Sensing the Landscape: Mapping the Dynamic Atmospheric Environment of the Urban Fabric

Craig Douglas[1]

[1]Harvard University, Cambridge, Massachusetts/USA · cdouglas@gsd.harvard.edu

Abstract: Working at the nexus of the social, ecological, and technological in the built environment, the project explores remote sensor technologies capable of continuous in-operation monitoring to measure atmospheric conditions at a hyper-local scale in the landscape. This approach seeks to make visible and reconstitute the urban landscape as a complex temporal and material manifold of differential space shifting across multiple scales in a constant state of flux. The research explores how a sensor network may be deployed to measure and describe airborne territories that might augment and challenge traditional concepts of site in which air is a matter of entanglement and interconnection.

Keywords: Digital representation, sensing, climate change, environmental systems, climate adaptation

1 Introduction

As the world is increasingly shaped by the ubiquitous and ever-growing range of connected devices through the Internet of things – in conjunction with the Internet and the emerging presence of artificial intelligence – the work explores possible interconnections of the digital and physical realms that are “expanding our understanding of the built environment and the implications for both the discipline and the practice” (CHRISTOFORETTI, 2010).

Data flows originating from countless sensors are driving performance models to map otherwise invisible streams of material, financial capital, and energy across a range of fields; from supporting the infrastructural management of our cities to the optimization of agricultural production. Smart farms integrate sensor technologies to reduce costs, optimize yield, and promote the efficient use of resources. The Agricultural Industry’s aims have been to increase the “production of accurate inventories for sustainability while the environmental impact is minimized by reducing the application of agrochemicals and increasing the use of environmentally friendly agronomical practices.” (PAJARES 2013). As the benefits of integrating the technology in farming practices evolve, so do the bespoke sensor-based technologies being developed for the industry. This includes, among others, intriguing developments such as taste and odour detection in the form of an electronic tongue and nose. Alongside the logistical goal to reduce costs, increase production, and reduce environmental impacts – aspirations that could be easily translated and utilized in landscape architecture – it is interesting to observe how these technologies continue to actively shape the operations, processes, and practices of the Agricultural industry.

The potential for the adoption and utilisation of sensor technologies in Landscape Architecture is equally vast in terms of its capacity to augment our understanding of the world and inform our capacity to respond to it through design, and in so doing potentially shift the practice itself. The research described in this paper ventures into this realm of possibility as it seeks to explore the capacity to continuously monitor and measure specific changing conditions over time that give rise to form that may be perceived as only a “stable moment in the system’s evolution” (ALLEN 1992 1992) within which there exists a perpetual exchange of information.

Journal of Digital Landscape Architecture, 9-2024, pp. 521-532. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-752-6, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537752048.

An important aspect of the work is to explore how the continuous data stream might be visualised. How might it be visually translated and re-presented to augment our observational field beyond that which is visible to the human eye to reveal the "motor of matter, the modulus that controls what it does" (KWINTER 2006) and shape new forms of engagement in and of the landscape? How might the transformation of the data into a simulacrum that describes air constituted with spatial and material attributes?

The work also enquires as to how this approach might make it possible to reconceptualise atmospheric conditions at an unprecedented degree of precision and reveal ways to understand, elucidate, and radically act to transform the relationship between ground and atmosphere. The agency to represent the vast quantity of collected data is explored through the action of translation that is critical to the aspiration of 'making visible' the projected extensive and intensive (DELANDA 2005) behavioural characteristics of the atmosphere. This extends the performative characteristics of the ground into the atmosphere as a thickened condition.

This is an exploration of the potential to inform new modes of practice that may be relevant to the changes that the climate crisis brings by making it possible to respond not only to developing and projected states of being but to simultaneously consider how we might act through dynamic states of change.

2 Method

2.1 Premise

A great deal has been invested into significant advances in energy conservation and sustainability in building design, construction, and management. This also includes the time of their subsequent occupation and operation through the continual monitoring of building performance involving sensors and computational simulation to optimise energy efficiency and comfort. Sensor technology has the capacity to change the way we understand and potentially also radically transform the urban environments that are our cities. The technology augments the human perceptual field and enables a "dynamic, flexible and interactive mapping of reality, fuelled by the staggering amount of data we produce" (RATI 2019) and ways of visualising the data in real-time to inform better design and management of cities.

The research considers how this technology might enable ways to analyse and visualise the multiscalar, dynamic, and elusory matter of air and utilise it as a measure in, and of, the constructed landscape environment. How might we explore and speculate on our capacity to inform its continual becoming and its reciprocal effect as a part of an ecology upon which humans and more-than-humans might survive and prosper? How might this approach create different forms of valuing, assessing, and designing the urban landscape?

The premise for the study described in this paper is 'House Zero', a model house, facility, and laboratory. The building is a pre-1940's typical suburban Cambridge 'triple-decker' house retrofitted into an ultra-efficient, healthy, positive energy structure. The building contains "nearly five miles of wiring that capture 17 million data points per day. Some sensors are critical to the operation of the building: for example, controlling the system of windows and shades in response to inputs about temperature, rain, wind direction, and indoor CO2 levels and airflows." (MALKAWI 2019). The house "promotes holistic change within the built environment, namely through the creation and continued improvement of sustainable, high-performance buildings and cities." (MALKAWI 2019)

To support and augment the aspirations of 'House Zero' the research of this paper sought to expand the active sensor network outside the building envelope to the extent of the home's plot boundary. The intention was to gather data specific to dynamic environmental parameters (e. g. solar and infrared radiation, air temperature, humidity, wind speed, carbon dioxide levels and significant air pollutants) that dynamically shape the network of outdoor urban spaces that envelop the building. This sought to understand the impact of the composition of outdoor spaces on the energy efficiency of the House Zero building operation. The enquiry asked how the landscape might support, or hinder, the efficient heating and cooling of the building, and how the building control system could be further augmented to act more carefully and efficiently with the external air qualities. This might include, for example, the utilization of optimal external conditions that may vary around the building at different times, and the identification of hazards that might alert and prevent venting the house from windows exposed to poor air quality that may arise, such as high levels of vehicle pollutants at peak traffic times on the street front.

The work also intended to make it possible to analyse and visualize the complexity of the atmospheric landscape system and identify its propensities in the form of its key operational characteristics. With this understanding, the research aspired to understand the atmospheric agency of the landscape to inform the design of spaces that contribute to the sustainability of the city and improve the health and well-being of its citizens. Given that the air in any one space and moment is a product of upstream conditions that shift and evolve through the outdoor urban landscape network in conjunction with the locally produced effects, and one that simultaneously informs downstream circumstances, the agency of designing an 'air-scape' is simultaneously local, territorial, and global.

2.2 Sensor Network

The development, installation, and management of the sensor network around the house and throughout the plot simultaneously raised a range of challenges and opportunities for the research project.

Plot as Module

The size and coverage of the sensor network are limited to the house plot boundary. The standard house plot size and the typical building mass arrangement on the site afforded the possibility of considering this study as a scalable module. This relationship made it possible to conceive a scaling up of the learnings of the study to the larger suburban-type fabric. It also acted as a model that could be physically implemented across a larger territory as a direct expansion of the research, and one that could be taken up by individual homeowners in the role of citizen scientists.

Distribution

The 'House Zero' test site is a typical inner suburban house plot 29.3m x 43.3m with a total area of 1,269m^2. The sensor network continuously measured the atmosphere at 15-minute intervals across a period of 12 months. It is comprised of 16 sensor stations with a total of 82 different sensors measuring air temperature and humidity, dew point, wind speed and direction, soil temperature and moisture, and solar irradiance (refer Figure 1).

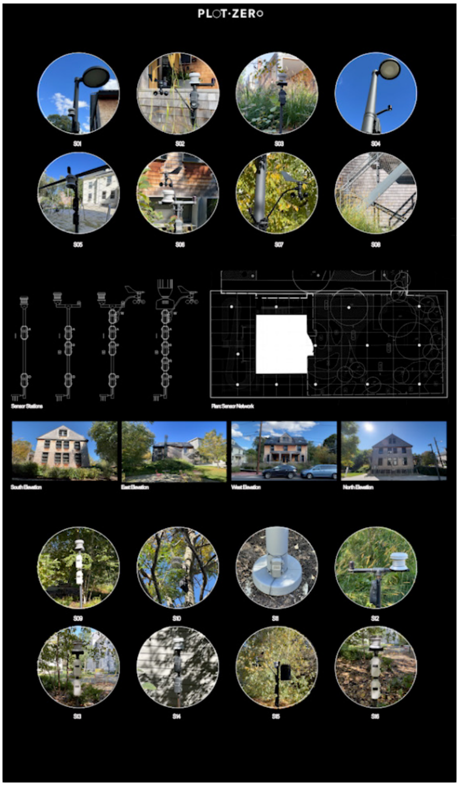

Fig. 1:
Remote Sensor Network: Site Plan & Sensor Stations

The intention was to evenly distribute the sensor network across the site at a regular 10m grid interval to measure the atmospheric conditions across the entire urban plot. The grid was also imagined extending vertically to form a three-dimensional array of sensors, therefore repeating the sensors at three heights above the ground plan: 0m, 1.5m, and 3m. As the tripling of the sensors proved to be financially prohibitive, the sensors were limited to a single stratum and located 1.5m above the ground plane. This height represented a useful position relative to a human body in the space, the average height of window openings in the building façade, and logistically a height that would be visible to people so that it would not become a hazard.

Garden areas to the East, South, and West of the building provided spaces for the pole-mounted sensor stations to be installed where they would not be disturbed by pedestrian traffic. Garden maintenance practices that might disturb the sensors in these areas were a concern that was managed by simple and respectful communications with the ground staff. Pedestrian paths, bike stands, and emergency vehicle access to the North of the house provided challenges to the distribution of the sensor grid array. In these spaces, it was not possible to install bespoke pole-mounted sensor stations. The sensors in this area were mounted on existing light poles, trees, and balustrades and are therefore slightly askew of the grid layout.

The semi-public nature of the site as a part of an extended university campus raised the potential for the sensor network to be abused, broken, stolen and damaged. In the 12 months of operation, this has not proven to be a problem with negligible damage to report, however, this would be a factor needing greater consideration in a more public space.

The elegant aesthetic of the House Zero design is an important aspect of the project that the sensor network of this study was required to respect. Sensors were coloured grey to blend in with the building colour pallet whenever they were in proximity to the house and where they were fixed to infrastructural elements around the building. The sensors located in the garden spaces remained white so they could be safely identified.

It would be easy to perceive the aesthetic considerations of the physical sensor network as not of great importance, however, without this care and attention the installation would simply not have been permitted. There can be no doubt of the significance of aesthetics in the design disciplines, let alone in our daily lives. The sensor network could be argued to have its own aesthetic value, however, without proper consideration this could prove catastrophic to its existence – this may be historically evidenced by the lack of attention paid to the aesthetic of sustainable technologies in architectural design such as solar panels in the late 1980's early 1990's.

Sensors
Within the urban context, a wireless sensor network was the obvious choice. This precluded the need to lay data and electrical cable, established flexibility in the network, avoided creating any electrical hazards, and made installation cost-effective and reasonably simple.

The commercially available sensor units selected are powered by (two standard AA) rechargeable batteries that are charged by a small solar panel built into the sensor housing. Low power warnings are sent automatically via email in the case that the batteries are running low and are not being adequately charged. During the 12 months of operation, 3 of the 16 sensor stations that happen to be located in heavily shaded areas have required a change of batteries only twice.

There is an appreciative difference in cost between the more simple and prolific type of sensor units that measure solar and infrared radiation, air temperature, humidity, and wind speed, and the more complex air quality sensors that measure levels of carbon dioxide, ozone, sulphur dioxide, methane, and other significant air pollutants (PM2.5, PM 10, and VOC) in the atmosphere. Given the economic constraints of the research, this project chose to utilize the simpler (more cost-effective) sensors as a proof of concept that might be upgraded at a later stage to include other types of sensors. Image-based sensors were omitted in this early stage of the research to avoid legal issues such as privacy and any subsequent delay that overcoming these hurdles might present. These sensors are also planned for future stages of the research.

Based on the logistical and practical learnings of this project to date, a series of sensors are now being made in-house utilising Arduino technologies to measure air pollutants (PM2.5, PM 10, and VOC), and sound. An important aspect of these sensors is that they are being designed as visible objects in the landscape that have the capacity to communicate the sensed data in real time.

2.3 Air

What we believe to be the reliable and predictable nature of the atmosphere made tangible through the phenomena of weather no longer holds true. The extreme global weather events of our recent past and the havoc they have wrought attest to this. A careful review of the relative global historic temperatures and future projections describes the climate stability of the Holocene epoch that supported the rapid proliferation, growth, and impacts of the human species worldwide, and the devastating effects being unleashed currently in direct relationship to the climate crisis.

Air, the Earth's atmosphere, is the invisible and indivisible matter upon which life depends. It holds the world together, yet simultaneously remains indifferent to our human notions of earthbound borders, to create a range of encounters across a host of scales that continuously signal and reframe the world in which we live.

The atmospheric condition is a register of the cumulative effects of its context that inherently describe the forces that have shaped it. It reflects the form of civilisation and the natural environment as an architecture that is "an arrangement of material in space and over time that determines their shape, size, behaviour, and duration, and how they come into being." (WEINSTOCK 2010) The quality of the air measured in terms of its physical, thermal, and chemical condition is a sign that "is simultaneously an indicator of a future potential and a symptom of a past. It envelops materials processes pointing forward and backward" (MASSUMI 1992).

The air is posited as the matter and agent of entanglement and interconnection registering the built environment through complex transient and dynamic interactions with space, material, surface, texture, moisture, light, and shade. The urban fabric acts to absorb, produce, and trap heat resulting in higher sustained temperatures 1-3C warmer than the surroundings. The heat generated in the city is trapped along with airborne pollutants adversely affecting water and air quality. Subsequently, this condition adversely affects water and air quality, and the health and well-being of its citizens and non-human residents. Energy demands simultaneously rise due to the prolonged and increased use of mechanical ventilation. Air-conditioning in response to the hotter temperatures strains energy resources and further contributes to the production of global emissions. The research seeks to understand the impact of the composition of outdoor spaces on the energy efficiency of building operations and the atmospheric agency of the landscape to inform the design that can contribute to the sustainability of the city and improve the health and well-being of its citizens.

The unbound air creates territories that emphasise alternative relationships between the elements and systems that traditionally shape the constructed environment. These airborne territories override traditional concepts of site that have been conventionally bound by rules of ownership demarcated by cartographic boundaries that too readily propagate an imagined hermetic seal allowing, and perhaps even encouraging, the misadventures that this notion emboldens. The matter of air advances strategies that both demand responsibility and give agency to design interventions to act as a part of a larger dynamic system. Through territories of air and atmospheric encounters, the research explores an approach to act across scales through the social, natural and technological environment rather than retreating into an "autonomous internal logic" that is "answerable to itself alone" (GISSEN 2020).

In the simplest of terms, a consideration of territories of air acknowledges that any intervention has an effect beyond itself and so design responses could be envisioned as an active part of a larger designed system. It also suggests that the physicality of any intervention is extended through the physical matter of air resonating as measures of speed, temperature, humidity, pressure, particles, and chemical pollutants well beyond itself. Territories of air are complex dynamic manifolds that describe a relationship between ground and air as a reciprocal one in which "intensive spaces act as the site of processes which yield as products the great diversity of extensive spaces" (DELANDA 2005).

2.4 Data Visualisation

The network of 82 sensors measuring atmospheric conditions at 15-minute intervals across a period of 12 months continues to generate a dense stream of numerical data. Conventional forms of data analysis are an excellent approach to determining a host of quantified conclusions, e. g. the temperature difference across the field of sensor stations measured in relationship to the duration of an hour, day, week, month, year, and other traditional temporal categories such as seasons, school calendars, annual events, etc. The results of these findings from the hyper-local scale sensor network can also be compared to the data of the city-wide scale municipal weather station data. This approach goes a long way to numerically elucidate the hypothesis that the urban landscape acts as a complex temporal and material manifold of differential space shifting across multiple scales in a constant state of flux.

The world that the sensors are measuring, and from which the data is gathered, is spatial, material, and temporal. Visualising this complex relationship is significant to the process of generating an understanding of a place that is figurative and potentially operational. This approach is subsequently critical to informing design responses, and a means to measure the product of the design process. How might the collected data be translated and re-presented in a three-dimensional digital modelling process that is a commonplace practice in landscape architecture? How might this spatially visualised data reveal characteristics and tendencies that augment an understanding of a landscape to reveal challenges and opportunities for design?

Visually mapping the data as a two-dimensional graph through specific sensor stations and across the site as a typical site section drawing provided a simple means to evaluate fluctuations in values. These initial data visualisations were drawn as singular defined moments in time and also as animations operating through periods of time (refer Figure 2).

Wrapping the graphed data sections into a circular configuration produced two interesting effects: firstly the internalisation of the atmosphere to the inside of the circle shifted the drawing hierarchy so that air now literally takes centre stage; secondly, by the action of enveloping the air it is now assigned a finite quantitative, and possibly qualitative value; and thirdly the cyclical nature of the diagram reinforces the reciprocal and resonant effects that each part might play in the formation of the whole (refer Figure 2). It is important to recognise that this form of representation delimits the site of investigation to be an autonomous condition operating outside any external influence.

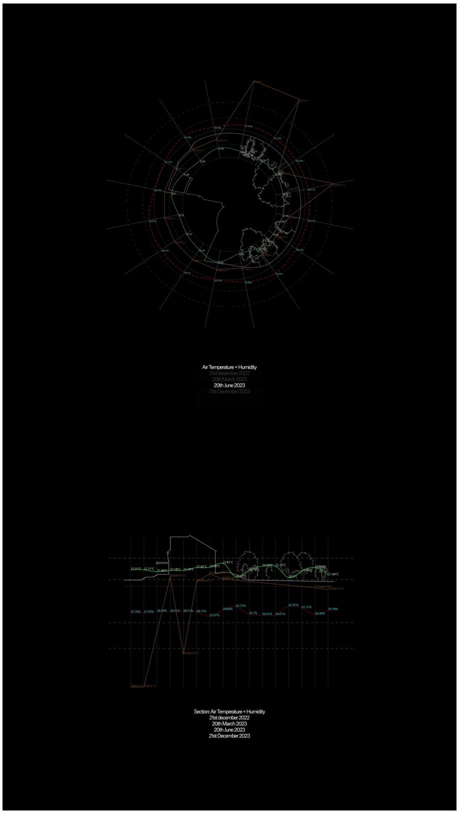

Fig. 2:
Data Visualisation: Conventional Section Representation(bottom)
& Circular Wrapped Data Graph (top) centring the atmosphere

The notion that air might be considered an enveloped entity led to a mapping exercise that describes the shadows generated across the site as spatial atmospheric envelopes. The volumes of air are now described to be discreet fields of influence (refer Figure 3).

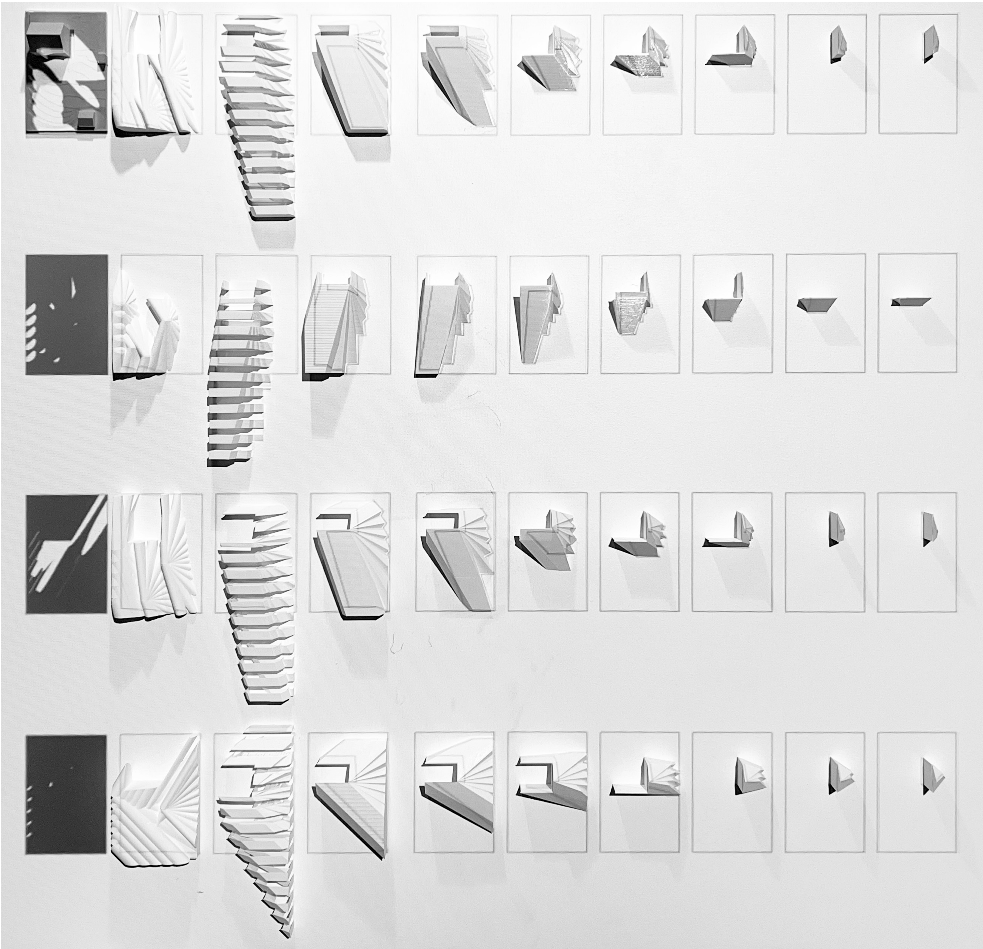

Fig. 3: Shadow Envelope Study Models March 10th, June 21st, September 23rd, & December 21st

Working in Rhinoceros 3D and Grasshopper software the three-dimensional digital model of the site's physical form was overlaid with a surface that aligned with the house plot envelope and mapped precisely to the sensor network. Data values of each sensor station act to precisely inform the surface height at each sensor location. The resulting surface adjusts and warps to represent the data value at each of the sensor stations on the 10m grid as a visual terrain. The surface consequently calculates the data values between each 10m grid interval across the entire data terrain.

Working with the temperature data terrain, a human comfort level range was employed to define further visual parameters that describe not only the shape of the surface but also a change in colour if the value fell under (blue), inside (green), or over (red) the specified range of values. The human comfort temperature range was utilised in this test as it was a useful indicator of the comfort level of people in the landscape and directly related to the building's interior temperature control parameters. This range of values can be modified to describe a host of criteria, for example, specific vegetation requirements, micro-climate ranges, and zones of specific values related to the building's internal operation (refer Figure 4).

This approach was individually applied to each air quality measure; temperature, humidity, dew point, and solar irradiance. Overlaying the individual air quality terrains in different combinations tended to become a little visually confusing in conventional views (e. g. perspective and axonometric), however, the ability to cut a section across any line of the data terrain made this multi-surface overlay visually clear (refer Figure 4).

Utilising the human comfort range of values in relationship to temperature, humidity, dew point, and solar irradiance a single data terrain was parametrically created from the relationship between all the individual data surfaces. This process made it possible to visually differentiate and territorialise the atmospheric landscape of the site through specifically defined criteria.

The data visualisation experiments generated from values measured and collected from the real-world sensor network supported explorations of airflow simulations. The two-dimensional air flow simulations described territories of wind speeds ranging from streams of dense air movement to pockets of stillness that formed, rolled, collapsed and emerged in relation to objects in the airfield. The three-dimensional airflow simulations conducted primarily described the characteristics of wind speed and density as they flowed around, over, and through the landscape (refer Figure 5). A comparative analysis conducted between the data-driven terrains and the various airflow simulations supported the invisible atmospheric behavioural characteristics described in each representation mode as a product of the air's dynamic entangled and interconnected nature.

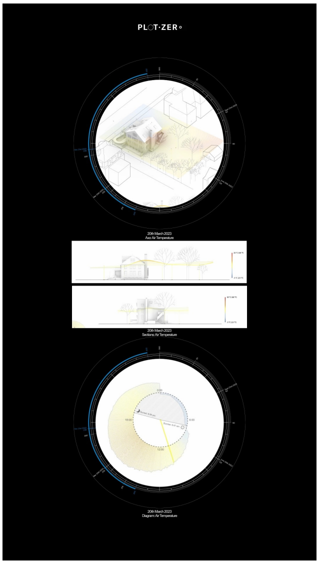

Fig. 4: Data Terrain Solar irradiance 3D Data Surface translated across the site

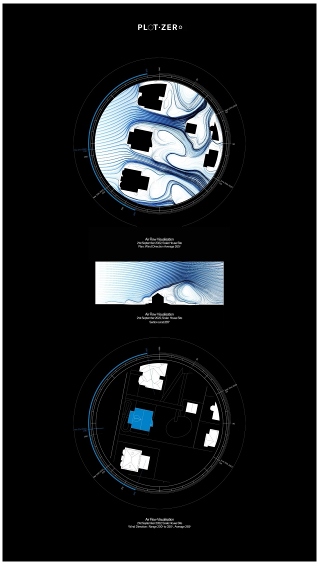

Fig. 5: Airflow Simulation 2D describing dynamic atmospheric conditions

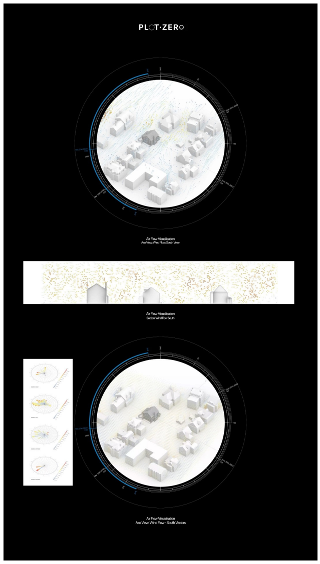

Fig. 6: Airflow Simulation 3D describing dynamic atmospheric conditions

3 Discussion

The sheer amount of data collected by the sensor network represents an abundant source for further analysis. More work can be done to explore conventional forms of data analysis that have the potential to expand the field of comparison of translation through a process of representation in the hope of determining productive differences, and opportunities for integration.

The data visualisation experiments described in this paper represent useful approaches that have the potential to be applied to real-time digital models supplied by a direct data feed from the sensor network. This may be usefully applied to visual communication to the public and calibrated as a maintenance tool to inform the automation of irrigation systems. Interfacing the outdoor sensor network with House Zero's existing indoor sensor network and automated environment management system has the potential to augment a more efficient system.

According to the United Nations Environmental Program "Air pollution is the largest environmental risk to public health globally. People everywhere are exposed to air pollution: in the workplace, during travel, and in their homes" (UNITED NATIONS ENVIRONMENT PROGRAMME). Extending the existing sensor network to include air quality sensors to measure particulate matter (PM2.5, PM 10, and VOC), Ozone, Carbon Monoxide, and Nitrogen Dioxide – listed by the World Health Organization as the critical measures of air quality – has the potential to describe the significant hazardous components of the air. It will be useful to explore how these might relate to the existing sensed air qualities – solar and infrared radiation, air temperature, humidity, dew point, wind speed and direction. In particular, it will be useful to determine where significant hazardous airborne territories may be developing, and what the reasons for this may be. This information would also be critical to the existing House Zero operations.

Sound sensors would also be an interesting addition to the sensor network to understand the quality of sound received, and produced, in the urban context. Image-based sensors, including infrared, and motion sensors that could be used to map occupation would also be a useful addition. In each case, the potential to make visible the measured data in real-time on-site is also of interest to the ongoing work to explore how this might be communicated, what effect it might have on the occupation of a space, and how other actuators might augment the network.

4 Conclusion

The research was undertaken on the working assumption that no form of analysis would be guaranteed to be a precise representation of the actual real-world atmospheric conditions of the site. What has been evidenced is the assumption that the atmosphere might be constituted as a range of dynamic interconnected airborne territories that have real-world effects and provide ways to reconceptualise conventional notions of site and opportunities for approaching design.

The parameters, limits, and constraints of each approach consequently describe a specific set of behavioural characteristics and tendencies. Each to some degree has confirmed a range of assumptions concerning the air as matter, and as a matter of entanglement and interconnection. Each reveals a range of opportunities by which to augment a conceptualisation of the site that includes the physicality, effect, and influence of air as a matter of design.

References

ALLEN, S (1992), 'Landscapes of Change', in Assemblage (19), The MIT Press, Cambridge, Massachusetts.

ANDERSON RESEARCH GROUP, (2012), Chemistry and Physics of Climate and Earth System Change, Energy and Climate, Harvard University, https://www.arp.harvard.edu/context-energy-climate (08.03.2024).

CHRISTOFORETTI, E (2023), Our Artificial Nature: Design Research for an Era of Environmental Change, https://www.gsd.harvard.edu/exhibition/our-artificial-nature/ (08.03.2024).

DELANDA, A. M. (2005), Space: Extensive and Intensive, Actual and Virtual, Edinburgh University Press.

GABRYS, J. (2016), Program Earth, Environmental Sensing Technology and the Making of a Computational Planet, University of Minnesota Press.

GISSEN, D. (2009), Subnature: Architecture's other Environments, Princeton Architectural Press, New York.

KWINTER, S. (2006), The Judo of Cold Combustion. In: REISER, J. & UMEMOTO, N. (Eds.), Atlas of Novel Tectonics, Princeton Architectural Press.

LATOUR, B. (1987), Science in Action: How to Follow Scientists and Engineers Through Society. Harvard University Press.

MALKAWLI, A. (2019), Harvard Center for Green Buildings and Cities, Harvard University, https://harvardcgbc.org.

MASSUMI, B. (1992), A User's Guide to Capitalism and Schizophrenia: Deviations from Deleuze and Guattari, MIT Press, London, England.

PICON, E. & RATTI, C. (2019), On Mapping, Domus. http://senseable.mit.edu/papers/pdf/20191001_PiconRatti_OnMapping_DOMUS.pdf (ß8.03.2024).

PAJARES, G., GONAZALEZ-DE-SANTOS, P. (n. d.), Sensors in Agriculture and Forestry. Sensors 2013, 13, 12132-12139. https://doi.org/10.3390/s130912132.

PHELPS, B. (2018), Beyond Heuristic design'. In: CANTRELL, B. & MEKIES, A. (Eds), Codify, Parametric and Computational design in Landscape Architecture, Routledge, NY.

ROBINSON, A. (2015), Owens Lake Rapid Landscape Prototyping Machine Reverse Engineering Design Agency for Landscape Infrastructures. In: GERBER, D. & IBANEZ, M. (Eds), Paradigms in Computing: Making, Machines, and Models for Design Agency in Architecture, Actar.

UNITED NATIONS ENVIRONMENT PROGRAMME (2023), Cities and Climate Change. https://www.unenvironment.org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change (08.03.2024).

WORLD HEALTH ORGANISATION (2023), Global Air Quality Guidelines. https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines (08.03.2024).