Geo data-based policymaking: National Tree Canopy Cover Example

Anna SHNAIDMAN,[1] Or ALEKSANDROWICZ,[2] Dariel RENN-PONI,[1] Moshe YANIV,[1] Medad HOZE[1] and Morel WEISTHAL[2] (Israel)

Key words: Climate Change, AI, Tree Canopy Cover Index, Automated Tree Canopy Contour Extraction, Climatic Policymaking, Geo-data

SUMMARY

In the era of global challenges, such as climate change and more frequent extreme weather events, geospatial data plays a crucial role in providing insights and facilitating informed decision-making processes and the establishment of long-term strategies. Israel has high predisposition to be adversely affected by the anticipated climate changes. Therefore, mitigation and adaption measures are to be taken to ensure healthy and sustainable living environment in the long run.

Trees were recognized as a critical resource and infrastructure to be preserved and expanded, as they contribute greatly to the habitability of cities. This paper demonstrates the importance of spatial data in creation of people-centered solutions. To facilitate the adoption of effective tree planting policies in cities, a *National Tree Canopy* map database has been created. The project was carried out by the *Survey of Israel*[1] in collaboration with the *Technion*,[2] actualizing the Governmental Decision 1022 by the Israeli Government: *Shading and Cooling of the Urban Space by means of Urban Forestry as an Adaptation Step toward Climate Change*.

First, AI techniques were employed on high-resolution orthophotos for efficiently extracting raw, vector-based mapping of tree canopies across the metropolitan centers in Israel. The algorithm utilizes a Machine Learning Mask-R Convolution Neural Network model.

Based on the raw mapping data, it was then possible to calculate *Tree Canopy Cover* values for cities, neighborhoods, public spaces, and individual street segments. Furthermore, *Summer Shade Index* values maps were generated per street segments as well as entire neighborhoods, thus creating maps that expose the hierarchies of shade tree allocation across urban areas.

High-resolution tree canopy cover mapping can serve local authorities in adopting informed and evidence-based policies regarding urban forests and pursue efficient monitoring and management of their stocks of shade-providing trees. By applying tree canopy cover mapping on a national scale, it would be also possible to expose inherent and systematic deficiencies in tree shade provision between urban settlements resulting from past national and local planning policies, to allocate resources for intensified urban tree planting in locations of high vulnerability to heat, and to effectively follow positive or negative changes in tree canopy cover and their relation to public investment.

---

[1] Survey of Israel – SOI: government agency for Mapping, Geodesy, Cadastre and Geoinformatics
[2] BDAR Lab, Faculty of Architecture and Town Planning, Technion - Israeli Institute of Technology

Geo data-based policymaking: National Tree Canopy Cover Example

Anna SHNAIDMAN, Or ALEKSANDROWICZ, Dariel RENN-PONY, Moshe YANIV, Medad HOZE and Morel WEISTHAL (Israel)

1. INTRODUCTION

Climate change has recently become a global cause of concern. Experts predict that the climatic transformation we are already experiencing will increase extreme weather events and exacerbate existing climatic challenges, and that these phenomena will be exceptionally damaging in cities and urban concentrations around the world. Urban environments have long been known to generate unique microclimates that tend to become warmer than the microclimates of their rural periphery, a well-documented phenomenon that is commonly known as the "*Urban Heat Island*" (UHI) [1–6].

In the backdrop of an increasingly urgent need for urban-scale design solutions to better adapt to urban heat, urban forests (a term used to describe all the trees that are planted in an urban area) and especially shade-giving trees (as opposed to trees with underdeveloped tree canopies) occupy a central position in the heat mitigation toolkit of planners and urban designers [7–9]. Shade-giving trees are significantly more effective than other UHI mitigation measures because tree canopies absorb solar radiation before it reaches and warms up sidewalks, roads, and building facades while locally cooling the air around them because of evapotranspiration from the vegetative layer. By blocking solar absorption of synthetic surfaces in cities, these surfaces are less likely to absorb excess amounts of heat during daytime and release it to the urban environment during nighttime. Shading from trees can also play an important role in relieving heat stress in urban spaces during the hot season since they block solar radiation that affects the human body [10]. Moreover, tree planting can be widely and easily promoted and controlled by municipal planners and decision-makers, enabling them to lead concerted efforts and policies for adaptation to urban heat by planting significant quantities of trees in a variety of locations, including streets, plazas, gardens, and parks [9]. Therefore, tree planting, especially in streets and public spaces, is seen today as one of the key heat mitigation measures of any urban-level climate adaptation plan [11–13].

Arguably, the limitations of mapping are currently the bottleneck that impedes the adoption of focused and efficiently distributed urban forestry actions. Without high-resolution and accurate mapping of tree canopies and tree trunk locations, it is hard to estimate the ratio of shade-providing trees in the entire urban forest and especially their presence in streets. This in turn affects the way governments and municipalities set their urban forestry goals and benchmarks. If goals are set in generalized terms, we cannot expect that public investment will easily find its way to streets and public spaces in which shade trees are in the utmost need. The same problem applies to places where the authorities pledged to plant a high number of trees (like the million-trees initiatives in Los Angeles and New York City) since these pledges were made without systematic mapping of the places of high need for outdoor shade and the actual tree planting potential in existing streets and public spaces [14, 15]. Moreover, without detailed and continuous monitoring and mapping, it is also almost impossible to evaluate the successes or failures of such urban forestry plans and planting campaigns, not in terms of achieving some simplistic quantitative targets (e.g., planting a certain number of trees within a specific timeframe), but rather in their longstanding effect on increasing shade levels in outdoor public spaces in cities.

2. NATIONAL TREE CANOPY (TC) MAP GENERATION

In January 2022 the Israeli government approved a decision on the promotion of street trees for shading urban spaces (Decision 1022), based on a report submitted by an inter-ministerial team [16]. The decision reflected an understanding that in the Israeli context street trees have a significant role in adopting climate change adaptation policies and, more specifically, in adapting to urban heat. The goal of promoting shading and cooling of urban spaces by planting street trees was later integrated into the Israeli government's 2022 Book of Work Plans. Moreover, the government's decision instigated an intensive process of consultation in separate work groups consisting of representatives of the central government, municipalities, civil society organizations, professional consultants, and academia, which were asked to put the government's decision into a more elaborate and concrete framework of gradual implementation. Their work was published as an official document in late November 2022 [17].

The goal of the 1022 Decision was threefold: assessment of the current state of urban forest inventory by creating an Urban Tree Canopy (UTC) national database, calculation of the Tree Canopy Cover - the percentage of the ground that is sheltered by tree crowns when viewed from above - and outlining of the framework for implementation plan for achieving the UTC goals to be carried out by the local government with the guidance of the Planning Authority.

There are two approaches to consider for conducting UTC assessment: A Bottom-up method which requires traditional, time and money consuming ground surveys and a Top-down way that utilizes remote sensing and AI/Deep Learning (DL) techniques to produce a much quicker and affordable cost-wise results.

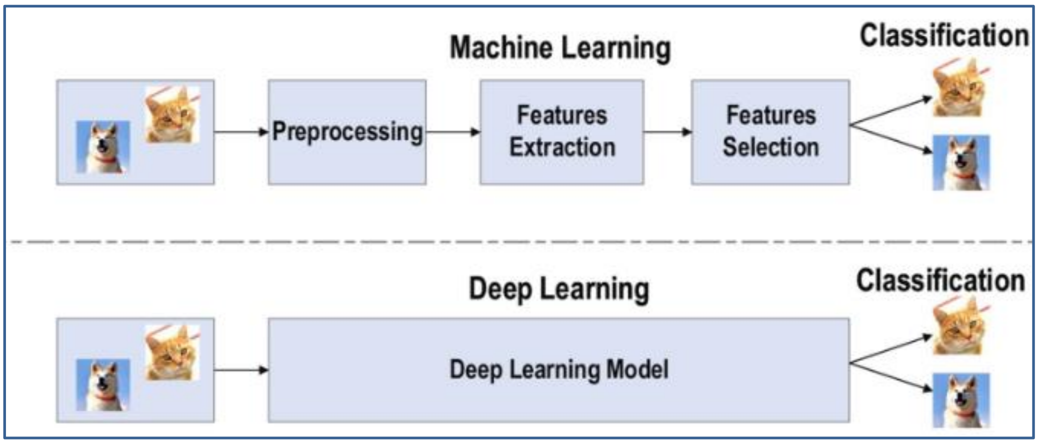

Figure 1: Deep learning vs. Traditional Machine Learning *(Alzubaidi et. al., 2021)*

In recent years, Machine Learning (ML) has become one of the most widely used tools in solving complex problems, especially in the field of image segmentation. Deep Learning (DL), unlike ML which improves overtime, is based on multilayered neural networks that learn from enormous amount of data (*Figure 1*).

The Survey of Israel was given the task of generation of a UTC layer to facilitate cost estimate for the cooling agenda. Based on previous experience with AI/ML, the characteristics of the expected product – identification of the tree canopy contour, and given the short time frame for providing results, a U-net Convolutional Neural Network with mask R-CNN as a backbone, a method in image segmentation which entails partitioning of a digital image into multiple segments to locate both objects and their boundaries, was a natural choice.

The process consisted of several steps:

- ***Mask Production***

Every model of DL requires sample data – examples of the objects to be identified. To this end several hundred masks were created by means of manually digitizing tree canopy on orthophoto tiles, as shown in *Figure 2*. The vector data was then rasterized to create the mask dataset (GDAL[3] library was used). It is important to mention, that the Survey of Israel is in charge of producing a high resolution (20 cm per pixel) orthophoto annually. The aerial image includes 4 bands: RGB and the NIR.

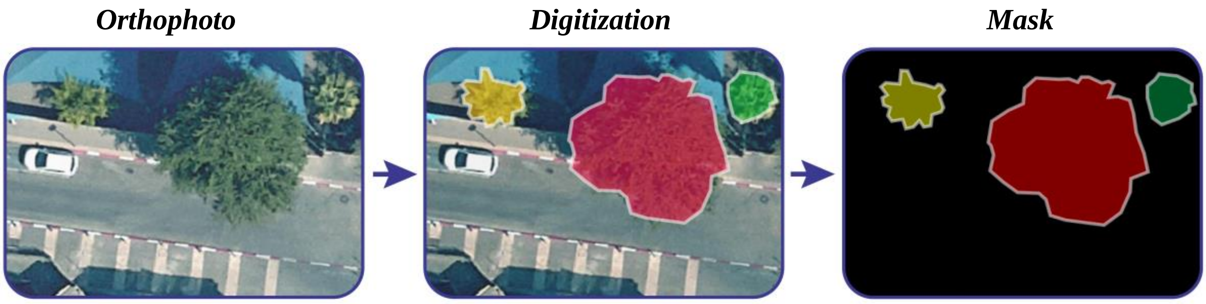

Figure 2: Mask Production

- ***Training Set Generation***

By applying the principles of DL, a training set is next created, consisting of pairs of orthophoto tiles and their corresponding B&W masks. As mentioned above, a U-Net model was used since it is simple to train and calls for a relatively small amount of sample data.

To avoid overfitting, the training employed orthophotos from 3 different years. Surprisingly, better results were obtained with the RGB bands alone. The NIR band was inconsistent. Lack of calibration of the forth channel or its lower resolution (50 cm) may be the reason since the model is looking for texture which is lost at 50 cm. Since the results were very accurate, no fine-tuning with the assistance of DSM and DTM was performed.

[3] GDAL - is a translator library for raster and vector geospatial data formats that is released under an MIT style Open Source

- ***Running of the Model – Prediction***

The trained model applied on a new raster image and its ability to detect tree canopy is examined. Then, manual quality control is performed. *Figure 3* presents typical results of the UTC in urban areas.

Figure 3: Canopies Segmentation Results

The quality of the model is tested based on several parameters such as: accuracy, precision, recall etc. Precision is a combined index of "*true positive*" - a tree which was identified as a tree; and "*false positive*" – another object which was identified as a tree. The higher the percentage of "*true positive*" vs. the other two, the better the precision (Figure 4). The false positive values were reduced to minimum with additional training, whereas "*false negative*" – a tree that wasn't detected - values were initially rather low.

Figure 4 demonstrates the true contribution and the capability of the algorithm via the example of Rishon LeTsiyon (a city in Israel, located along the central Israeli coastal plain eight kilometers south of Tel Aviv. It is part of the Gush Dan metropolitan area) municipally. A clear picture of the current tree canopy inventory and the areas suitable for tree planting are displayed. Allowing the stakeholders to make strategic decisions regarding planting efforts and track the UTC goals progress on a continuous basis.

Figure 4: The TC of Rishon LeTsyion Municipality

In the case of UTC and the purpose of cost assessment, the objective is to know how many trees were identified correctly rather than how many were falsely labeled. In other words, small trees, trees without leaves etc. weren't expected to be detected. The precision of the classification was the main goal rather than the shape of the canopy contour. After several days of training and testing, the model's outcome was 96% precision.

Figure 5: Precision

3. TREE CANOPY COVER MAPPING AND SHADE MAPS

The availability of high-resolution mapping of tree canopies alongside DSM and DTM raster layers of urban areas in Israel opens up new opportunities for analyzing the climatic and environmental properties of large urban areas based on several metrics [8]. Probably the most immediate of them is that of a Tree Canopy Cover (TCC) ratio at different scales. A TCC ratio describes, on a scale of 0 to 1, the ratio between the area of the projection of all tree canopies located within a certain space on a horizontal plane and the total area of the same space. The higher the value, the higher is the tree canopy cover of the area. TCC ratios are normally calculated for the entire urban area or at the neighborhood level. Nevertheless, assuming we are interested in TCC values of smaller spatial units (street segments, urban open spaces), the high-resolution mapping of tree canopies enables us to generate maps showing hierarchies of shade-tree provision at the scale of the most basic urban design units. Such maps can become an important tool for planners and designers in locating weak and strong points in the current distribution of trees in public spaces and particularly street trees.

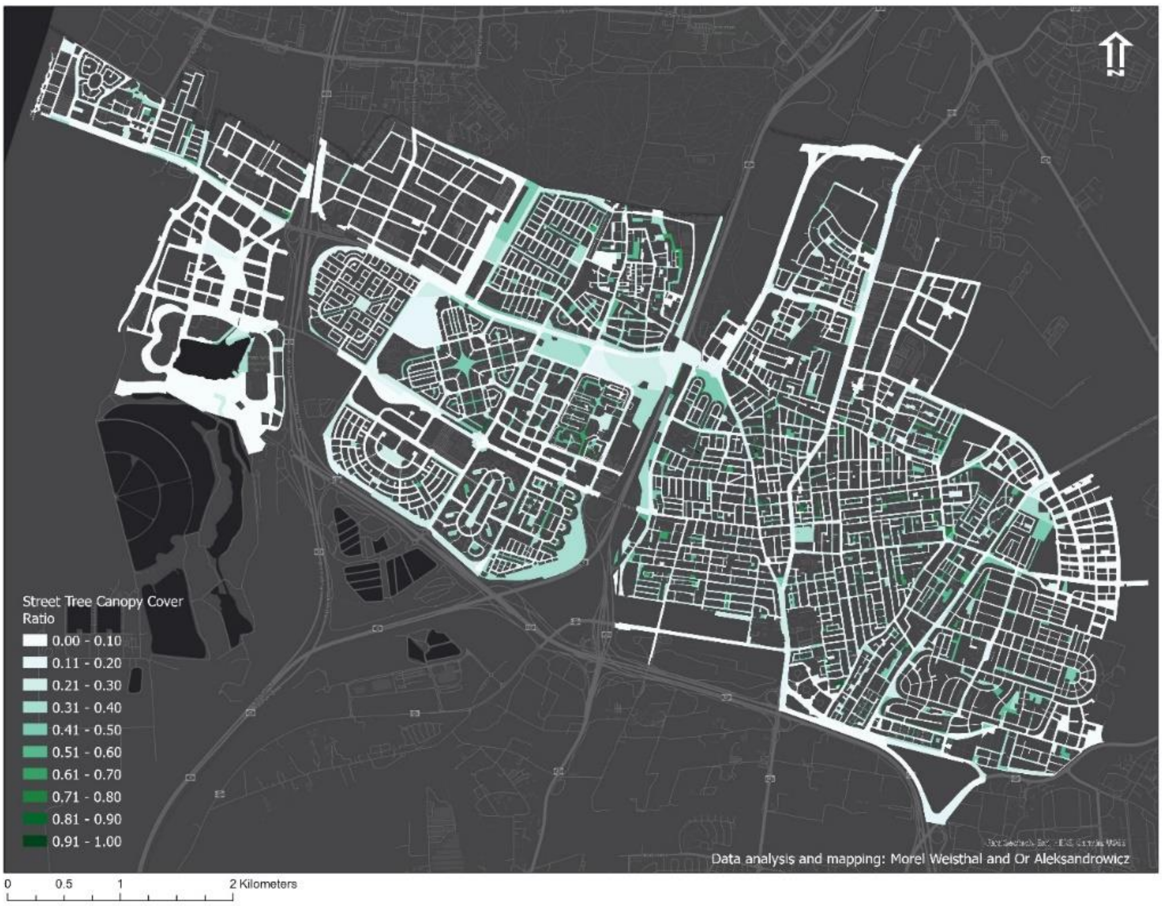

Figure 6: A street-segments Tree Canopy Cover map of the city of Rishon LeZion*, based on the raw tree canopy mapping produced by the Survey of Israel and additional spatial analysis (data analysis and mapping by Morel Weisthal and Or Aleksandrowicz)*

While TCC values can give an indication of the likelihood of street segments or neighborhoods to enjoy high levels of street-level shading cast by wide-canopied trees, since street-level shade depends also on the shade cast by buildings, TCC alone may not describe well the overall shade availability, especially where TCC values are low. One option for quantitatively evaluate outdoor shade provision is by calculating a Shade Index (SI) for a certain spatial unit. An SI describes on a scale of 0 to 1 the ratio between the blocked insolation at ground level at a certain location and the maximum insolation of an unobstructed horizontal surface at the same time and location. The higher the value, the higher the shading.

This indicator considers shade produced by all elements in an urban environment: buildings, trees, and other shade-giving elements. It can be formulated as follows:

$$SI_p = 1 - \left(\frac{Insolation_p}{Insolation_r}\right)$$

where SI_p is the SI at a certain point, $Insolation_p$ is the insolation at that point, and $Insolation_r$ is the insolation at an unobstructed reference point during the same period [8, 18].

When applied to a street segment or a specific part of a street, SI is calculated as an average of all sampled point SI values contained in that area (the sampling density depends on user preference, though a sampling rate higher than 1 m may overlook fine differences in spatial shade distribution). The SI depends on the date and time of calculation: different dates and times will produce different SI values for the same location and urban morphology. While it is more effective to calculate SI values for mid-summer, when daytime air temperatures are at their peak and heat stress is at its highest level, it is possible to use other dates as reference dates for shade evaluation (for example, during spring and autumn). To evaluate the overall shading effect of street and building geometry during daytime hours, it is better to use the cumulative exposure of ground level during a time range that represents all or most of daytime hours. Nevertheless, it is also possible to calculate SI values for a certain hour, or for a short time range of a couple of hours.

The Survey of Israel's high-resolution DSM and DTM mapping, when combined with the new mapping capabilities of tree canopies, facilitates the production of large-scale and high-resolution shade maps for entire urban areas. Using the GIS-based solar irradiance calculation method described elsewhere [18], it is possible to calculate SI values for each pixel of a DSM for an hour or a day (based on the cumulative daily insolation at that point), and then to calculate spatial SI values of street segments or neighborhoods by averaging the SI values for all the pixels contained within each spatial unit, as follows:

$$SI_a = \frac{\sum_{i=1}^{n} SI_n}{n}$$

where SIa is the average SI value of an area and n is the number of pixels contained within that area. If calculated for an entire neighborhood, the averaged SI value calculation should exclude pixels contained within building footprints, since they do not represent street-level shade.

Figure 7: A summer shade map of the town of all street segments and open spaces in the town of Netivot*, based on a DSM, a DTM, and the raw tree canopy mapping produced by the Survey of Israel and additional spatial analysis. The values represent the Shade Index of each spatial unit (data analysis and mapping by Morel Weisthal and Or Aleksandrowicz)*

When calculated for a relatively large number of street segments and neighborhoods, the SI can reveal the variance in street-level insolation across an entire urban area, and therefore can be used by planners and designers for prioritizing interventions focusing on outdoor shade provision. Through shade mapping, a municipality may decide to designate certain streets for "shade intensification" (in streets of low shade values) or "shade conservation" (in streets of exceptional levels of shade). The prioritization can integrate additional quantifiable factors, such as the likelihood of a street to attract pedestrians or the socioeconomic condition of a neighborhood. For example, streets prioritized for "shade intensification" can be defined as only the streets with low SI values and high likelihood to become pedestrian attractors.

4. SUMMARY AND FUTURE WORK

Geodata holds an enormous potential in addressing the negative effects of climate change. Policy makers can rely on raw data as well as the insights derived from processed data to make informed and knowledge-based decisions. Mapping agencies gather, analyze and disseminates the information with stake holders and the general public. However, the true richness of available data and what it has to offer in terms of producing climate models, scenarios and analysis is still being underestimated. The case study presented in the paper demonstrates the vast possibilities of utilizing such data. The creation of a country wide UTC layer, paves the way for further research and development of tools to promote concerted and climatically-effective greening efforts in cities.

One of the challenges with Deep Learning techniques is results validation. Therefore, future efforts will first be directed at detailed analysis of the results, validation of the product by conducting a comparison with available ground surveys data. The next steps will include fine tuning of the model, calibration of the NIR channel, as well as filtering out false positives and avoiding false negatives based on DSM data.

Furthermore, seeing that urban forest densification is one of the key measures that is currently being adopted in almost any climate adaptation strategy around the world, to enhance urban forest development and intensification and to support efficient and effective allocation of resources, a comprehensive and evidence-based methodology for accurately calculating tree planting potential in cities is a needed.

Therefore, future work will include the generation of shade maps of all urban concentrations in the country, upon which a novel comprehensive method will be developed to allow for high-resolution, quantitative evaluation of urban tree planting potential based on regularly produced physical mapping of cities. The work will be based on the Survey of Israel's existing physical mapping databases of more than 30 of the most populous Israeli cities. The outcomes of the study will consist of tree-related interactive maps of the analyzed cities and a digital platform that will allow users to explore different urban planting scenarios based on the climatic qualities of existing trees and buildings, physical constraints, social equity considerations, and a novel street tree density benchmarking system that we will develop in the study.

REFERENCES

1. Landsberg, H.E.: The urban climate. Academic Press, New York and Toronto (1981)
2. Oke, T.R.: The energetic basis of the urban heat island. Q. J. R. Meteorol. Soc. 108, 1–24 (1982). https://doi.org/10.1002/qj.49710845502
3. Oke, T.R.: Boundary layer climates (second edition). Routledge, London (1987)
4. Stewart, I.D.: Why should urban heat island researchers study history? Urban Clim. 30, 100484 (2019). https://doi.org/10.1016/j.uclim.2019.100484
5. Voogt, J.A.: Urban Heat Island. In: Munn, R.E. (ed.) Encyclopedia of global environmental change. pp. 660–666. Wiley, Chichester, NY (2002)
6. Arnfield, A.J.: Two decades of urban climate research: A review of turbulence,

exchanges of energy and water, and the urban heat island. Int. J. Climatol. 23, 1–26 (2003). https://doi.org/10.1002/joc.859
7. Erell, E., Pearlmutter, D., Williamson, T.J.: Urban microclimate: Designing the spaces between buildings. Earthscan, London and Washington, DC (2011)
8. Aleksandrowicz, O.: Mapping and management of urban shade assets: a novel approach for promoting climatic urban action. In: Khan, A., Akbari, H., Fiorito, F., Mithun, S., and Niyogi, D. (eds.) Global Urban Heat Island Mitigation. pp. 1–27. Elsevier, Amsterdam, Netherlands ; Kidlington, Oxford, England ; Cambridge, Massachusetts : (2022)
9. Aleksandrowicz, O., Vuckovic, M., Kiesel, K., Mahdavi, A.: Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository, (2017)
10. Aleksandrowicz, O., Pearlmutter, D.: The significance of shade provision in reducing street-level summer heat stress in a hot Mediterranean climate. Landsc. Urban Plan. 229, 104588 (2023). https://doi.org/10.1016/j.landurbplan.2022.104588
11. Turner, V.K., French, E.M., Dialesandro, J., Middel, A., M Hondula, D., Weiss, G.B., Abdellati, H.: How are cities planning for heat? Analysis of United States municipal plans. Environ. Res. Lett. 17, 064054 (2022). https://doi.org/10.1088/1748-9326/ac73a9
12. Lin, B.B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., Elmqvist, T., Evans, K.L., Frantzeskaki, N., Fuller, R.A., Gaston, K.J., Haase, D., Jim, C.Y., Konijnendijk, C., Nagendra, H., Niemelä, J., McPhearson, T., Moomaw, W.R., Parnell, S., Pataki, D., Ripple, W.J., Tan, P.Y.: Integrating solutions to adapt cities for climate change. Lancet Planet. Heal. 5, e479–e486 (2021). https://doi.org/10.1016/S2542-5196(21)00135-2
13. Pataki, D.E., Alberti, M., Cadenasso, M.L., Felson, A.J., McDonnell, M.J., Pincetl, S., Pouyat, R. V., Setälä, H., Whitlow, T.H.: The Benefits and Limits of Urban Tree Planting for Environmental and Human Health. Front. Ecol. Evol. 9, 1–9 (2021). https://doi.org/10.3389/fevo.2021.603757
14. Garrison, J.D.: Seeing the park for the trees: New York's "Million Trees" campaign vs. the deep roots of environmental inequality. Environ. Plan. B Urban Anal. City Sci. 46, 914–930 (2019). https://doi.org/10.1177/2399808317737071
15. McPherson, E.G.: Monitoring million trees LA: Tree performance during the early years and future benefits. Arboric. Urban For. 40, 286–301 (2014). https://doi.org/10.48044/jauf.2014.027
16. The Inter-Ministerial Team for Urban Forestry: Promotion of street trees in Israeli cities [in Hebrew]. Government of Israel (2022)
17. Ministry of Environmental Protection, The Israeli Green Building Council, Ministry of

Agriculture and Rural Development, The National Economic Council: National strategic plan for shading and cooling of urban spaces using trees. Government of Israel, Jerusalem (2022)
18. Aleksandrowicz, O., Zur, S., Lebendiger, Y., Lerman, Y.: Shade maps for prioritizing municipal microclimatic action in hot climates: Learning from Tel Aviv-Yafo. Sustain. Cities Soc. 53, 101931 (2020). https://doi.org/10.1016/j.scs.2019.101931

BIOGRAPHICAL NOTES

Anna Shnaidman is the Chief Scientist at the Survey of Israel. She received her BSc (Cum Laude) and MSc and PhD (Ph.D. thesis presented a new unconventional approach that employs Biological Optimization to attain uniform and accurate coordinates under customary cadastral requirements - Genetic Algorithms) degrees in Mapping and Geo-Information Engineering from Israeli Institute of Technology - Technion. Shnaidman is a Licensed Surveyor and a Lecturer as well. For the period of 2018-2020 she worked as a postdoctoral researcher and a Lecturer at the GIS Technology Section, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands – main research objective was the revision of Land Administration Domain Model (LADM - ISO 19152).

Or Aleksandrowicz is an Assistant Professor in the Faculty of Architecture and Town Planning at the Technion – Israel Institute of Technology, where he heads the Big Data in Architectural Research (BDAR) lab. Aleksandrowicz graduated from the Azrieli School of Architecture at Tel Aviv University in 2002 and holds a master's degree in Building Science and Technology from TU Wien (2012) and a doctorate in Technical Sciences from TU Wien (2015). His latest research involves empirical monitoring of outdoor climatic indicators, big data analysis of spatial and climatic factors using geographic information systems, indoor monitoring of diverse performance indicators of advanced building envelopes, and the history of building technologies in Israel.

Dariel Renn-Poni is the head of Technologies section at the department of Chief scientist at the Survey of Israel. Renn-Poni holds a BSc. In Mapping and Geoinformation Engineering from the Technion – Israeli Institute of Technology and a licensed surveyor as well.

Moshe Yaniv is a data analyst at Survey of Israel at the department of Chief Scientist, at Survey of Israel. Yaniv holds a degree in Architecture from the Technion – Israeli Institute of Technology and has vast experience with AI and GIS applications.

Medad Hoze is a former GIS expert in survey of Israel, and UN, currently works as a GIS team leader at KKL, and as a GIS consultant for the UAE. Hoze holds a B.A in geoinformatics from the Hebrew University of Jerusalem, Master degree from Bar-Ilan University with specialization in integrating GIS into machine learning algorithms, creating WEB applications and apply geometrical manipulations.

Morel Weisthal is a Planner and a GIS specialist at the City Planning Department of Ramat Gan Municipality. Weisthal holds a B.A in Geography with expertise in geoinformatics (2011) and an MA in Environmental Planning the urban planning and architecture unit in Sde-Boker (2014). from the Ben Gurion University. The master degree research thesis included the assessment and analysis of shadow patterns in urban environments. Works as a GIS expert and Urban planner in Ramat-Gan Municipality.

CONTACTS

Anna Shnaidman
Survey of Israel
Lincoln 1, Tel Aviv
Israel
Tel. +97236231829
Email: shnaidman@mapi.gov.il
Website: www.mapi.gov.il

Dr. Or Aleksandrowicz
Technion – Israel Institute of Technology
Technion City, Haifa
Israel
Tel. +97248294041
Email: oraleks@technion.ac.il
Web site: oraleks.net.technion.ac.il

Dariel Renn-Poni
Survey of Israel
Lincoln 1, Tel Aviv
Israel
Tel. +97236237415
Email: dariel@mapi.gov.il
Website: www.mapi.gov.il

Moshe Yaniv
Survey of Israel
Lincoln 1, Tel Aviv
Israel
Tel. +972544979992
Email: moshe.yaniv@gmail.com

Medad Hoze
KKL - Jewish National Fund
Jerusalem
Israel
Tel. +972 545364738
Email: medadhoze@hotmail.com
LinkedIn: www.linkedin.com/in/medad-hoze-04908216b

Morel Weisthal
Ramat Gan Municipality
Bialik St 35, Ramat Gan
Israel
Tel. +97236753413
Email: morel-w@ramat-gan.muni.il