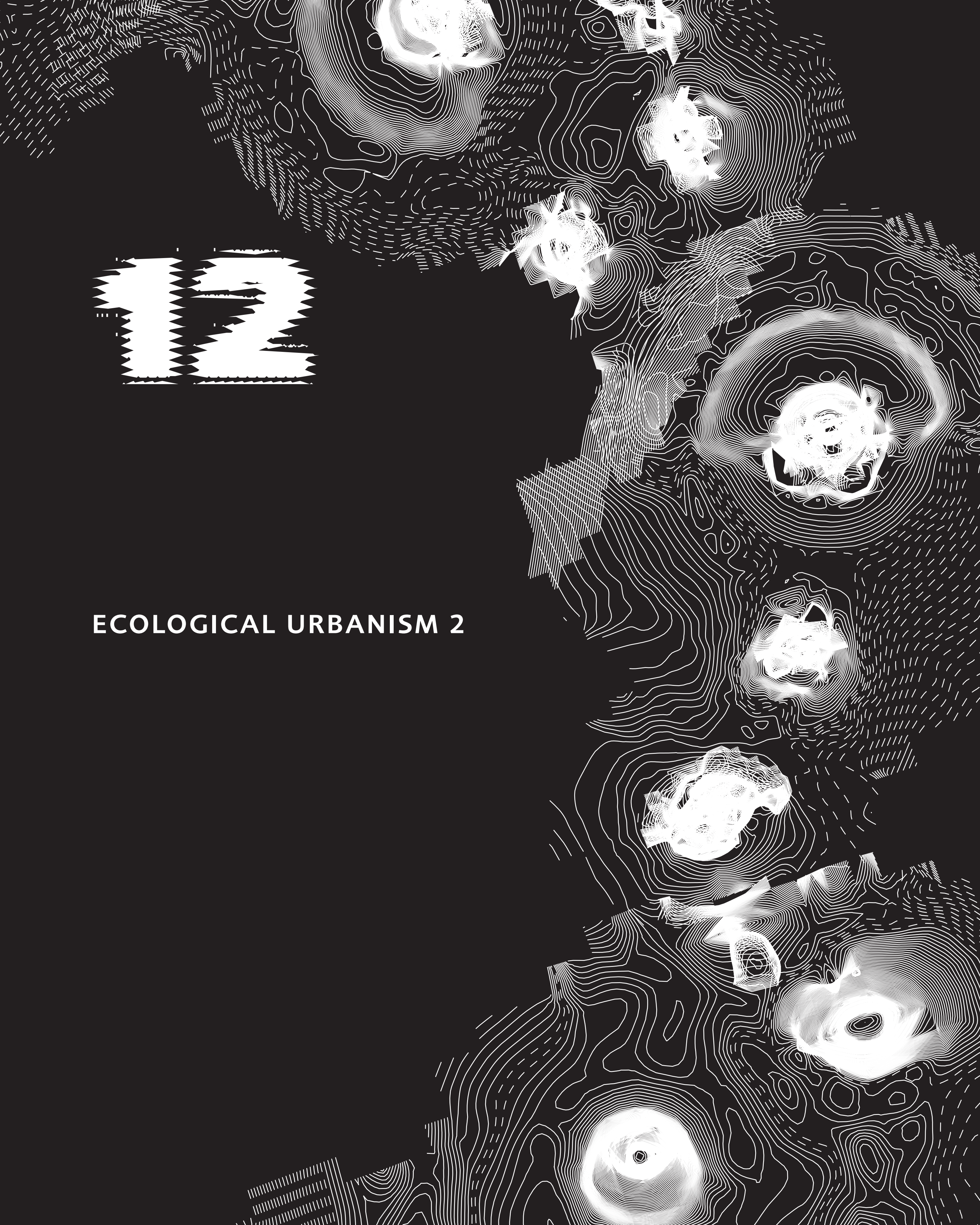
12

ECOLOGICAL URBANISM 2



SENSING URBAN MICROCLIMATES

Maider Llaguno Munitxa

Biayna Bogosian

ABSTRACT

Our understanding of the relationship between city morphology, materiality, and urban microclimate has been limited due to the lack of availability of urban microclimate data. In order to better understand the influence that building geometries, trees, or topographical variations play in urban microclimates, it is necessary to utilize measuring techniques that gather higher spatial resolution urban environmental data rather than data provided by weather stations or static sensor networks. With this purpose, this research proposes to utilize accessible low-cost technologies for environmental sensing coupled with dynamic devices. A custom sensor kit to record temperature, humidity, and CO2 concentrations, has been mounted to a bike for pedestrian level microclimate sensing. The same sensing kit has been attached to an Unmanned Aerial Vehicle (UAV) for the vertical gradient profile measurements. Image, video processing techniques, and GIS data have been utilized to visualize the recorded measurements and to parameterize the urban properties (green areas, impervious surfaces, and building masses) around the acquisition trajectories. The correlation of the acquired measurements and the urban parameters, show that maximum CO2 concentrations mainly peak in road intersections. Building masses and greenery also appear to affect the distribution of pollutant concentrations both in the pedestrian level and in the vertical profiles. While dynamic sensing attains sufficient spatial resolution, it does not provide high temporal resolution. With the aim to improve data accuracy through data redundancy, the proposed DIY sensing kit utilizes readily available sensors and operates on open-source platforms to encourage the engagement of larger audiences.

INTRODUCTION

The World Health Organization reported that in 2012, around 7 million people died—one in eight of the total global deaths—as a result of air pollution. This finding more than doubles previous estimates and confirms that air pollution is now the world's largest single environmental health risk. Thermal pollution and pollutant concentration peak in cities, as opposed to the countryside, as much due to growing anthropogenic activities as to the formal and surface materials that construct the cities. Luke Howard, a British chemist and meteorologist, was one of the first scientists who addressed this evidence through observatory work in 1830s; since then, the research on air pollution has been ongoing in the sciences of urban climatology (Howard 2012).

Despite the fact that the science of urban climatology is nearly two centuries old, the translation from scientific knowledge to technique, and architectural design processes, has been rare and often not successful. The reasons for this slow progression are manifold and include problems that are to be addressed by the scientific community as well as by designers and planners. On the one hand, one of the obstacles in convergence of methods has been the complexity of the physical phenomena of the Atmospheric Boundary Layer (ABL) and the limited comprehension of such processes by designers. On the other hand, scientists' lack of awareness regarding the socio-political and cultural concerns that are part of multidisciplinary urban design and planning processes, has contributed to the disconnected research trajectories (Oke 1984).

The practice of formatting scientific data as microclimate maps has contributed to the establishment of a dialogue between city climatology and urban planning processes. Originally proposed by Rudolf Geiger in 1965, the Klimaatlas was devised as a synthetic tool to relate environmental and planning data. Composed by a juxtaposition of a pair of maps, the first one displayed the structure of the local climate in relation to characteristic land use areas or climatopes, while the second map drew out policy recommendations. Based on this method, in one layer the repetitive climatic patters (humidity and temperature gradients, pollutant concentrations and wind directionality) as well as land features were registered, while in the second layer a planning proposition was sketched informed by the zonal climate specificities. The Klimaatlas or urban climate map, allowed connecting meteorological studies to urban growth projections and policies.

In the last decade, Geographic Information Systems (GIS) have enabled the overlapping of urban data with climatic data for a more comprehensive urban planning study. GIS has been proven successful in managing diverse sets of data for a multidisciplinary field such as, urban planning. However, there are limitations in regard to the availability of data related to urban climatology, especially when the required level of information zooms from the zoning scale to the building scale, where a higher spatial resolution of microclimatic data is necessary. Lack of availability of this data limits the capability of architects and urban designers to fully analyze the role design parameters such as building geometries, street directionalities, the presence of trees, and topographical variations play in local microclimate and air quality.

Environmental data collected from weather stations and climate monitoring sensor networks have been widely used for the study of atmospheric physics. However, the space resolution obtained from these sources is often insufficient to analyze urban microclimate (Stroh 2007; Zheng 2009). Therefore, when operating at the building and neighborhood scale, the coarseness of the available atmospheric data, requires either complementation with numerical models (which are computationally highly demanding) or field measurements (which are often very expensive to implement and still do not provide sufficient information of the area under study) (Stewart 2011). Consequently, in order to satisfy the needs of urban designers or architects, an exploration of alternative means of capturing quantitative environmental data at a finer spatial resolution is necessary.

Data collected from Weather Stations	**Data collected from DIY Sensing Methods**
Scientific data	Crowd-sourced data
Precise, calibrated	Less precise, achieved through redundancy
Expensive	Inexpensive
Require expertise	For the beta culture
High time resolution	Medium time resolution
Low spatial resolution	Higher spatial resolution
Often not public data	Public

Figure 1
Static (distributed weather station collection) vs. dynamic (utilization of mobile devices and readily available sensors) climatic data collection comparisons.

Sensor controlled systems have become an integral part of our everyday devices (Akyildiz 2002; Rogers 2011). In recent years, there have been numerous studies focusing on the incorporation of everyday dynamic objects such as private vehicles, bicycles and mobile devices in the data collection process. Building upon the concept of dynamic sensing, this research proposes to develop environmental field measurements with the coupling of a customized air-quality sensing kit to a bike and an Unmanned Aerial Vehicle (UAV). Through this dynamic sensing data collection method and deployment of low cost sensing technologies, the research aims at the collection of high spatial resolution microclimate data. While this method attains sufficient spatial data, the dynamic sensing does not provide high temporal resolution. Thus, the proposed sensing kit is utilizing readily available sensors which operate on open-source platforms. The DIY nature of the sensing kit as well as the collection method, aims at the utilization of a larger user community. The larger user group would result in data collection redundancy which would accumulate accuracy of the archived data (Figure 1).

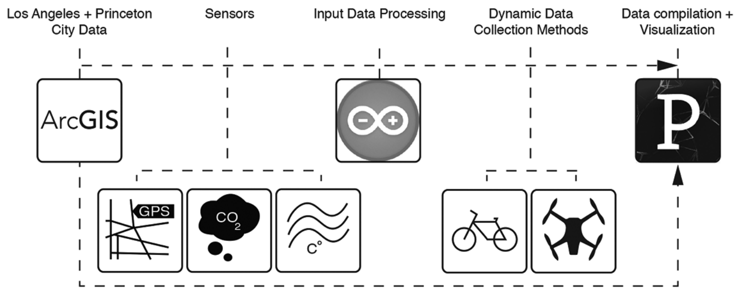


Figure 2
Workflow diagram of the customized dynamic sensing method.

The following research explores dynamic sensing through the coupling of a sensing kit to a bike and UAV to measure street temperature and CO2 concentration. The measurements have been gathered on and around the University of Southern California campus in Los Angeles, and Princeton University campus in Princeton. In both locations, pedestrian level measurements have been collected with the aid of a bike, and vertical profile field measurements have been taken with the aid of an UAV. Coupling GIS data with the graphic user interface of the coding platform of Processing *(Figure 2)*, allows plotting of the recorded measurements over the neighboring urban parameters (green area, impervious surface, building volumes). Through the deployment of a 3D urban map where the urban parameters and the recorded microclimatic data are highlighted, we aim at a direct qualitative and quantitative visual feedback of the influence of urban design parameters on immediate urban microclimates.

URBAN MICROCLIMATE AND AIR POLLUTION

Since the early 1920s, air pollution has been regarded as one of the central problems that concern urban climatologists were pioneers in studying the phenomena of urban fog (Shaw 1925), and many have followed in their footsteps to research air pollution in cities. Britain, as the "first industrial nation," was the first to become predominantly urban and consequently the place in which the modern idea of pollution was recognized (Thorsheim 2006). The meteorological foundation initiated the Committee for the Investigation of Atmospheric Pollution in 1912, establishing the first independent group to document the pollutant concentration in cities. The first air quality policy was established in the UK—The Clean Air Act of 1956—which was followed by the US clean air act in 1963. Under United States Environmental Protection Agency (EPA) legislation, the National Ambient Air Quality Standards (NAAQS) are currently established and enforced for carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, particulate lead, and suspended particulate mass. However, more than 70 communities throughout the United States have been found to violate the NAAQS standards (Federal Register 1987; Code of Federal Regulations 1994; Chow 1993).

It is known that substantial health risk could be associated with high particulate matter (PM) concentrations in ambient air (Dockery 1993; Kunzli 2001). Presently, a major branch of research focuses on urban environment concentration and composition of PM (Particle Matter) that originates to a significant extent from traffic sources (Schauer 1996). High concentration areas usually happen in street canyons, given their lack of ventilation potential (Van Dingenen 2005). Despite the fact that major pollutant concentration in urban environments is originated to a significant extent from traffic sources, the concentration levels often depend on the surface properties (surface structure, surface materiality, and land coverage). Architectural features modify pollutant concentration by affecting airflow patterns, turbulence intensities, and atmospheric instabilities (Oke 2012). High concentrations of automobile exhaust in urban street canyons are typically associated with low wind velocities or conditions where the urban morphology and the street orientation block the air access to street canyons (Kastner-Klein 2001). Therefore, the role of urban surface properties in street ventilation has to be taken into account when studying mechanisms to improve urban air quality.

Carbon dioxide (CO_2) is the primary greenhouse gas emitted through anthropogenic activities, and while CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution (NRC 2010). CO_2 emissions in the United States increased by about 7% between 1990 and 2013 (EPA CO_2 Trends). Going forward, CO_2 emissions in the United States are projected to grow by about 1.5% between 2005 and 2020 (U.S. Department of State 2007). The excess of CO_2 can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues. At high levels, CO_2 can cause deaths (EPA CO_2 guidelines). The effect the emission of greenhouse gases produce in global warming and the health risks associated with exposure determine the necessity for the regulation and monitoring of CO_2 concentrations in urban environments.

Along with CO_2, thermal pollution is another important aspect to take into account in urban climatology. Urban roughness and the presence of impervious surfaces promotes the accumulation of thermal pollution in the urban canopy layer (UCL) contributing to the urban heat island (UHI) effect in cities (Cui 2012; Oke 2012).

Near-surface pollution concentrations have been documented in several cities across the world to evaluate the dynamics of atmospheric CO_2 and thermal entrapment (Chandler 1965; Berry 2003; Nasrallah 2003; Velasco 2005; Vogt 2006). Vertical concentration profiles of CO_2 have been reported by Vogt (2005) for a street canyon in Basel, Switzerland; and Kanda (2005) developed field measurements for wind velocity and temperature profiles in a 29 meter- tall tower in a residential area in Tokyo.

Previous studies show that pollutant concentration gradients vary significantly in time and space. Therefore urban field measurements should be gathered at a range of different sites, at several times of the day as well as in different seasons to fully understand the fluxes of CO_2, temperature, as well as the fluxes of other pollutants.

However, the cost and technical complications associated with field experiments are to be taken into account. This is the reason why the investigation into the influence of urban geometry on pollutant concentration has been mainly developed through wind tunnel experiments and numerical simulations. Furthermore, given the lack of spatial resolution of the available field measurements, few site studies have concurrently compared urban neighborhood morphologies and pollutant concentrations to determine the amount, pollutant concentrations peak in relation to urban features and whether any increases are sustained and consistent from neighborhood to neighborhood. The cost and technical difficulties get aggravated to obtain vertical profile measurements. Therefore, to understand the influence of architectural morphology and materiality on pollutant concentration, high spatial resolution field measurements are still to be developed both at the pedestrian level and vertical profiles.

DISTRIBUTED VERSUS DYNAMIC SENSING

Dynamic sensing, or "measuring trips" as Albert Kratzer called them, were remote sensing techniques that were devised to obtain high spatial resolution microclimate data of cities. Temperature curves were plotted through the city profile looking for a better understanding of the temperature variability in the city landscape. The pioneering studies were undertaken by Schmidt (1927) across the city of Vienna, Peppler (1929) in Karlsruhe and Budel (1933) in Munich. As Krazer (1937) described for all these trips, and for those that followed, the automobile and the bicycle rendered service in bringing the observer to even the most widely dispersed locations in the area quickly enough.

Toni Chandlers developed extensive research on the urban climatology of London following the footsteps of Luke Howard. Chandler's work "The Climate of London" (1965) developed a climatological survey that composed one of the most spatially intensive climatological studies of the time. He used a mobile recording station mounted on a car which he drove at different times of the day along the streets of London. He measured the heat fluxes to reflect on the heat island effect as well as the pattern of air pollution. In his concluding paragraph, among other points, he summarizes the positive influence of the presence of green for the reduction of temperatures and pollutant concentrations. He also promotes urban climatology as applied science: "It is to be hoped that enlightened planning might do something in future years to reduce further unconscious deterioration of London's urban climate."

In the last decades, the increasing curiosity concerning our environment has started to add to the number of sensors used in everyday objects, resulting in more information collection for better analysis (Akyildiz 2002; Rakotonirainy 2003; Rogers 2011). For instance, twenty years ago, the typical automobile had approximately five sensors; but, today, over fifty sensors are used to control navigation, safety, and emission. It was discussed in the Internet of Cars panel at the 2014 SXSW festival that "the cars we drive nowadays are giant sensors on wheels, generating tons of data."

Bikes are also integral parts of our cities. Already proven in New York and London, city bike initiatives are being adopted in many cities world-wide aiming at reducing the amount of traffic congestion and pollutant concentration in urban environments. The growing presence of bikes in cities as well as the potential they offer for further applications, are motivating experimental projects. This is the case for the Copenhagen Wheel initiative (Outram 2010) where the dynamic energy of physical effort is stored and used to power environmental CO, NOx, temperature, noise (dB), humidity, and location sensors.

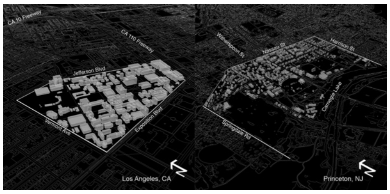


Figure 3
a) Aerial view of the University of Southern California; b) Aerial view of Princeton University.

Public transport such as trains, trams and buses are also adequate horizontal environmental mapping vehicles. This was the motivation for the Open Sense project in Zurich (Li 2012), where the environmental sensing kits were attached to the city trams.

Various strategies can be deployed for horizontal environmental mapping in cities; however, the possibilities to develop vertical or three dimensional readings are more limiting. Tower-stations have been deployed in urban environments to record the vertical temperature, wind velocity, or pollutant concentration profiles (Rotach 2005). However, given the fixity of the tower stations, the number of vertical readings that can be gathered is often constraining.

As drone technologies are becoming more accessible and affordable (Valavanis 2007; Steffen 2008; Fetterman 2011), we can start to classify them along with devices that facilitate transportation and efficient navigation. Their 3-dimensional mapping capability opens new possibilities for urban sensing. UAV's are suitable devices to gather data of vertical profiles that with traditional systems are complicated to record especially in urban settings. Therefore, despite their short stay aloft time, it is sufficient to perform vertical environmental readings. Their 3-dimensional quality and movement flexibility make drones superior to other techniques for such purposes.

CASE STUDIES

This paper presents the technical setup for the dynamic data collection and analysis of two extreme climatic settings: the campus of the University of Southern California in Los Angeles and the campus of Princeton University in New Jersey *(Figure 3)*.

The experiments were conducted in the first and second week of March (on the USC and Princeton campus respectively). Two recordings one in the morning and another one in the afternoon were collected during five days for each location. GIS data was utilized for geolocation and visualization purposes and to extract data related to roads, green areas, location of trees, building geometries, and topographical information. In both campuses several recording trajectories were performed to understand the variability in the area.

Customized Sensor Kit

The sensing kit is composed of an Arduino Uno Board, an Arduino GPS shield, an infrared CO_2 sensor, and a temperature and humidity concentration sensor *(Figure 4)*.

An essential aspect of this sensing kit is that using a GPS shield enables to geotag the data sampling intervals. Using these geolocations, all the collected data are overlaid on the GIS based 3D model. The collected data are stored in a micro SD card.

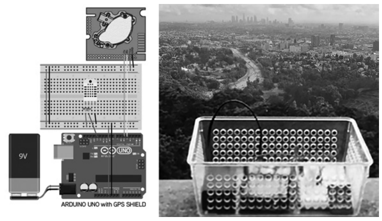


Figure 4
a) Sensor kit wiring diagram (Humidity/Temperature + CO_2 sensors) + GPS shield; b) Portable sensor kit.

Data interpretation	*Data Collection*
"GPS1_Time_Stamp",year,month,day,hours,minute,seconds,milliseconds,true to log to SD when GPS has a fix	GPS1,2014,10,26,22,33,2,0,fix_1
GPS2_Info",latitude,N,longitude,W,altitude,speed,int satellites	GPS2,3401.225097,N,11817.194335,W,2.80,1.02,7
DHT(distributed hash table)", humidity,temp_celsius,temp_fahrenheit,heatIndex	DHT,43.80,24.90,76.82,78.31
CO2 sensor type", CO2 level Parts Per Million	K30,417

Figure 5
a) Collected data types; b) An instance of collected data on the University of Southern California campus.

Field Measurements

For the horizontal collection process, the sensing kit is attached to a bicycle. For both locations, the collection paths define a complete loop that starts from the center of the campus continuing along the high traffic streets to document the whole variation range. The same sensor kit is placed in a customized package that is mounted to the bottom of a UAV for the vertical collection process. The UAV has been equipped with a built in GPS and Gyro boards and a Wi-Fi spy aerial vision camera. These built in systems allow tracking and documentation of the experiment. Flight elevation is kept between the pedestrian level and 1.5H in order to obtain the variability between the street canyon and over the urban canopy layer (UCL).

Urban Parameterization

A number of urban parameterization schemes, often used in meso-scale models to approximate the effects of the urban canopy, have been locally computed based on the GIS data to cross-correlate generic urban parameters with the recorded pollutant concentrations. Parameters such as the built to total area ratio, height variability, or built-to-green ratio, have been computed around the measuring acquisition points. The recorded CO_2 and Temperature values have been visualized and compared against the urban parameterizations *(Figure 6)*.

Average Height:	$\overline{H}$ = Average Building Height
Built to total area ratio:	$\lambda_P = \frac{\Sigma A_b}{Total\ lot\ area}$ (A_b= Built Area)
Height variability:	$\frac{\sigma H}{\overline{H}}$ (σH= Height Standard Deviation, $\overline{H}$ = Average Building Height)
Built to green ratio:	$\lambda_B = \frac{\Sigma A_b}{\Sigma A_g}$ (A_b= Built Area, A_g= Horizontal Green Area)
Road to green ratio:	$\lambda_R = \frac{\Sigma A_r}{\Sigma A_g}$ (A_r= Road Area, A_g= Green Area)

Figure 6
Urban parameterization: a) Average building height; b) Built to total area ratio; c) Height variability; d) Built to green ratio; e) Road to green ratio.

Results

CO_2 measurements, collected from the bicycle measurements in the USC campus, showed large differences between the campus promenades and perimeter traffic roads, especially when in close proximity to the 110 freeway on the east side of the campus. The increase on building height variability also appeared to be correlated with a reduction in CO_2 concentration while the increase of A_B and A_R appears to induce an increase in CO_2 concentration *(Figures 7, 8)*. Street directionality also seems to affect the concentration levels. North-South oriented street canyons show lower CO_2 concentrations. These differences are most likely due to the wind directionality that dominated in the days in which the measurements were taken.

For the case of the temperature gradient, traffic does not appear to play a decisive role while the temperature variations appear to be sensitive to A_B and A_R *(Figures 7, 8)*.

The vertical gradient of CO_2 shows little variability between the pedestrian level and 1.5H. The vertical variation in temperature appeared to be most sensitive to the building height variability, A_P and A_B. At 1H, the temperature consistently drops in relation to the pedestrian level *(Figures 9, 10)*.

The CO_2 measurements collected in Princeton show similar trends. Given that traffic concentration on the Princeton campus is more distributed than on the USC campus, the concentration differences between main and secondary roads in the case of Princeton are not as large. The dispersed nature of the urban fabric in the Princeton campus complicates the rationalization of the data, however as shown in Figure 11 and Figure

Figure 7
a) Bicycle mounted sensor kit + camera on the University of Southern California campus. Image processing based on dynamic data collected using bicycle (pixel color: temperature variation, pixel scale: ppm concentration variation); b) Aerial view of collected Data (line color: temperature variation, line scale: CO_2 variation).

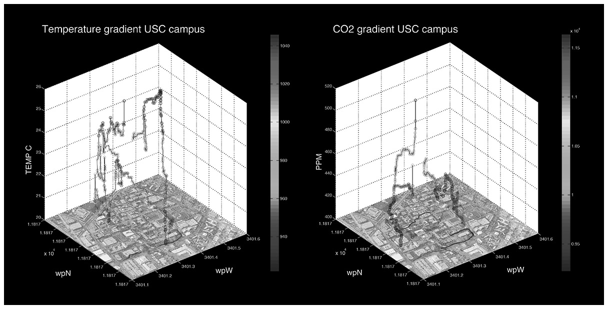


Figure 8
a) 3-dimensional plot of the University of Southern California Temperature reading; b) 3-dimensional plot of the University of Southern California CO_2 reading.

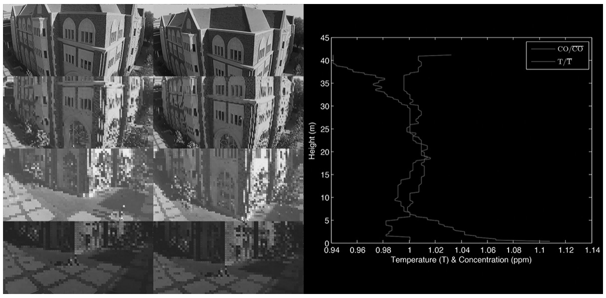


Figure 9
a) Image processing based on dynamic CO_2 and temperature sampling in Z altitude 0-120 feet, using UAV technology on the USC campus (pixel color: temperature variation, pixel scale: CO_2 variation); b) CO_2 and temperature sampling chart of a Z altitude sampling using UAV technology on the USC campus.

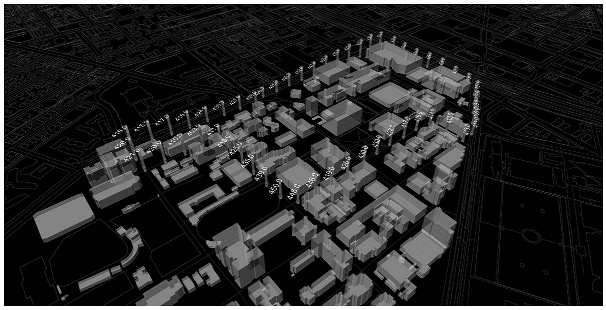


Figure 10
Multiple CO_2 and temperature samplings of Z altitude using UAV technology on the University of Southern California campus at 30 feet intervals.

Figure 11
a) Bicycle mounted sensor kit and camera on Princeton campus. Image processing based on dynamic data collected using bicycle (pixel color: temperature variation, pixel scale: ppm concentration variation); b) Aerial view of collected Data (line color: temperature variation, line scale: CO_2 variation).

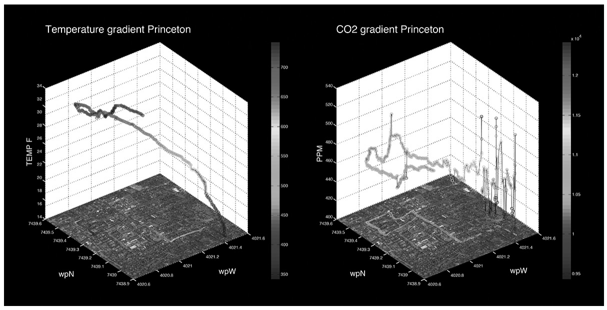


Figure 12
a) 3-dimensional plot of the Princeton campus temperature reading; b) 3-dimensional plot of the Princeton campus CO_2 reading.

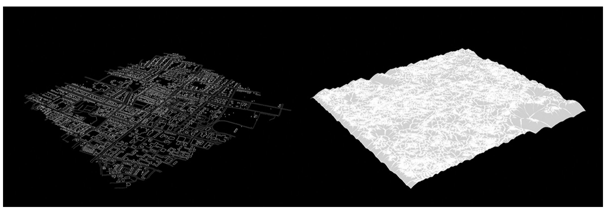


Figure 13
Princeton campus and surrounding area parameter correlation map: a) Distilled; b) Green topology.

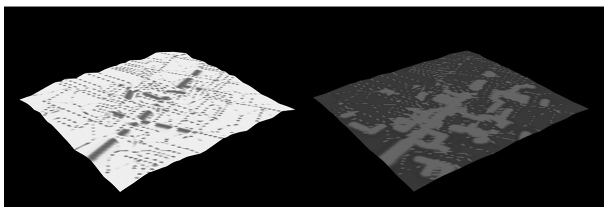


Figure 14
Princeton campus and surrounding area parameter correlation map: a) Temperature landscape; b) CO_2 landscape.

12, the increase in A_P, A_B and A_R appears correlated with higher CO_2 levels. The pedestrian level temperature variability on the Princeton campus appears to be most sensitive to the variability in the topography

CONCLUSIONS

The presented work has aimed at increasing the engagement of urban designers and architects on the question of microclimate and air quality in our cities. Environmental policies are most commonly addressed from high level authorities that often disregard the role of architectural geometry and materiality in urban microclimates. However, recent research has shown that architecture plays a decisive role in the shaping of neighboring microclimates, and therefore, the environmental quality of cities would substantially benefit from an active role of architects on the exploration of the influences of different design decisions on the immediate urban microclimates.

Having addressed the lack of availability of high spatial resolution environmental data of our cities, a sensing kit has been prepared and attached to bikes (for horizontal recordings) and UAV technologies (for vertical collection) to obtain higher spatial resolution environmental data. UAV technologies have proved to be adequate vehicles to record vertical profiles.

The recordings have been compared against an initial set of urban parameterizations. The data comparisons have shown that architectural and urban design features influence pollutant concentrations. However, further data collection is required to identify more specific trends on the relation between architecture, urban parameters and air quality. In order to encourage an incremental and scalable data collection platform, DIY sensing technologies have been used and the architectural and climatic information has been collapsed in the open source processing platform which has been linked to a GIS database. The interactive graphic interface of Processing has been considered appropriate to reveal urban design questions in relation to the recorded air quality information in a 3D design and analysis environment.

Future work will be focused on the development of an open platform to enable larger communities to participate in the acquisition as well as in the data rationalization process.

REFERENCES

Akyildiz, I. F., W. Su, Y. Sankarasubramaniam, E. Cayirci. (2002). Wireless Sensor Networks: A Survey. Computer Networks 38(4): 393-422.

Berry, R. D., J. J. Colls, W. Peter. (2003). Particle and Trace Gas Emission Factors Under Urban Driving Conditions in Copenhagen Based on Street and Roof-level Observations. Amospheric Environment 37: 2735-2749.

Chandler, T. J. (1965). The Climate of London. London: Hutchinson of London.

Chow, J. C., J. G. Watson, D. M. Ono, C. V. Mathai. (1993). PM10 Standards and Nontraditional Particulate Source Controls. A Summary of the A&WMA/EPA International Specialty Conference.

Code of Federal Regulations. (1994). Reference Method for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method). Washington: U.S. Government Printing Office.

Cui, Y. Y., and B. de Foy. (2012). Seasonal Variations of the Urban Heat Island at the Surface and the Near-Surface and Reductions due to Urban Vegetation in Mexico City. American Metereological Society 2012: 855–868.

Dockery, D., C.A. Pope, X. Xu, J. Spengler, J. Ware, M. Fay, B. Ferris, F. Speizer. (1993). An Association Between Air Pollution and Mortality in Six U.S. Cities. New England Journal of Medicine 329: 1753-1759.

Federal Register. (1987). Revisions to the National Ambient Air Quality Standards for Particulate Matter, 40 CFR Part 50. Federal Register 52:24634.

Fetterman, M. R., T. Hughes, N. Armstrong-Crews, C. Barbu, K. Cole, R. Freking, K. Hood, J. Lacirignola, M. MacLarney, A. Myne, S. Relyea, T. Vian, S. Vogl, Z. Weber. (2011). Distributed Multi-modal Sensor System for Searching a Foliage-covered Region. Technologies for Practical Robot Applications (TePRA) IEEE.

Geiger, R. (1965). The Climate Near The Ground. Cambridge: Harvard University Press.

Howard, L. (2012). The Climate of London. Reprint of the 2nd edition by the International Association for Urban Climate. Lulu.com, Print-on-Demand edition. Accessed July 30, 2015. *http://urban-climate.com/wp3/resources/classic-texts/luke-howard-the-climate-of-london*.

Kanda, M., R. Moriwaki, Y. Kimoto. (2005). Temperature Profiles Within and Above an Urban Canopy. Boundary-Layer Metereology 115: 499-506.

Kastner-Klein, P., E. Fedorovichb, M. W. Rotach. (2001). A Wind Tunnel Study of Organised and Turbulent Air Motions in Urban Street Canyons. Journal of Wind Engineering and Industrial Aerodynamics 89: 849-861.

Kratzer, A. (1937). Das Stadtklima. Braunschweig: Verlag Vieweg.

Kunzli, N., S. Medina, R. Kaiser, P. Quenel, F. Horak Jr, M. Studnicka. (2001). Assessment of Deaths Attributable to Air Pollution: Should We Use Rist Estimates Based on Time Series or on Cohort Studies? American Journal of Epidemology.

Li, J. J., B. Faltings, O. Saukh, D. Hasenfratz, J. Beutel. (2012). Sensing the Air we breathe - the OpenSense Zurich Dataset." Proceedings of the Twenty-Sixth AAAI Conference on Artificial Intelligence, 2012.

Nasrallah, H. A., R. C. Balling, S. M. Madi, L. Al-Ansari. (2003). Temporal Variations in Atmospheric CO2 Concentrations in Kuwait City: Kuwait with Comparisons to Phoenix. Environmnetal Pollution: 201-305.

NRC. (2010). Advancing the Science of Climate Change. Washington: The National Academies Press.

Oke, T. R. (1984). Towards a Prescription for the Greater Use of Climatic Principles in Settlement Planning." Energy and Buildings, 1984: 1-10.

Oke, T. R. and I. D. Stewart. (2012). Local Climate Zones for Urban Temperature Studies. American Metereological Society 93(12).

Outram, C., C. Ratti, A. Biderman. (2010). The Copenhagen Wheel: An Innovative Electric Bicycle System that Harnesses the Power of Real-time Information and Crowd Sourcing. Senseable City Lab.

Peppler, A. (1929). Das Auto als Hilfsmittel der meteorologishen Forschung. Das Wetter: 305-308.

Peppler, A. (1929). Die Temperaturverhaltnise von Karlsruhe an heissen Sommertagen. Deutsche Meteorologisches.

Rakotonirainy, Sven Meyer Andry. (2003). A Survey of Research on Context-aware Homes. In Proceedings of the Australasian information security workshop conference on ACSW frontiers 2003, Volume 21.

Rogers, Y., H. Sharp, J. Preece (2011). Interaction Design: Beyond Human - Computer Interaction. New York: John Wiley & Sons.

Rotach, M. W., R. Vogt, C. Bernhofer, A. Clappier, B. Feddersen, S.-E. Gryning, G. Martucci, H. Mayer, V. Mitev, T. R. Oke, E. Parlow, H. Richner, M. Roth, Y.-A. Roulet, D. Ruffieux, J. A. Salmond, M. Schatzmann, J. A. Voogt. (2005). BUBBLE: An Urban Boundary Layer Meteorology Project. Theoretical and Applied Climatology, 2005: 231-261.

Schauer, J.J. et al. (1996). Source Apportionment of Airborne Particulate Matter Using Organic Compounds as Tracers. Atmospheric Environment 30: 3837-3855.

Schmidt, W. (1927). Die Vertilung der Minimurntemperaturen in derl Frostnacht des 12.5.19.27 im Gemeindegebiet von Wien. Fortschritte der Landwirtschaft.

Shaw, N., J. S. Owens. (1925). Smoke Problems of Great Gities. London.

Steffen, R. and W. Forstner. (2008). On Visual Real Time Mapping for Unmanned Aerial Vehicles. Bonn: University of Bonn, Department of Photogrammetry University of Bonn.

Stewart, I. D. (2011). Redefining the Urban Heat Island. PhD. Dissertation, Department of Geography, University of British Columbia, Vancouver.

Stroh, E., L. Harrie, S. Gustafsson. (2007). A Study of Spatial Resolution in Pollution Exposure Modelling. International Journal of Health Geographics 6: 19.

Thorsheim, P. (2006). Inventing Pollution: Coal, Smoke, and Culture in Britain Since 1800. Athens, Ohio: Ohio University Press.

U.S. Department of State. (2007). Fourth Climate Action Report to the UN Framework Convention on Climate Change: Projected Greenhouse Gas Emissions. Washington, D.C.: U.S Department of State.

Vakeva, M., K. Hameri, M. Kulmala, R. Lahdes, J. Ruuskanen, T. Laitinen. (1999). Street Level Versus Rooftop Concentrations of Submicron Aerosol Particles and Gaseous Pollutants in an Urban Street Canyon. Atmospheric Environment, 1999: 1385-1397.

Valavanis, K. P., ed. (2007). Advances in Unmanned Aerial Vehicles: State of the Art and the Road to Autonomy. Netherlands: Springer Publishing Company.

Van Dingenen, R., J.-P. Putaud, S. Martins-Dos Santos, and F. Raes. (2005). Physical Aerosol Properties and Their Relation to Air Mass Origin at Monte Cimone (Italy) During the First MINATROC Campaign. Atmospheric Chemistry and Physics 5: 2203-2226.

Velasco, E., S. Pressley, E. Allwine, H. Westberg, B. Lamb. (2005). Measurements of CO2 Fluxes from the Mexico City Urban Landscape. Atmospheric Environment 39: 7433-7446.

Vogt, R., A. Christen, M. W. Rotach, M. Roth, A. N. V. Satyanarayana. (2006). Temporal Dynamics of CO2 Fluxes and Profiles over a Central European City. Theoretical and Applied Climatology 84: 117-126.

Zheng, J., L. Zhang, W. Che, Z. Zheng, S. Yin. (2009). A Highly Resolved Temporal and Spatial Air Pollutant Emission Inventory for the Pearl River Delta Region, China, and Its Uncertainty Assessment. (2009). Atmospheric Environment Volume 43(32): 5112-5122.

MAIDER LLAGUNO MUNITXA

Maider Llaguno Munitxa is a Ph.D. researcher at the Institute of Technology in Architecture (ITA) at the ETH in Zurich and the Civil and Environmental Engineering department at Princeton University. Maider is Principal at AZPML (Alejandro Zaera-Polo & Maider Llaguno) architecture and is currently the director of the AA Bilbao/SanSebastian Visiting School and Adjunt Faculty at GSAPP Columbia University. Maider has held teaching positions in the past at Yale School of Architecture, Berlage Institute, and the ETH in Zurich. Maider obtained her diploma in architecture with honors from ETSASS/ETSAB in 2006 and graduated with distinction from GSAPP Columbia University in 2010. While studying architecture, she started her studies in broadcasting and communications at the University of the Basque Country and in summer 2010 she was part of the New York University Interactive Telecommunications Program. After graduation, from 2006 until 2009, she worked at Foreign Office Architects in London.

BIAYNA BOGOSIAN

Biayna Bogosian is pursuing a Ph.D. in Media Arts & Practice in the School of Cinematic Arts at the University of Southern California. She holds a Master of Science in Advanced Architectural Design from Columbia University and a Bachelor of Architecture from Woodbury University. Biayna is principal of Los Angeles-based studio Somewhere Something that works at the intersection of art, architecture, computation, fabrication in order to design interactive virtual and physical environments. Since 2011, Biayna has taught digital media seminars and architectural design studios at Columbia University Graduate School of Architecture Planning and Preservation, USC School of Architecture, Woodbury School of Architecture, Tongji University College of Architecture and Urban Planning, and Tumo Center for Creative Technologies in Yerevan. Biayna's work has been exhibited and published extensively in various international periodicals and newsletters.