Urban Ecological Interaction: Air, Water, Light and New Transit at the Human Scale of Barcelona's Superilles

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As everyday transit options are shifting from autocentric to pedestrian and bicycle oriented modes for healthy living, downtown streets are becoming more attractive places to live. However, tools and methods to measure the natural environment at the small scale of streets do not exist. Fortunately, a combination of mobile data collection technology and parametric urban design software now allows an interface to relate urban ecological conditions. This paper describes creation of an interactive tool to measure urban phenomena of air, water, and heat/light at the scale of new three-by-three block pedestrianized areas in Barcelona called Superilles. Each Superilla limits transit to the exterior of the blocks and to create more walkable and bikeable interior streets for healthy living. The research will describe the integration of data collection, analysis, and design output via a live interface using parametric software Rhino Grasshopper and the Human User Interface (UI) plugin.

Keyword: transit, urban design, GIS, parametric design, Superilles, Barcelona, urban ecology

I. INTRODUCTION

NEW radical changes in urbanism and transit are taking hold, some planned, others occur as unplanned phenomena of urban processes. In Barcelona, city wide bus and bike lanes have recently been completely reorganized to form islands of refuge from traffic for human scaled livability called Superilles, or "super islands" in Catalan. Barcelona's air quality, according to World Health Organization data, has an annual mean concentration of particulate matter of 56, surpassing car-dependent North American cities such as Los Angeles at 20 and New York at 14 [1]. Epidemiology research now points to serious neurological and respiratory health effects for children [2]. Air pollution modeling for cities has largely been based on traffic to predict simple relationships to air pollution. However, urban form and urban ecology as a complex interdisciplinary study of urban systems [3] suggest more complex causes.

Air quality researchers, for example, are able to use direct data collection, rather than modeling, at various stations across two locations in the city to determine the chemical properties of air pollution [4]. With new mobile data collection and handheld sensors along with open parametric software platforms, urban designers are able to approach an integrated analysis and design approach to include and understand the most fundamental natural qualities of our urban spaces including air, water, and heat/light.

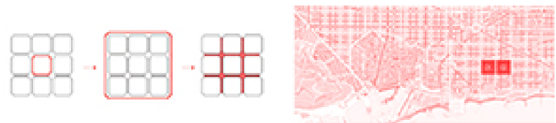

Fig. 1 1859 Example block, new Superblock three-by-block area with periphery streets, and Superilla interior pedestrianized streets of limited vehicular traffic

While the Superilles of Barcelona are currently being analyzed using urban ecologist Salvador Rueda's theory of urban sustainability including 1) *Land Use, 2) Public Space and Livability, 3) Mobility and Services, 4) Urban Complexity, 5) Green spaces and Biodiversity, 6) Urban Metabolism, 7) Social Cohesion,* and 8) *Management and Policy* [5] in first analytic studies [6], some aspects dependent on urban phenomena are excluded from measurement. These exclusions include social interaction, part of a parallel research by the author [7], [8], and the fundamental qualities of healthy living. Recently, a pilot Superilla was opened in Barcelona's Poblenou district, limiting traffic to interior streets by temporal painted traffic lines and similar temporary solutions at intersections, but received criticism from local residents for lack of detailed study at the small scale within streets [9].

The methodology described in this paper will use protocols learned from similar research of air pollution phenomena [10]. Unlike traditional GIS analysis using existing data locations and of existing data types, the research will create custom chosen data indicators each for air, water, and heat/light and consider those qualities in the urban design output at the very small scale of landscape architectural features including tree species and location, paver spacing, angle and shape, and vegetation species and planter size and locations for pollution sequestration. The methodology will use a recently released Rhino 3D Grasshopper software plugin called Human User Interface (UI) [11] to visualize in real-time the integration of various qualities from the larger dataset.

II. BACKGROUND

The inclusion of ecological and atmospheric qualities with urbanism has had its theoretical origins from a number of ecologists. Salvador Rueda's own *Ecologia Urbana: Barcelona i la seva regio metropolitana com a referents* [12] acknowledged Ramon Margalef as the father of modern ecology utilizing Margalef's ideas of biodiversity, information and urban ecology, pollution as external to ecological systems, and flows of energy and people [13]. Ramon Folch's recent book *Ambiente, Emocion y Etica*, or *Environment, Emotion* *and Ethics*, likewise include ideas linking ecology, economic, and urbanism [14]. The work of air pollution expert Xavier Querol also shows the link between geospatial differences and air quality across metropolitan space within the city [15] as well as differences air pollution differences across modes of urban transit such as walking, bicycle, tram, metro or bus [16].

The research follows similar data collection, analysis, and visualization methodology by the author at the same scale of street addresses with three-by-three block Superilles but instead focused on qualities of social interaction. In that case, the indicators of social phenomena were based on the measured ability of the fixed urban environment, vegetation and business qualities to support social interaction. Such data was often measured only once. Meanwhile the data methodology here based on direct measurement of atmospheric phenomena relied on learned protocols working directly with Spanish National Research Council CSIC air qualities experts Xavier Querol and MariCruz Minguilon using learned approaches to repeat data collection, control times of data collection, calibration of handheld instruments and careful consideration of environmental conditions such as temperature, wind, humidity and human sources of pollution.

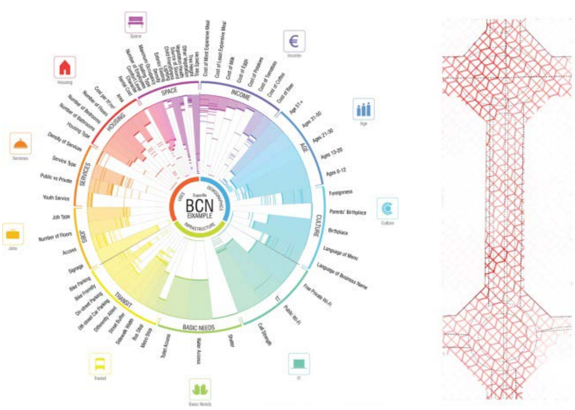

Fig. 2 Prior Social Interaction Tool circle diagram and simple plan visual

Other research methods that test the application of measuring atmospheric conditions and parametric urban analysis and design contributed to this work through different disciplinary methods. Work from architects Kieran Timberlake's two research projects use microprocessors, a green roof post occupancy study using soil moisture sensors and analysis for a plaza design. MIT SENSEable Cities Lab, directed by Carlo Ratti, likewise operates in urban spaces but often at the scale of a district, city or region and uses computer science methods to leverage real-time data sets, existing or newly created [17]. Landscape architects have more closely approached this smaller scale of ecological urbanism using simulations with real conditions such as a project using real materials and water digitally measuring the processes of water and soil over time in a lab in a synthetic ecology [18] that "test protocols, simulations and manipulations" using real-world "tactical models" to understand system dynamics [19]. Other architects have brought experience in indoor atmospheric and thermal conditions to exterior spaces such as plaza designs [20].

A significant part of the research methodology leveraged new interface software that allows a user of the 3D parametric modeling environment to test relationships between qualities in real-time. Typical urban design and planning visualization occurs at larger scaled data because 1) the source data is larger such as census tract data, 2) urban design input such as transit, open space and land use may not be differentiated or relevant at the street scale such as walkability to metro stops, and 3) a visualization of differences of planning data at the street scale is not yet a normative practice in planning (see Fig. 4).

Previous research by the author made the important distinct to move from visualizing data over the space of a block, including both private built space and streets, to the experiential public space in the right-of-way [7]. Rhino 3D Grasshopper work without the use of Human User Interface (UI) users have to alternate between the parametric interface of formulation components and a separate window of resulting analysis and design results. The plugin Human UI allows a single user friendly visualization environment to test, in real-time, relationships between urban ecological input data such as wind speed, wind direction, solar radiance analysis, slope for water runoff, air pollution particulate matter or nitrogen oxide. The user interface can: 1) make changes to computation; 2) turn on and off visualization of layers of information and 3) test changes to formulation that effects design outputs such as planters, tree species, tree location, paver design and orientation or seating.

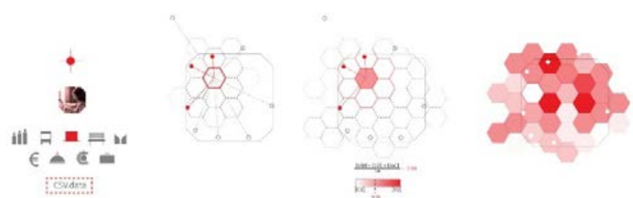

Fig. 3 Prior plan drawings and diagrams of differentiated data

III. Methodology

The qualities of air, water and heat / light were chosen to measure phenomena that effect healthy living in cities. Previous research to measure qualities and respective indicators of social interaction at street addresses at the scale of Superilles in Barcelona, Portland and Eugene, Oregon, measured social phenomena indirectly to study a location's ability to support phenomena. For example, a given sidewalk location rated the ability to lockup a bike with a formal bike stand, a metal pole, a tree or remain unlocked within view of the owner or a nearby shop keeper. Proximity to a metro station is rather fixed but bus stops, for example, change. Trees and vegetation were measured – which change naturally through growth, with weather and decision making both top down from City agencies and bottom up from rogue residents. Business indicators were also measured and these qualities on the urban environment changed with operating hours, August vacation closures and business closures and subsequent changes. To more broadly measure urban ecology in cities it became evident that 1) methods more similar to measuring air pollution with CSIC would be needed to measure both social and natural urban phenomena and 2) broader understanding of urban ecology would be assisted by the ability to include natural phenomena. The qualities of air, water and heat / light have been considered in various forms of sustainability indicators sets for architects and planners [21], [22], [23].

A. Sensors

Sensors were chosen for each quality of air, water and heat/light and an Arduino microprocessor based platform was developed and built for each. See the attached dataset as Appendix 1.0. Some data was collected off-site using existing dataset sources to complement on-site data. Their locations were noted.

1) AIR:
PM 0.5*, PM 2.5*, tree species, wind speed, wind direction, smell intensity, smell type, noise level, noise source (water, wind, vegetation, people + animal, city), NO, CO, average wind speed by month (off-site), prevailing wind direction by month (off-site)
*PM measurement used an existing handheld rechargeable Dylos 1700.

2) WATER:
Occupancy – building area, occupancy – number of floors, occupancy – building type, soil type, slope x-axis*, slope y-axis*, slope degrees*, air temperature, humidity
*Slope measurement used a smart phone and application.

3) HEAT/LIGHT:
Reflectivity surface temperature, shading – surface temperature (infrared)*, shading – tree canopy density, façade material, width to nearest building (off-site), height to nearest building (off-site), height/width ratio (off-site).
*Ladybug software and associated Radiance data was used.

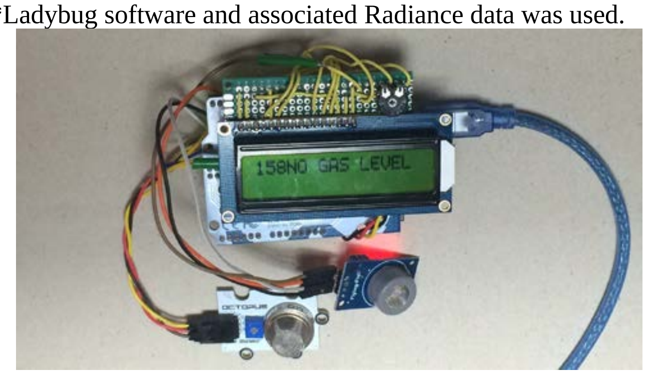

Fig. 4 Arduino microprocessor based sensor platform with gas sensors (Image by BettyLou Poston)

B. Data Collection

Data was collected at street addresses within three-by-three Superilles to understand differences: 1) between two Superilles across the city; 2) within a Sueprilla and 3) within a street of a Superilla. Test data collections for this work and similar work have been done in resolution as high as each building address and even different ground floor shops. Final data collection for this study divided 100m square Barcelona Eixample blocks into three points, 33m apart. A typical Superilla area would thusly result in 108 points, twelve points per each of nine blocks. Control tests occurred in controlled interior environments and then in exterior environments to test sensor devices. Pilot tests of one test block to consider the impact of exterior environmental conditions.

C. Study areas

Study areas were chosen using Barcelona’s Superilla plan already with bus and bicycle lanes following the new orthogonal grid around the Superillas. Superilla study areas were chosen for their pre-existing characteristic of greater traffic at periphery blocks either because of greater width and lanes of traffic or greater through traffic beyond the Superilla resulting in greater street level traffic already at the periphery of the block.

D. Poblenou

A Superilla in the Poblenou neighborhood was chosen for data collection in July and August 2016 knowing that this Sueprilla study area would be the first Superilla in September 2016. The Superilla was bound by Carrer de Badajoz, Carrer de Tanger, Carrer Llacuna and Carrer de Pallars. This Superilla was already characterized by perimeter streets Carrer de Badajoz and Carrer de Llacuna with through traffic connecting to the nearby waterfront and beltway road Ronda Lateral. Interior streets are less connected. Additional data point locations were recorded along the atypical diagonal street Carrer de Pere IV. 124 total data points were measured. Construction was noted at the time of data collection within the interior streets of the Superilla and data was accordingly removed when it was judged to be effected by the construction work. Two datasets were recorded on weekdays, one on the afternoon of Thursday July 28, 2016, 4:20pm until 6:40pm and another in the morning of Wednesday, July 27, 2018, 9:29am until 12:37pm.

E. Eixample Esquerra

A more downtown location in the Eixample Esquerra neighborhood was chosen for similar reasons that the exterior roads were already of greater surface vehicle transit including Gran Via de les Corts Catalanes with nine lanes of traffic, Carrer de Compte de Urgell, Carrer de Arago / Avinguda de Roma and Carrer de Muntaner. The downtown location of this area more severely exhibits evidence of vehicle traffic and observed pollution. 108 total points were measured on Wednesday, July 27, 2016 from 9:29am until 12:37pm. This Superilla exhibits a denser built fabric almost completely built to six stories with zero street setback unlike the Poblenou area with lesser density and as a previously industrial use, exhibits fewer open block patios, zero setback conditions or consistent street wall edge.

Additional baseline areas were tested including individual plazas and streets already recognized by Superilla planners as examples of high social interaction [6]. Plaza del Sol, Plaza de la Vila de Gracia, Plaza de la Revolucio and Carrer de Enric de Granados were all measured for their already recognized high level of pedestrian street level activity and safety.

A Google map was generated for each Superilla, plaza or street and pins were dropped at evenly spaced intervals. The locations were then exported to Google Sheets for their latitude and longitude coordinates. The Google Sheets were then used while walking and confirming positions via nearby street addresses using a handheld mobile smartphone in teams for each air, water and heat/light qualities recording the data entries measured by others using the sensor platforms. This was done in person because GPS sensor based coordinates would only achieve accuracy within 2m radius, pointing out the new challenges small-scaled high resolution GIS urban data collection. Future research will continue to explore how to automate this process of data recording.

The data was then combined to a single Google Sheet and exported to be used along with an OpenStreetMap.org OSM file of street centerlines. A 3D model of building shapes was generated via Google aerial view, existing floor height data and on-site observations to confirm the data. This data was then converted to CSV and linked to the Rhino Grasshopper environment for formulations 1) first for each of air, water and heat/light and 2) then combined as one single formulation and computation and visualized using the Human UI interface for Grasshopper.

The methodology described here was aimed to begin to compute and visualize the data rather than come to affirmative conclusions of the data that would otherwise require repeated data collections of the phenomena to normalize the data results.

IV. QUALITIES

The objective of the urban ecological interaction tool was to empower designers to make informed decisions based on the ability to make and relate information. The tool would facilitate relating dissimilar information without combining them by turning on and off the visualization and modifying computation of different aspects of air, water and heat/light data. While the tool may currently show specific design output features of groundscape, vegetation and trees, the tool rather shows a workflow that could also include seating, eating and play surfaces to further engage natural / atmospheric phenomena with social interaction.

A sub-section of investigation was done for each air, water and heat/light. This section will describe the decisions for each study and the individual design output of each.

A. AIR

The inclusion of air qualities intended to make visible to urban designers the differences of air quality within a street and allow that data to directly inform urban design differences within the small spaces of a street. Air quality formulation of input data was used for two design outputs: 1) tree species selection for their ability to sequester certain air pollutants and 2) planter design to accommodate smaller planting vegetation for their ability to both sequester other air pollutants and flowering that provides an interactive design element for people to engage. Air pollutants measured included PM 0.5, PM 2.5, NO and CO. Experiential qualities included small type and intensity. Wind was measured for direction and speed on-site and off-site data included monthly averages to adjust the tool across the year. Noise levels were measure for intensity and diversity of type.

The resulting tool provided a computational output for evenly spaced locations of street trees and human level planting vegetation. Formulation was done in the Rhino Grasshopper environment. That formulation is adaptable within the native Grasshopper environment for different users to make evaluations. The street tree output can vary across a street and intersection. Tradition street tree selection is often one single species as we see in city managed selection today or prescriptive selections by owners using various aesthetic criteria. The research designed street-level planter can vary in height and width using modular elements to support the varied qualities of the computed planting type.

The air pollution sub-section of the overall tool was important because it used data selected by the research team to design the tool. It then used newly collected data on-site and existing data off-site. The new data was certainly only a test dataset. To make conclusive findings from the methodology data collection on-site would have to be repeated, tools calibrated more carefully with certified equipment and observed phenomena such as construction, temperature, humidity and social activities more carefully recorded to ensure they did not adversely affect the data collection. As air pollution research including that of particulate matter and nitrogen oxide are given more focus and as small handheld sensor technology is improving [24], and while urban design strategies such as Superilles differentiate urban space from interior to exterior streets, a computation design approach may effectively connect technology with urban design theory.

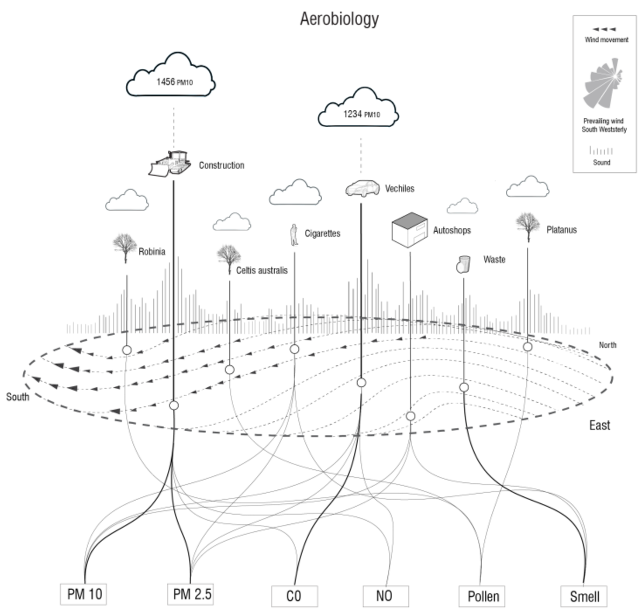

Figure 5 Air quality study diagram (Image by Derek Rayle)

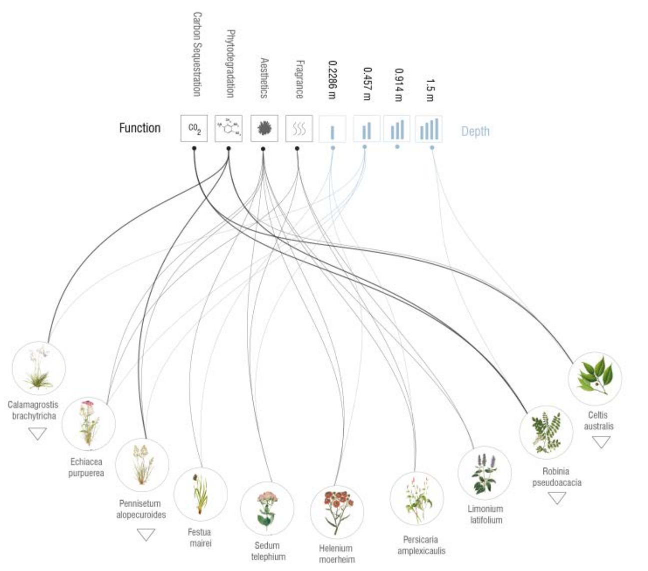

Fig. 6 Air quality planting species and air pollutant sequestration diagrams (Image by Derek Rayle)

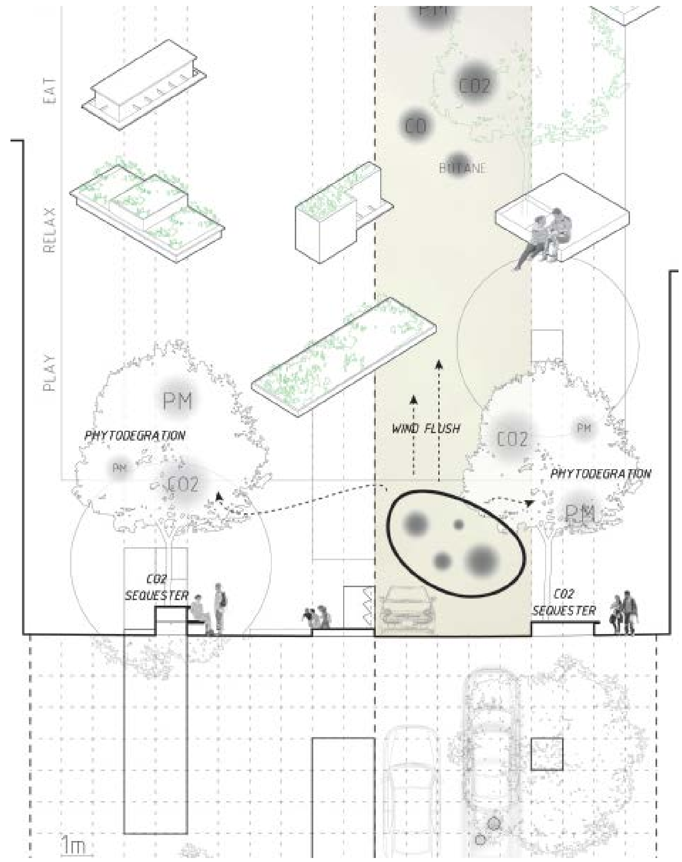

Fig. 7 Air quality output street-tree and modular planter design for computed street-level vegetation selection (Image by BettyLou Poston)

WATER

Water qualities were studied to understand the relationship between water use in a street and Superilla area and the opportunity to 1) manage water in various rain events using qualities across streets and 2) provide an everyday urban design experience that allows people to understand these natural and urban phenomena. In the case of this sub-study the design output of paving design did not vary within a street but vary across the streets of the Sueprilla corresponding to respective input variations. Street slope was measured in direction and intensity. Grey water contribution from residents was measured with building use type, building area and number of floors. Soil type was included. Temperature and humidity variations were measured on-site. Formulation was also to understand the rainfall volume in various storm events such as typical rain, heavy rains, storm event and atypical storm event.

The resulting tool provided a computational output for street pavers slope, spacing and orientation. These variations would provide opportunity for water to be filtered and absorbed into the ground soil and diverted from storm water collection. The resulting water capture could provide additional benefits to support vegetation and contribute to the local aquifer. Thresholds for the various rain events can be changed in the tool as well as location and weather data. The resulting variations of the very small pavers suggest the importance of small variations to respond to larger weather events at the scale of the region and city.

The water sub-section of research contributes to the ability to find methods that input data across various scales. At the urban scale within streets data varied by adjacent building use such as residential versus industrial and their corresponding potential grey water contribution. Slope varied only at the scale of the street. Meanwhile soil type for example in Barcelona only varies along one line in the city. Rain fall data is a single data value for the entire city. Thusly the tool was challenged by its reliance on existing data. Small-scale differences other than building use relied on off-site existing data. Still street pavers typically do not vary across districts if not cities. Even a variation across individual street blocks would be a radical proposal for cities but made possible by such a tool.

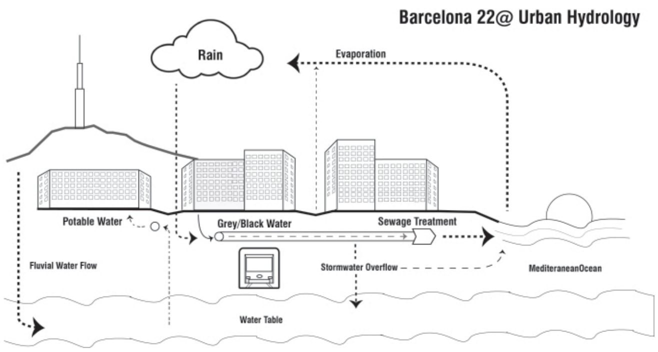

Figure 8, Flow diagram of water including rain, grey, potable, sewerage and sea water. Image by BettyLou Poston

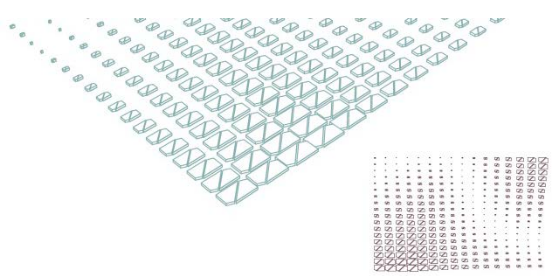

Figure 9, Street paver design study. Image by Andrew Maragos.

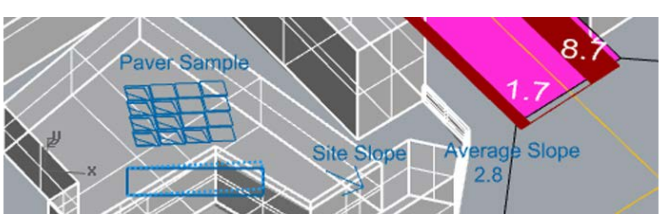

Figure 10, Final paver design and site slope data in the Human UI environment. Image by Joel Mbala-Nkanga.

B. HEAT/LIGHT

The objective of the heat/light sub-section of study was to measure and design around the impact of urban heat island effect at the small-scale differences within streets. Computation for this sub-section of the tool was greatly supported by the Ladybug plugin for Rhino Grasshopper and the radiance dataset. The application is often used for indoor daylighting and radiance analysis but in this case was used to determine the heat absorption at the street-level public space. Initial data collection of ground and air temperature was done on-site however inconsistency from the sensors and via tree canopy led the research to instead use the data from the Ladybug plugin simulation. All buildings for the Superilla were modeled. On-site date for building façade materials was used. Off-site measurements of street width and approximate building height was converted into a ratio and used in the computation.

The design output was analytical information of annual heat island effect based on the buildings, materials and solar orientation and the specific output of street tree location and species selection. A balance of tree canopy size and type was made between abundant shading to reduce heat island effect and ambient light penetration to support street level social activities. Computation also addressed the recent understanding of tree leaf canopy structure that not only shades but allows air pollution to escape. For example, in Barcelona, London plane trees are now thought to trap PM air pollution at the street level. The computational design output of a tool that varies tree species based on adjacent buildings has not been found and one could a rich diversity of tree canopy that slowly evolves either when new construction occurs and or trees die and are replaced.

This sub-tool that measures the small scale of urban heat island effect and light resulted in a rich variation of tree variations within a street. While data collection of phenomena was challenging, the variation of built fabric and the resulting tree species represents a relatively adaptive urban system in the long term urban planning of cities. External radiance and weather data was not locally collected. However, the adaptation to measure individual buildings was a necessary part of this tool and reinforces the value of small-scale data analysis to respond to large scale problems such as urban heat island effect.

C. Tool integration for air, water and heat/light

The integration of the air, water and heat/light sub study and sub-tools provided significant challenges. Air and heat/light sub-tools for example both provided a design output for tree species selection. Additionally the visualization of all the varied data requires the active participation of the user to create data visualization that is organized and understandable in the Human User Interface. Despite these challenges the current evolution of the urban ecological tool (figure 11) contributes to the research area since most data of this type at a larger scale. The methodology allows 1) design selection of ecological qualities; 2) custom data collection at the small-scale of streets and experiential urbanism; 3) custom analysis formulation with opportunities for reevaluating relationships and 4) direct computational urban design output at the scale of streets including street trees species and locations, vegetation planters and ground pavers for hydrological performance. Future development of the tool will look for way to more smoothly integrate the design output (figure 12). However, the methodology described here should not be evaluated on the success of the product of integration but on the successful interface of custom data collection and parametric urban design within a traditional context of little urban design variation at this scale that directly using data of natural phenomena.

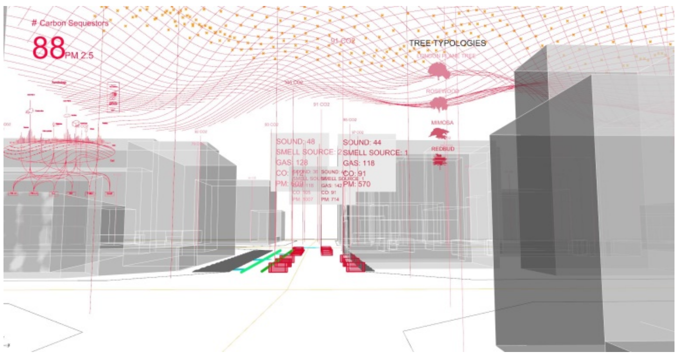

Fig. 11, Final integrated air, water and heat/light design tool user interface. User interface data allows a live 3D zoom and variation of data visualization while heads up display information remains in fixed display locations (air information to the left, heat/light tree species selection to the right, and water related paver data to the bottom) (Image by Josh Rosenthaul)

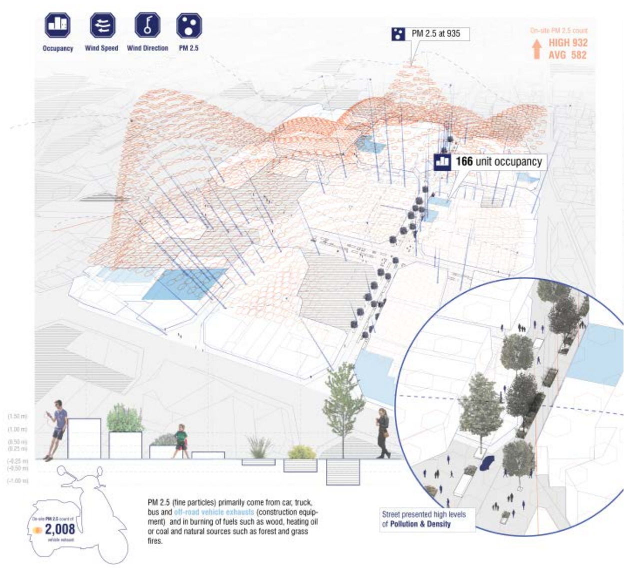

Fig. 12, Pre-final post-processed analytical sub-tool for air along with preliminary street tree and street-level planter design. Future final integrated tool may aim to visually integrate data and design like this (Image by Chazandra Kern)

CONCLUSIONS – USER VARIED INTEGRATION

The methodology contributes to the area of computation and urban design, specifically to the inclusion of urban ecological data in the small-scale urban design of streets. The application of the methodology within Barcelona's new three-by-three Superilles allowed the study to examine differences between streets. The research methods were interdisciplinary combining urban theory, data collection hardware and software and 3D geospatial analysis and design. The integration of this design varied from traditional urban design planning by allow integration of analysis and design in one platform, namely the Rhino 3D Grasshopper parametric modeling and Human UI interface for design visualization.

The results of the methodology exposed the challenges of measuring atmospheric and ecological data of air, water and heat/light at this scale. Only by working through various scales of data across the scales of street address on-site collection, off-site data at the scale of the city and simulation as seen in the use of Ladybug weather data integration, was the research able to assess and utilize different types of data to achieve the desired output of urban design features such as trees, street-level vegetation and ground-level street pavers. Still the diverse types of data include scales of time such as annual, monthly and on-site temperature, humidity and rain data were able to be formulated in the parametric design environment unlike traditional GIS software that is not intended for 3D modeling and design work at the small scale of landscape architecture within streets. The research aimed to reveal the challenges of data selection and collection, formulation and direct design in one integrated computational design environment. Current challenges reside within the need to acknowledge data in the design of geospatial variations of ecological performance and human experience within these first interior streets of Barcelona's Superilles [25].

Future research will: 1) establish more refined data collection protocols and inputs; 2) investigate how to integrate different types of air, water and heat/light data and design output that clearly overlap in computational association and 3) investigate how the user interface may be enhanced by evaluating when in the process that visualization environment should be tested. Additional post-analytical tests may also be performed as well as case studies of existing successful urban spaces. A pilot test of temporary installation of trees, vegetation and paver may also be possible with data collection to occur before and after the design installation. As handheld sensor technology improves, as well as accessibility to mobile computing devices, the idea of including atmospheric data of natural phenomena such as air, water and heat/light only becomes more possible as a tool for urban designers to create streetscapes that more accurately support the healthy and comfortable use of urban space at the small scale of human experience.

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