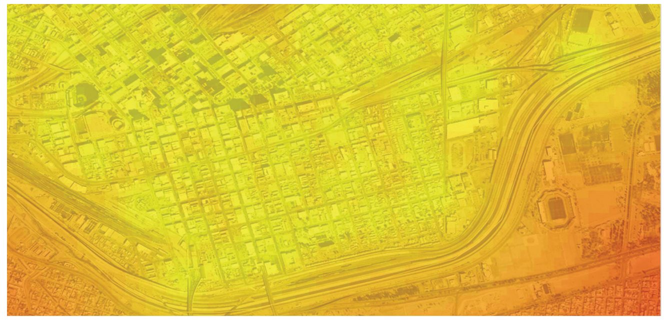

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2 Land surface temperature map.

3 Diffuse radiation map.

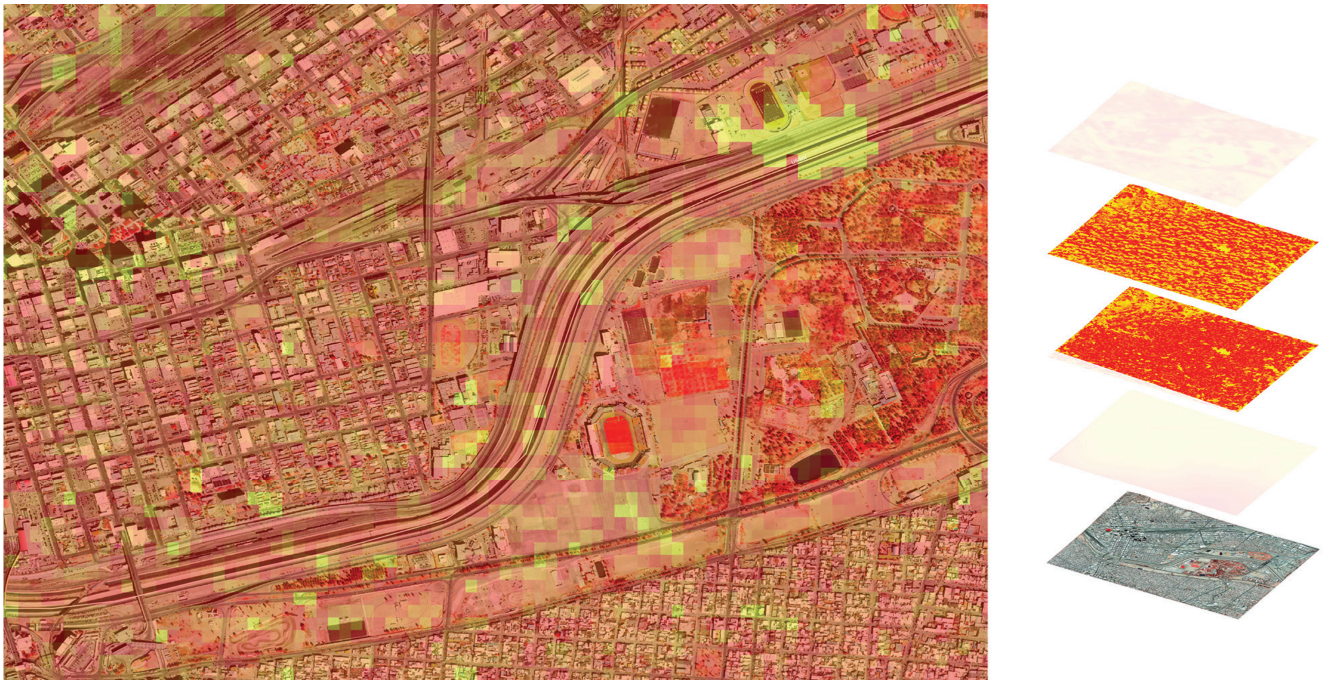
4 Direct radiation map.

5 Pedestrian intensity map.

techniques. Satellite imagery and sensor data serve as inputs for a series of initial mapping underlays that help to describe the major environmental conditions impacting urban ultraviolet exposure in the study region.

A digital elevation model (DEM) is a common input for solar radiation analysis in geographic information system (GIS) mapping platforms, as the slopes and shadows of topographic features impact the amount of radiation absorbed by a given exposure. The DEM available for the study area from the National Elevation Dataset provides topographic information in the metroplex at a relatively low 1 arcsecond resolution. Higher resolutions are available for US topography, but these datasets end abruptly at the international border. The available DEM can be used with built-in solar radiation analysis tools in ArcGIS Pro (ESRI 2021) to generate low-resolution, transboundary assessments of direct, diffuse, and total solar radiation in the borderland. But the model at this resolution approximates only topographic features, largely ignoring elements of urban geography (e.g., buildings and bridges). Additionally, this 2.5D height information fails to capture more complex, layered canopy conditions from street trees and other overhanging elements common to urban environments and likely to impact radiation exposure. Asymmetries in ultraviolet exposure with this method are most certainly below what Eyal Weizman has termed the "threshold of detectability" (Weizman 2017), and additional measures must be taken to increase the resolution of the investigation.

Three other readily available data sources can help to augment the analysis: optical, thermal, and height-field data. Satellite data from LANDSAT 8 includes both optical and thermal information at a resolution of 60 cm for the study area, and is contiguous across the international boundary, including portions of Ciudad Juárez. The LANDSAT program captures and publishes satellite imagery in different spectral bands, including optical and thermal bands. By processing the optical bands in GIS software, a false-color image of the urban environment can be produced, which in turn can help distinguish areas of vegetation, shown in red, within urbanized land, shown in light blue. Raster-based analysis comparing these aspects of the false-color image can identify likely areas of street trees impacting urban UVB exposure. By processing the information stored in the thermal bands, a land surface temperature map can be produced,[2] identifying areas in which populations may be exposed to the most heat stress, and therefore most likely to seek shade. To better analyze the impact of the three-dimensional urban environment on solar radiation exposure, a three-dimensional model of the buildings and other built structures is needed. The study area lacks comprehensive building footprint and building height data, and open-source data presents only a partial understanding. LiDAR (light detection and ranging) data sources[3] are published as point clouds of natural and man-made elements, which can also be used to conduct analyses of direct, diffuse, and total radiation. While this level of three-dimensional resolution is an essential and



6 Composite map.

expedient component of a study in this region, readily available datasets from the United States Geological Survey (USGS) capture only portions of the study region south of the international boundary.

Noting that no single available dataset—or single analysis from such dataset—can capture the full complexity of urban-scale solar radiation as outlined above, and that the resolution of any one dataset is inadequate to inform analyses below the scale of a city block, the project explored two parallel hypotheses and two parallel investigations.

First, by compositing available datasets and producing a series of graphic and computational overlays, we suggest that the compound effects of multiple urban and environmental factors contributing to urban shade and UV exposure may be better ascertained, and sites most at risk of "irradiated shade" may be identified.

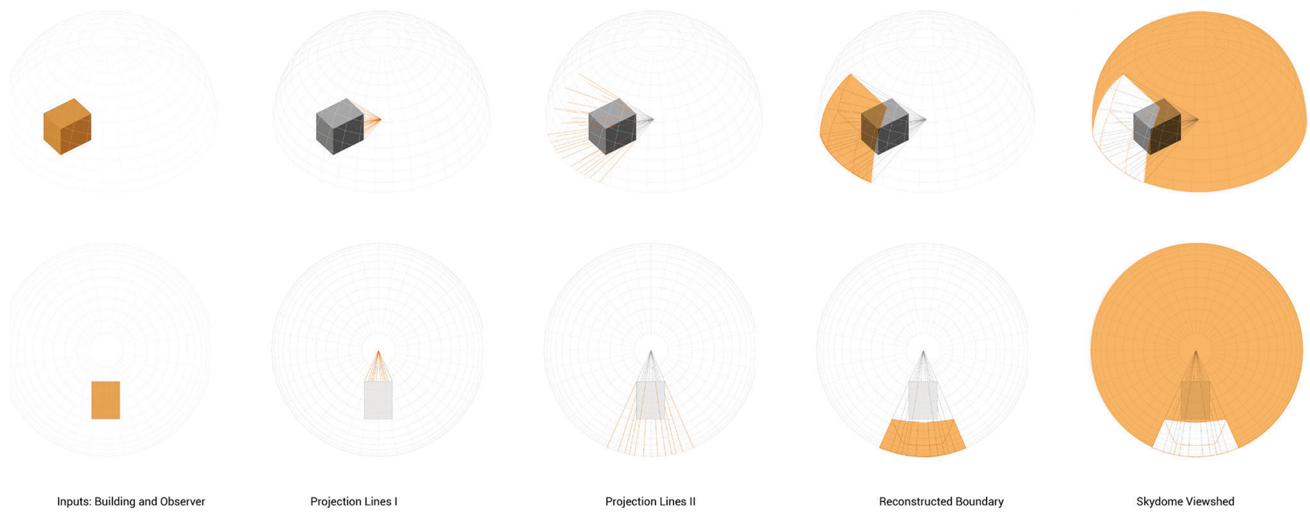
Second, since the calculation of urban UV exposure depends primarily on "hidden" processes within GIS software platforms conditioned by three-dimensional constructs of the urban environment, we suggest that a higher-resolution analysis may be possible by translating the hidden logics of common solar analysis tools through computational algorithms, to produce detailed representations of the geometric and spatial relationships, and resulting conditions of solar radiation and shade on a specific site.

Composite and Computational Mapping

Our composite mapping efforts start with a focus on the area near the international boundary, where there is a high degree of pedestrian activity from travelers entering and leaving the US via pedestrian bridges. The channelized Rio Grande/Rio Bravo, tracking across the maps from left to right, serves as the international boundary. The midrise and high-rise urban core of downtown El Paso, Texas, is shown toward the top of the map, with lower-rise neighborhoods moving south into Ciudad Juárez. The maps are developed in ArcGIS Pro, using some built-in tools and raster-processing workflows to extend what is visible.

Processing the thermal band information from the LANDSAT data, we produced a *land surface temperature map* (Fig. 2) of the study region during the summer solstice, showing the cool mountain peaks and intense heat of the urban heat island within which populations seek shade. This base map begins to describe the character of the urban environment and some initial areas of likely risk, with increased heat island effects throughout the approach to the border and particular hot spots near the pedestrian bridges and transit connections near the port of entry.

We then produce a *direct solar radiation map* (Fig. 4), using the 1-arcsecond DEM and the Solar Radiation toolset in ArcGIS Pro. The resulting rather noisy map shows direct solar radiation averaged over the same period. The impact of the topography on solar exposure is evident, with the



7 Spherical projection algorithm diagram.

low area of the river valley shown with a relatively even distribution of direct radiation. Higher topography and the building masses of the downtown core provide some protection from solar radiation away from the border. Building masses are registered in the checkerboard pixelization but clearly at a low resolution, given the source data.

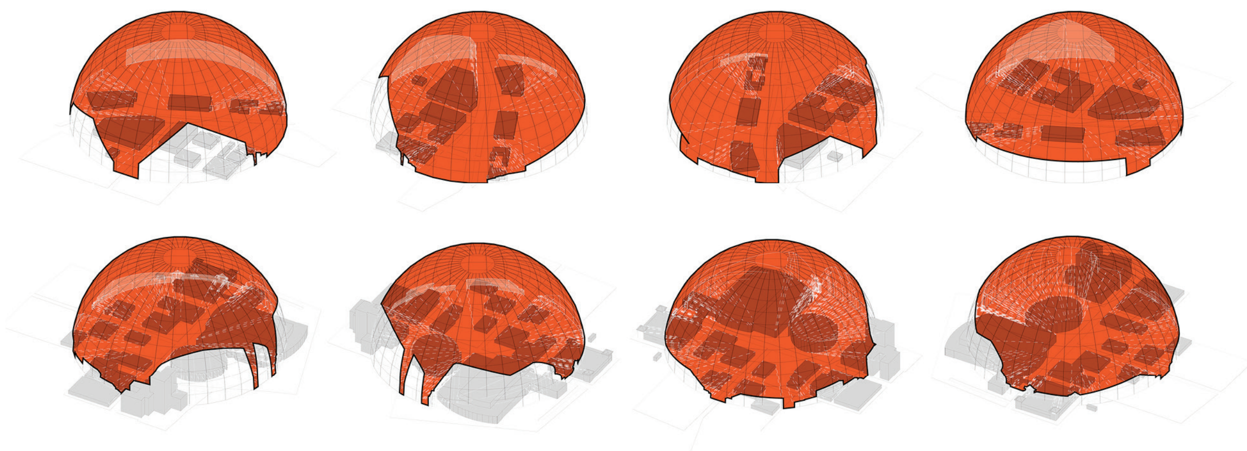
Next we produce a *diffuse solar radiation map* (Fig, 3), also from the DEM and the built-in Solar Radiation toolset. The diffuse map begins to capture the effects of UV scatter in the border environment. Built into the calculation is a degree of cloud cover, which approximates the diffuse radiation bouncing off clouds and atmospheric particles. The UVB spectrum is more prominent in diffuse solar radiation, and its spread is conditional on the amount of sky visible to an observer at any given point. Diffuse radiation is thus impacted in this map by both the topography and the urban canyons. The map begins to capture a clearly unequal, asymmetrical distribution of UV protection in the study area. Relatively low amounts of diffuse radiation, shown in the yellow tones, are abundant in the urban core but few and far between in the approach to the bridges, a result of the low building heights, wide streets, reflective surfaces including transit zones and parking areas, and low number of street trees. These broad swathes of high exposure to diffuse radiation cover some of the lowest-income zip codes in the city, and in fact in all of the US, signaling access to urban UV protection as an underconsidered condition of environmental inequity.

To get even higher resolution on the distribution of radiation, we use LiDAR point cloud data to generate the urban terrain with better detail, making possible a more focused study at the block level, revealing areas of relatively high protection against diffuse radiation in the urban core, and conditions of general overexposure along the streets approaching the bridges.

The risk of harmful effects due to solar radiation are tied to the length of an individual's exposure, so we also find proxies for the likely locations of high intensities of pedestrian activity in the study area. We produce a *pedestrian intensity map* (Fig. 5), layering in municipal GIS data, like the location of bus and streetcar stations and population data, to calculate walking distance to transit stops. The distribution reveals some transit shadows along the approach to the Paso del Norte bridge and throughout the low-income neighborhoods, indicating increased exposure time for pedestrians seeking access to transit.

We next analyze the optical bands of the LANDSAT data and convert the raw data to a false-color image to reveal the distribution of vegetation, including likely areas for street trees. We note also that this protective amenity corresponds to areas already well-protected by taller buildings and topography, likely increasing the disparity of exposure conditions in the study area.

Using these maps as base layers, we then developed a *compound analysis workflow* that weights each input in order to identify areas of compound risk. The *composite map* (Fig. 6) reveals an abundance of ultraviolet exposure and a pronounced shade deficit near the international border. Major pedestrian areas near international bridges and ports of entry—where urban density, building heights,



8 Urban sky exposure analysis using spherical projection algorithm.

and amount of street trees are low—are particularly overexposed. A number of hot spots emerge, demonstrating where ultraviolet exposure is most extreme. By running graphic and numeric overlays of the various base layers, we can begin to see some compound effects. By overlaying the land surface temperature and pedestrian intensity map, for instance, we can see and calculate the areas that are generally hotter, and in which pedestrians would have longer commutes. Overlaying the direct and diffuse radiation maps, we can better understand the need to design for changing concerns throughout a single urban corridor.

Spherical Projection Algorithm

To calculate solar radiation, ArcGIS Solar Analysis tools and other GIS platforms use a similar approach, first analyzing height data stored in a digital elevation model to compute a hemispheric viewshed, creating a kind of circular map of the areas of exposed sky. The resulting *viewshed map* is based on a sampling of the surrounding height field in a specified number of directions (Tovar-Pescador et al. 2006). Its accuracy is conditional on the resolution of the height data provided, and while a useful visualization, the map is left "behind the scenes" of the solar analysis tools, an intermediate step in the production of the more common visualizations: the *sunmap* and *skymap*.

The sunmap is a familiar architectural and urban solar analysis tool, describing the path of the sun at different times and days throughout the year. Calculations overlaying the sunmap with the viewshed diagram yield direct radiation values. The skymap calculates diffuse radiation values for different sectors of the sky dome. Calculations overlaying the skymap with the viewshed diagram yield diffuse radiation values (Tovar-Pescador et al. 2006). Both the sunmap and the skymap are shown in a similar hemispherical projection, similar to what would be captured by a fish-eye photograph. Researchers comparing this geometric computational approach in GIS software to the real-world analysis of urban environments have shown the computational to correlate accurately with empirical measurements. In one related example, researchers confirmed the relative accuracy of calculated Sky View Factors (SVF) using skymaps produced through fish-eye photography compared to the GIS simulation (Chen et al. 2012).

It has further been shown that exposure to indirect radiation under a shade structure correlates to the amount of sky visible from the position of an observer (Gies and Mackay 2004). To provide "safe shade," designers must be able to map and model the impact of the built environment on UVB exposure on urban sites with higher precision and evaluate the effectiveness of architectural designs in protecting populations from UVB scatter.

Borrowing from some of the hidden logics built into solar analysis in GIS software, we developed our own tools to visualize and assess conditions of urban UV exposure, translating the "behind the scenes" operations to a more immediate, interactive, and responsive design environment. To better understand the impact of building geometry on UV exposure in urban space, we developed a *spherical projection algorithm* (Fig. 7) in Rhino and Grasshopper (Robert McNeel & Associates 2020; Rutten 2020). The algorithm translates the hidden logic of the GIS calculations into an interface more familiar to architects and urban design professionals, and allows for real-time feedback for site studies and design evaluations, more immediate than waiting for GIS software or plug-ins to render results. This helps us to analyze the impact of existing building forms on diffuse UV exposure and assess the impact of any future intervention. By seeing the particular geometry of sky exposure from one or several public spaces, we can calibrate the extents of a new building mass or shade canopy to provide better protection

Drawing on the evidence that the amount of UV radiation entering a shaded condition is directly proportional to the amount of visible sky seen from the shade, we have developed a technique for spherical projection that takes any point in the city, scans the surrounding cityscape, and masks any obstructions on the sky dome (Fig. 8). This computational technique yields both a computable surface and a graphic representation of the areas of potential vulnerability, as well as metric information, including the percentage of sky cover and other orientation vectors. We can "unroll" this projection in a panorama-style drawing to better understand how the surrounding city offers protection against UV exposure, and work in this environment with design proposals in real time to see how interventions might additionally mask the sky dome. An additional algorithm unrolls the spherical projection in a panorama-style drawing, allowing designers to see the particular geometry of the skyline clearly in every direction so we can begin to assess and address these overexposed orientations.

The research team has begun deploying the algorithm at highly trafficked intersections in the borderland to reveal the varying degree of exposure to the sky, and therefore to diffuse radiation and damage from UVB. We then developed a custom technique to map and measure the sky exposure, and direction of exposure at each intersection, to find likely zones of exposure. We needed first to construct a comprehensive building model of the study region to more accurately physically compute three-dimensional conditions. By deploying the algorithm in the digital model, we further reveal trends in increased UVB exposure near the international boundary, in pedestrian areas approaching the crossing, where pedestrians are at the greatest risk of unhealthy exposure.

We have sampled every major pedestrian intersection in the study area near the border to compile a *sky exposure catalog* of the metroplex, color-coding each by their exposure area, graphically identifying areas at highest risk of exposure to diffuse radiation. The resulting masked sky dome represents an optimized form for maximum UVB protection for any given point in the city. From each masked sky dome we compute the ratio of exposure, rendering the most exposed forms in deepest orange, indicating the intersections with highest risks. The catalog reveals significant differences in urban ultraviolet exposure in the study region. From these assessments we can see at much higher resolution the differences in exposure along the pedestrian corridors and can locate areas most in need of additional protection. Each intersection yields a different and highly articulated sky exposure map, which we use as a computable surface (Fig. 9). Raw data from the surface area, for instance, allow us to make quick assessments about the extent to which each intersection is exposed to diffuse radiation. From the images, we can better see which orientations have clear channels of exposure from ground to sky.

RESULTS AND DISCUSSION

As we continue to develop the interface and the outputs from the computational toolset, we are integrating an ability to better visualize and assess the relationship of sky exposure to solar orientations, using the sky dome geometry as an input for other environmental analysis tools. Using the Ladybug plug-in for Grasshopper (Roudsari 2020), for instance, we can map monthly averages of high and low solar radiation on the sky exposure map of a single site to better understand where the geometry of the sky dome is exposed to the most dangerous orientations, and where the surrounding built environment is already providing adequate protection.

We plan to further develop the tools by integrating the science of UV exposure and scatter. We know that as the sun angle varies, it changes the angle of incidence for direct UVA radiation, and therefore the intensity of direct solar radiation. But we also know that UVB radiation typically enters the environment in a diffuse manner, with intensities that do not correlate to standard solar studies. Diffuse UVB radiation is at its highest just before and just after solar noon, so these are the hours of the design space for projects seeking to protect against UV radiation. We are planning to integrate the computational workflow with existing analytical tools in GIS software and environmental analysis plug-ins for Rhino/Grasshopper to incorporate these variables, and we plan to develop a shared tool or script for other designers to use.

CONCLUSION

The project suggests computational mapping and modeling techniques that urban and architectural designers may employ to more successfully investigate and address conditions of UV exposure within urban environments. The computational mapping workflow presented can assist designers in overcoming the challenges of attaining and assessing the necessary geographic and environmental information pertinent to a robust analysis of urban UV exposure while suggesting productive overlays to help in identifying areas of increased exposure risk. The mapping workflow leverages remote sensing and raster analysis techniques using transboundary data in GIS to increase the spatial resolution, continuity, and complexity of solar radiation analysis in an otherwise fragmented cross-border datascape. This workflow enables the identification of areas with limited protection from UV exposure, supporting investigations capable of supporting environmental and spatial justice initiatives in the US-Mexico borderland. The computational spherical projection algorithm further increases the spatial resolution of solar radiation analysis by translating the logics of radiation calculations into an interactive, three-dimensional design environment. This algorithm assists designers in understanding the built environment to better address diffuse solar radiation levels in apparent shade by producing clear representations of the exposed sky dome, a critical factor in preventing ultraviolet radiation from entering shaded conditions.

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NOTES

1. The US-Mexico Border Health Initiative, a major transboundary environmental health initiative, no longer publishes cross-boundary environmental data for the US-Mexico borderland. See https://www.usgs.gov/about/organization/science-support/international-programs/us-mexico-border-environmental-health
2. See, e.g., https://www.esri.com/arcgis-blog/products/product/analytics/deriving-temperature-from-landsat-8-thermal-bands-tirs/
3. See, e.g., USGS LiDAR Explorer: https://prd-tnm.s3.amazonaws.com/LidarExplorer/index.html#/

REFERENCES

Bloch, Sam. 2019. “Shade.” *Places Journal*, April, 2017. https://doi.org/10.22269/190423.

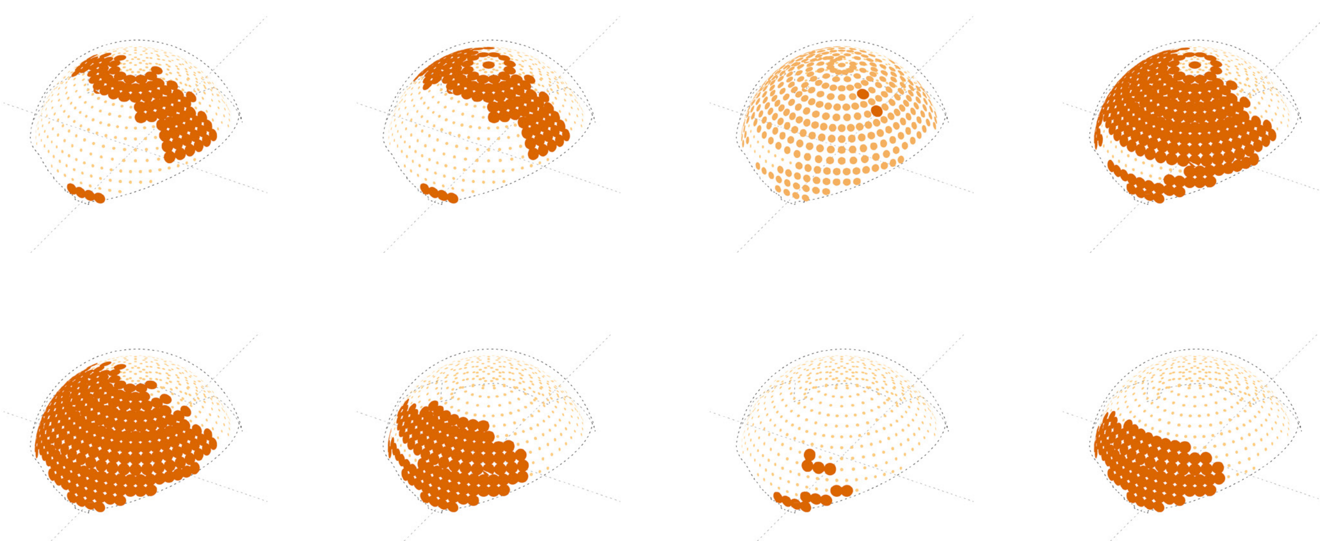
Chen, Liang, Edward Ng, Xipo An, Chao Ren, Max Lee, Una Wang, and Zhengjun He. 2012. “Sky View Factor Analysis of Street Canyons and Its Implications for Daytime Intra-Urban Air Temperature Differentials in High-Rise, High-Density Urban Areas of Hong Kong: A GIS-based Simulation Approach.” *International Journal of Climatology* 32, no. 1: 121–136.

ESRI. 2021. *ArcGIS Pro*. V.2.8. ESRI. PC.

Gies, Peter, and Christina Mackay. 2004. “Measurements of the Solar UVR Protection Provided by Shade Structures in New Zealand Primary Schools.” *Photochemistry and Photobiology* 80, no. 2: 334–339.

Kapelos, George Thomas, and Mitchell Rolland Sutherland Patterson. 2014. “Health, Planning, Design, and Shade: A Critical Review.” *Journal of Architectural and Planning Research* 31, no. 2: 91–111.

Kripa, Ersela, and Stephen Mueller. 2020. “An Ultraviole(n)t Border.” *e-flux architecture*. https://www.e-flux.com/architecture/at-the-border/325756/an-ultraviole-n-tborder/.



9 Solar radiation analysis of sky exposure computable surface.

Kripa, Ersela, and Stephen Mueller. 2021. “Inhabiting the Data Border.” In *Less Talk More Action [Proceedings of the ACSA Fall 2019 Conference]*, Stanford, CA, 13–15 September 2019, edited by A. Larimer, D. Berke, D. Lin, D. Krafcik, J. Barton, and S. Bald, 86–90. ACSA Press.

Mueller, Stephen. 2021. “Designing for Irradiated Shade.” In Carbon *[Proceedings of the 2020 AIA/ACSA Intersections Research Conference]*, Philadephia, PA, 30 September 2020. ACSA.

Robert McNeel & Associates. Rhinoceros. V.6.0. Robert McNeel & Associates. PC. 2020.

Roudsari, Mostapha Sadeghipour, and Chris Mackey. Ladybug Tools. V.1.1.0. Ladybug Tools LLC. PC. 2020.

Rutten, David. Grasshopper. V.1.0.0007. Robert McNeel & Associates. PC. 2020.

Tovar-Pescador, J., D. Pozo-Vázquez, J. A. Ruiz-Arias, J. Batlles, G. López, and J. L. Bosch. 2006. “On the Use of the Digital Elevation Model to Estimate the Solar Radiation in Areas of Complex Topography.” *Meteorological Applications: A Journal of Forecasting, Practical Applications, Training Techniques and Modelling* 13, no. 3: 279–287.

Turnbull, David J., and A. V. Parisi. 2005. “Increasing the Ultraviolet Protection Provided by Shade Structures.” *Journal of Photochemistry and Photobiology B: Biology* 78, no. 1: 61–7.

Weizman, Eyal. 2017. *Forensic Architecture: Violence at the Threshold of Detectability.* New York: Zone Books. doi:10.2307/j.ctv14gphth.

IMAGE CREDITS

All drawings and images by POST (Project for Operative Spatial Technologies).

Stephen Mueller is a Research Assistant Professor at Texas Tech College of Architecture (CoA) and founding director of research at POST (Project for Operative Spatial Technologies), a territorial think tank and CoA research center situated on the US-Mexico border. Mueller’s research seeks novel applications for emerging spatial technologies to analyze, engage, and transform urban environments. POST engages transformations in the borderland through projects intersecting urban geography, border studies, and digital humanities. Mueller is a registered architect and founding partner of AGENCY, and the recipient of several awards, including the Rome Prize in Architecture from the American Academy in Rome and Emerging Voices award from the Architectural League of New York.