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THE APPARATUS OF THE INVISIBLE LANDSCAPE: SENSING BEYOND SIGHT

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Regarding Sensory Data

The act of extravisual sensing in the landscape has a long tradition that dates back to the first attempts to describe the behavior of our surroundings, which evade pure observation. These experiments led to the first scientific discoveries regarding our non-visible environment, and the very first tools with which to quantify these phenomena.

It is perhaps no coincidence that the term "atmosphere" can be as easily applied to non-visible sensory data as to the tangible and often emotional impact of a space on its occupant. The influence of these atmospheric effects on human comfort and well-being is in and of itself a well-documented and dedicated discipline of research.[1] In order to understand our complex and ever-evolving cities and built environments, the collection and study of atmospheric data forms a key part of both the research and design at the Landscape Visualization and Modeling Lab (LVML), at the Chair of Christophe Girot.

This data can be thought of as part of the mass of information that is commonly referred to as "Big Data," a term which has come to describe firstly the massive excess of all the data generated and collected by our cultural interaction with digital technologies, and secondly the process of its centralization. This field of research and its resulting data fascination is often used to describe the performance of the actors, fabric and spaces of the city.[2] Such data is often intriguing for its sheer complexity, the apparent wealth of information and its cyclical patterns. What we can observe based on current tendencies is that embedded in this concept of Big Data is the aim to create a comprehensive, all-encompassing, temporal model of the subject of study, in which no data is without merit.

That is not to say that there is not a fair share of skepticism in this rapid shift to implementing Big Data within the design realm.[3] Indeed, this trend toward an all-encompassing dataset can be seen to present an

1 Sigrid Reiter and André De Herde, "Qualitative and Quantitative Criteria for Comfortable Urban Public Spaces," in *Proceedings of the 2nd International Conference on Building Physics* (2011), 2. ORBi.

2 Bernd Resch, Rex Britter and Carlo Ratti, "Live Urbanism – Towards SENSEable Cities and Beyond," *Sustainable Environmental Design in Architecture* (Springer, 2012), 175.

inherent flaw—its recent implementation has tended to treat all data equally, regardless of source, quality or collection method. The sheer amount of spatial sensory datasets and sources can only be expected to increase over time, making the task of data discernment even more difficult. This tendency toward publicly available yet anonymous data does nothing to raise its empirical value—issues with sample rates, average or peak values, and other collection discrepancies persist.[4]

In order to counter this tendency and make this data both more useful and applicable to spatial design, an understanding of the nature of the data, including its source, tolerances and method of capture, may prove crucial. Whether they are reviewed on the territorial scale or in a detailed, local manner, these varied densities, methods and objectives of the collection-processes further their potential applications. In statistical terms, this reflects the importance of data subjectivity and sampling—pitting data with a purely random sample pattern (a case that is extremely rare) against stratified random sampling (a designed sampling pattern).[5] Information regarding the sampling methods is rarely maintained within a database and is intrinsically linked to the "design" of the sensory capture session. The potential of Big Data shall only be accessed once the core concepts of data filtering and "data curation" are addressed.[6]

Before we can discuss the data itself, it is the source of this data, the tools and the metrics of their use, that are of fundamental interest. The quantification of the performance of the environment, beyond the capabilities of our innate senses, can be considered an attempt to extend these very senses—the apparatuses thus becoming sensory prostheses.

3 Rem Koolhaas, "My Thoughts on the Smart City," in *United Nations, High Level Group Meeting on Smart Cities* (Brussels: United Nations, September 24, 2014), http://ec.europa.eu/archives/commission_2010-2014/kroes/en/content/digital-minds-new-europe.html.

4 Veronika Peralta, "Data Freshness and Data Accuracy: A State of the Art," Tech. Rep. TR0613 (Montevideo: Instituto de Computación, Facultad de Ingeniería, Universidad de la República, 2006), 3.

5 Carlos Guestrin, Andreas Krause and Ajit Singh, "Near-Optimal Sensor Placements in Gaussian Processes," in *Proceedings of the 22nd International Conference on Machine Learning* (Bonn, 2005), 7.

6 Hamid Ekbia, Michael Mattioli, Inna Kouper, Gary Arave, Ali Ghazinejad, Timothy Bowman, Venkata Ratandeep Suri, Andrew Tsou, Scott Weingart and Cassidy R. Sugimoto, "Big Data, Bigger Dilemmas: A Critical Review," *Journal of the Association for Information Science and Technology* (2014), 27, DOI: 10.1002/asi.23294.

Within the field of design, what role does the quality and therefore also the reliability of data play in the transformation of the built environment—and what does the sensing process do to our understanding of place?

In order to address this question, we shall look at specific moments in the discovery and development of the sensing process as well as related tools. This discussion focuses on one scientist in particular, the work of whom demonstrates the close potential of theory, inquiry and invention.

The Development of the Apparatus

"We live submerged at the bottom of an ocean of air."
–Evangelista Torricelli, 1644

This description of the nature of our invisible atmosphere, penned by mathematician and physicist Torricelli in a private letter to his colleague Michelangelo Ricci, seems whimsical and poetic by modern scientific standards and empirical discourse.[7] To put this in perspective: at the time, Torricelli would have been described by his peers as a "natural philosopher" rather than a "scientist." This more contemporary term, attributed to William Whewell, would not appear until two centuries after Torricelli's work was finished.[8] This apparent nuance between the arts and the sciences is not surprising, with scientific endeavors navigating the apparent contradictions between theology, superstition and empirical observation. This conflict was nowhere more apparent than in the sciences that focused on the environment or the processes of the natural world. The empirical approach was governed by observation, with visible and tangible evidence remaining the fundamental building blocks of scientific progress. The most celebrated of Torricelli's discoveries, the mercury barometer, represents perfectly this translation from invisible atmospheric property (air-pressure or density) into the instantaneous, physical response of a liquid—a 'sensor' that is still commonly in use today.

7 Philip J. Robinson, "Evangelista Torricelli," *The Mathematical Gazette*, vol. 78, no. 481 (1994), 47.

8 Laura J. Snyder, "William Whewell," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta (Winter 2012 Edition), http://plato.stanford.edu/archives/win2012/entries/whewell/.

Through subtle shifts in its density, this apparatus, ideal for the observation of localized atmospheric phenomena, transfigures air into both lineal and linear vectors—the epitome of empirical simplification. The conceptual simplicity of this experiment has meant that the modern analogue to this tool is an identical yet scaled-down version of the original, experimental installation. The direct visual feedback, combined with the conceptual paradox of suspending a heavy metal, suspends the disbelief of the observer.

> *"... winds are produced by differences of air temperature, and hence density, between two regions of the earth."*
>
> –Evangelista Torricelli, 1645

This statement, made during Torricelli's lectures at the Accademia della Crusca, Florence, is widely regarded as the first "scientific" description of the phenomenon of wind.[9] It demonstrates, at a local scale, the theoretical application of the concepts demonstrated by the invention of his barometer: the territorial and global phenomena of shifting air densities. He was able to bridge the divide between the solitary sample of a sensory tool, limited to a finite, local application, and the more complex dynamic pressure system of global air movement. The mention of an additional factor—temperature—and its relationship to pressure, demonstrates a relationship, which would have been readily apparent from the personal observations of the development of Torricelli's barometer-like tool.

It may be argued that the decisions and observations made during tool- and experiment preparation can influence and inform subsequent relationships between the various factors that affect environmental performance and subsequent site-specific observations. In the same manner, scientific results are often retrospectively separated from the laboratories and tools that generated them once an accepted scientific proof has been obtained. This incremental scientific process could be seen to separate the origins of scientific endeavor from subsequent deductions in order to simplify the process of further inquiry.

9 John B. West, "Torricelli and the Ocean of Air: The First Measurement of Barometric Pressure," *Physiology* 28 (2) (March 2013), 66–73.

Apparatus as Focus

In parallel to his work on physical phenomena, Torricelli was refining the work of Galileo within the field of mathematics through studies in parabolas and trajectories. In particular, he redefined the method of measuring the ballistic trajectory of a projectile. Although considered a theoretical treatise in mathematics, he almost exclusively used military analogies and examples in his writings and lectures. With his calculations and the development of the mathematics behind ballistics, he disproved existing and commonly held beliefs behind military artillery. In so doing, he inadvertently also disproved the perceived accuracy of these commonly used field tools: artillery calibration and prediction.[10]

Following on from his treatise on ballistics, Torricelli proceeded to develop a subsequent tool: a military apparatus for the calculation of artillery trajectory. As with Torricelli's barometer, it was primarily designed as a theoretical tool, a physical embodiment of a conceptual argument, translating abstract principles into physical form. It was, however, adopted by the Italian artillery and beyond, and the tool and associated mathematical model remained the most accurate model for the next century.[11] While this tool has fallen into obscurity compared to the barometer, it is the perfect embodiment of a tool for the abstract construction of space, describing movement over time. This tool can also be understood as a sensory tool, deducing finite information from an abstract, spatial configuration of cultural elements. Ironically, the trajectories did not take account for air-friction, or the substantial nature of air, as was implied by his other research. In this case, empirical interests were resulting in military tools. The modern usage demonstrates the opposite—research and the development of military technologies drive much of the innovation of industry, commercial and civilian technology.

The detailed parallels between the development of military technology and the subsequent development of spatial tools lie beyond the scope of this research. There is, however, an intrinsic instrumentalization of the implementation of tools in the resulting discourse on the nature of space.

10 Domenico Bertoloni Meli, *Thinking with Objects: The Transformation of Mechanics in the Seventeenth Century* (Baltimore: Johns Hopkins University Press, 2006), 220.

11 Robinson, "Evangelista Torricelli," 47.

The drive behind military research can be argued to lie in its relentless ambition—beyond current capabilities and requirements, there is a constant reconnaissance of current shortcomings and liabilities in the imminent technological terrain. As with many technology strains, military technologies lead in both the development and forecasting of potential developments and synergies within the application of sensing technologies.[12] The retrieval of reliable, historical and real-time data is one of the primary goals of military operations, whether friendly, adversary or civilian. Furthermore, this gathering process should also be seamless and invisible. The culmination of this requirement is what is known as "persistent" sensing—the constant and indefinite sensing of the environment.[13] Returning to the guise of natural philosopher, this could be ironically argued as a form of sensory omnipotence, wherein the environment becomes one with the apparatus. As is the case with such military strategy, such technologies are simultaneously seen as opportunity and risk. This eventual dissemination of all technologies and techniques is one that applies across disciplines and specializations.

Apparatus Development in Spatial Design

The observation, understanding and transformation of the environment have been the focus of many other fields beyond empirical and military inquiry. As the cultural and environmental demands on our spaces rise, the need for interdisciplinary cooperation in the design of the built environment becomes increasingly important. The figure of Torricelli, in his various roles as natural philosopher/scientist, mathematician, military theorist and teacher, sampled from the theory and practice of many fields. His subsequent role as an inventor can be seen as a clear byproduct of this varied work, in which the intentions themselves remain unfinished, having served their demonstrative purpose. Without replacing or downplaying the relevance of these accosted disciplines, this insight through invention is a perfect example of an individual, interdisciplinary workflow.[14]

12 William Schneider Jr. and Julia E. King, *Report of the Joint U.S. Defense Science Board and UK Defense Scientific Advisory Council Task Force on Defense Critical Technologies* (2006), 5.

13 Schneider and King, *Defense Critical Technologies* (2006), 99.

14 William W. Hackborn, "The Science of Ballistics: Mathematics Serving the Dark Side," in *Proceedings of the Canadian Society for History and Philosophy of Mathematics*, vol. 19 (Toronto: York University, 2006), 3.

The design implementation of interdisciplinary technologies in the LVML resulted in a tangible transformation of our existing methods of site appraisal and alteration. The applications of these techniques are nevertheless rooted in an understanding of the evolving requirements of the professional practice of landscape architecture. The gradual inclusion of various techniques, such as laser scanning, photogrammetry and discrete atmosphere sensors, have formed the incremental means for combined environmental and spatial inquiry. Since their integration into the research, teaching and practice of landscape architecture, each instrument and its accompanying sensing technology satisfied both existing and expected demands on the site, while also raising entirely new perspectives and potentials.

Because the instruments are often used outside their typical applications, the resulting datasets often reveal unconventional coverage patterns, densities and site characteristics. The inherent technical and practical limits of the instruments often result in clues as to the areas in which tools can be augmented and combined. The simultaneous implementation of laser scanning and UAV photogrammetry, in particular, transformed our methods and spurred tool development. While these developments are now well documented, several specific aspects to their implementation remain relevant to the subsequent shift into the development of discrete tools and a site-specific adaptation of our methods.[15]

Terrestrial and Aerial Apparatuses

The implementation of the long range terrestrial laser scanner (a 10 kg cylindrical apparatus with an extreme range) has directly influenced the practice of landscape design and its potential for landscape transformation. The resulting point clouds, with their minutely-detailed depiction of the existing environment, are a perfect example of not only the capture but also the transfiguration of landscape into a separate, analogous form, allowing it to be transformed both conceptually and physically. The actual method of laser

15 Luis E. Fraguada, Christophe Girot and James Melsom, "Ambient Terrain: The Generation of Large-Scale Landscape Site Data for Design Applications," in *Proceedings eCAADe 2013: Computation and Performance* (Delft, 2013), 433–438.

scanning, which involves transmitting and re-collecting laser signals, as well as measuring their interval and quality, is technically complicated yet conceptually simple. As a true projective apparatus, the function of the apparatus is directly analogous to Torricelli's ballistic apparatus: Although the trajectory is straight, the concepts of range, line of sight and air resistance all play identical roles in its function. The resulting "shadows," caused in point cloud data by obscuring objects, place identical restrictions on data collection as they do in mathematical and military ballistics.

While seemingly an optical measurement device for reading empirically-stable physical environments, the terrestrial laser scanner transforms the eye of the surveyor into one which immediately appreciates the visual range as well as the role and influence of topography, vegetation and obstacles on the perception of the site. Pragmatic requirements—in this case the practical need to minimize the number of scans and achieve ideal data density—result in the ability to understand the site through the instrument itself, allowing for an additional mode of understanding space to take place. Such instruments are designed expressly to generate massive, precise datasets, which tend to lead to a saturation of site data. The strategies develop an approach to refine the usage of the instruments based on site-specific observations and the technical limitations of time, movement and data usability.[16]

The integration of the first long range, fixed-wing drone (UAV) and subsequent forms of airborne photogrammetric craft resulted in a further shift in the perception and transformation of the landscape. Its deployment required not only technical skills in flight control and software, but it also resulted in an instant awareness of the local environmental conditions and their subtle changes. While flight is governed by physical laws far beyond those of ballistics, the computer-controlled flight path, its finite positioning and its timing resulted in minute control over the possible perspectives and representations of

16 Pia Fricker, Christophe Girot and Georg Munkel, "How to Teach 'New Tools' in Landscape Architecture in the Digital Overload," in *Computation and Performance – Proceedings of the 31st eCAADe Conference*, vol. 2, eds. Rudi Stouffs and Sevil Sariyildiz (Delft: Faculty of Architecture, Delft University of Technology, 2013), 545–553.

the landscape. Relying on the visual spectrum with which we most often construct and describe the environment, the combined photogrammetric result creates not only a highly accurate but also a visually believable portrayal of the site. The flexibility of a constantly shifting viewpoint and a potentially unrestricted site access frees the user from a terrestrial and thus limited understanding of the territory and its terrain. For the researcher, this process results in both an increased understanding of the invisible environment and a gradual detachment of the site from a purely terrestrial perspective. This was evidenced in specific fieldwork observations.

The Aspect of the Operator

Through extended campaigns of laser scanning in low and high altitudes, the nuances of the site environment become clear: air humidity, condensation, temperature—and as we can infer from Torricelli's work, related pressure—influence the scale and accuracy of the data collected.[17] As the landscape surveyor adopts the role of pilot, the resulting influence on the understanding of site is also marked. This involves understanding the wind as a temporal, volumetric phenomenon with direction, acceleration, layers and vertical dynamics, as well as understanding the relation to objects, topography and environmental differentials in height levels.

This emerging environmental site awareness spawned the adoption of sensing as a key method utilized by the LVML, and subsequently led to an adaptation of the use and application of these existing tools. This catalyzed a process of integrating sensory data capturing methods into our teaching curriculum through workshop-based exercises. Initial workshops, such as those conducted with Luis Fraguada in Tiergarten park, Berlin as part of the Design Modeling Symposium Berlin (DMSB 2011), provided linear data based chiefly on user behavior.[18] In this case, each tool was comprised of low-cost sensors, a battery and a case, allowing it to be carried in the hand of a pedestrian. While the

17 Constantin Cosarca, Andrea Jocea and Adrian Savu, "Analysis of Error Sources in Terrestrial Laser Scanning," *RevCAD – Journal of Geodesy and Cadastre* (Alba Iulia: University Alba Iulia, 2009), 120.

18 Luis E. Fraguada and Felipe Pecegueiro, *Masterclass Workshop at the DMSB Design Modeling Symposium in Berlin* (2011), https://www.design-modelling-symposium.de/frontend/index.php?folder_id=198.

resulting data was compelling, the ad hoc nature of its collection and the lack of coordination between sensor location and use highlighted issues typical of civilian Big Data collection.

The collaborative research that followed focused on the combination of a terrestrial-based approach with the advantages of UAV deployment.[19] This combination of programmable geolocation and timed sensors resulted in a hybrid of previous tools, in which specific sensors could be deployed, timings triggered and a first spatial-volumetric image generated.

Designing the Extension of the Senses

The shift from using existing hardware to constructing unique assemblies of electronics, sensors and programming, is a fundamental one. Instead of replacing traditional methods entirely, it seeks to augment existing modes of site inquiry and to provide novel perspectives on both site and its context. The simultaneous application of site inquiry and tool creation results in a fundamental shift in spatial design. What is of interest here is not the novel or inventive nature of finite or discrete tool development, but instead the development of a skillset that enables the creation of site-specific tools, which are in many cases evolving with each new application. This development, and especially the manner of the tools' application, is what enables and directs possible design outcomes.

Shifting ambitions in the nature of the collected data has also required novel approaches in tool development. While collecting data from the skies over London, the need for extended, uninterrupted sensing led to the introduction of working with helium balloons.[20] This, in turn, revealed other aspects of the site, such as subtle changes in wind patterns, which were analyzed through the real-time streaming of video and sensor data. This has led not only to the application

19 Luis E. Fraguada, Christophe Girot and James Melsom, "Synchronous Horizons: Redefining Spatial Design in Landscape Architecture through Ambient Data Collection and Volumetric Manipulation," *Peer-Reviewed Proceedings ACADIA 2012: Synthetic Digital Ecologies* (San Francisco, 2012), 3.

20 Alexandre Dubor, Luis E. Fraguada and James Melsom, "(A)synchronous Streams," in *SmartGeometry 2013 Conference* (London: Bartlett, UCL, 2013), Smartgeometry.org.

and design of new sensing techniques in various spatial contexts, but also to an expanded site context to be considered for spatial design, thus testing the limits of the field of landscape architecture.[21] Beyond the experience of the operator, however, the design of such sensing operations need not be complicated, nor should it rely on intuition. Rather than further complicate the design process, conceptual tools solve ideal configurations of sensors in space through statistical data analyses.[22] These environmental characteristics and operating restrictions, unique to each site, require the operator to design the sensing collection in order to maximize the efficiency and accuracy of a site scanning operation.

It can be argued that in order to attain an optimal understanding of the built environment, we must be able to quantify and weigh the various factors influencing the sites, whether physical, cultural or invisible. Environmental simulation is an evolving and growing field of massive complexity. The heterogeneity of local conditions reflects a necessary simplification of large-scale simulation results into a controlled simulation "vacuum" analogous once again to Torricelli's experimental tool development. Rather than increase the complexity of the model, it has been proposed that the process of simulation can benefit from the introduction of sensors within the existing urban fabric as a method to improve the local accuracy of large-scale simulation platforms.[23]

In this case, where the site surveyor also carries the role of future site designer, the design process gains power in both an empirical and intuitive manner. This is not a simple process of appropriation; rather, it is a mode of translation, in which the resulting techniques and

21 Luis E. Fraguada and James Melsom, "Urban Pulse: The Application of Moving Sensor Networks in the Urban Environment: Strategies for Implementation and Implications for Landscape Design," in *Peer-Reviewed Proceedings Digital Landscape Architecture 2014 at ETH Zurich*, eds. Ulrike Hayek, Pia Fricker, Erich Buhmann (Offenbach: Wichmann Verlag, 2014), 2.

22 Guestrin, Krause and Singh, *Near-Optimal Sensor Placements in Gaussian Processes*, 7.

23 Peter Moonen, Thijs Defraeye, Viktor Dorer, Bert Blocken and Jan Carmeliet, "Urban Physics: Effect of the Micro-Climate on Comfort, Health and Energy Demand," *Frontiers of Architectural Research*, vol. 1(3) (2012), 215.

intended use become transfigured. As with the example of Torricelli's barometer, it often remains easiest to postulate design concepts in a vacuum—to design without friction. With our combined knowledge and customized tools, comes the ability to quantify this friction in a truly site-specific and temporal mode.

Apparatus as Lens

Toward the later stage of his academic career, Torricelli was additionally appointment as lecturer on military fortifications at the Accademia of Design, Florence. This demonstrates in part the fundamental relationship between this deductive technique, in which mastery of the [ballistic] degradation of a site conversely implies expertise in [ballistic] longevity of the built environment through the understanding of the properties of space and movement beyond material form.[24] Indeed, ballistics research and its military application were considered both by Torricelli and Galileo to be both morally and aesthetically acceptable.[25] This aesthetic relation between mathematics, ballistics and military technology continues to this day, visible in the overwhelming majority of significant twentieth-century mathematicians attending the "Proving Ground," an installation for U.S. weapon development.[26] The aesthetic abstraction of these theories, processes and their physical manifestation could be perceived as immoral in their adherence to the fundamental performance of the environment regardless of cultural impact.

In Torricelli's lectures military theory meets natural philosophy. The uncanny result sheds light on the design and understanding of both object and space.

> *"If sculpture is a representation of bodies, painting not only mimics the corpulence of solid objects but also intangible qualities such as the colours, the light and the shadows: the sculptor with his tricks can't give expression to things painted, but painting can figure out both created things and sculpted."*
>
> –Evangelista Torricelli

24 Michael Segre, "Torricelli's Correspondence on Ballistics," *Annals of Science*, vol. 40, iss. 5 (1983), 498, DOI:10.1080/00033798300200351.

25 Hackborn, "The Science of Ballistics," 12.

26 David A. Grier, *When Computers Were Human* (Princeton: Princeton University Press, 2005), 152.

At first glance, this excerpt from Torricelli's lecture at the Accademia del Disegno, Florence appears as an esoteric description of the design of military fortifications, which underscores little more than a practical insight into military camouflage and deception—perhaps the tactical use of representation. There is, however, a clear attempt to address the difficulties of describing the ephemeral and environmentally specific appearance and performance of spaces. Furthermore, Torricelli describes not only the work of the tools, but also the process of representing the environment, as well as the potential of atmospheric representation surpassing physical processes.

The change of phase between the physical sciences and the arts that we see in the complimentary application of abstract mathematics in military trajectory, artistic expression and the nature of representation itself perfectly reflects not only the difficulty but also the potential of the crafted apparatus to understand the environment to new depths. The contemporary potential of surveying, scanning and sensing, in addition to further landscape surveillance techniques from spatial research and design fields, combines the [ballistic] probing and projection of site with potential forms. Today, it is apparent that the challenge—and necessity—of describing the complexity of the environment, both perceived and immaterial, was not lost on Torricelli. While each attempt to translate the invisible and atmospheric is, by definition, subjective, this continual process of phase-change is fundamental to our understanding of the world around us. Through the lens of the apparatus we can construct subsequent means with which to view and represent the invisible—and in so doing, we may restructure the relationship of space and substance.