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Performance, data and the expanding field of sustainable design

Ulrike Passe

Contact:

Director Center for Building Energy Research
Iowa State University
146 College of Design
Ames Iowa 50011 USA

upasse@iastate.edu
www.design.iastate.edu/architecture/faculty/upasse/
www.cber.iastate.edu/

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Introduction

Architecture has always occupied a thought space at the boundary between technology and humanism. This paper presents the theoretical framework for interdisciplinary research into sustainable neighborhoods. The theoretical base supporting this work is *Hermès V Le Passage du Nord-Ouest* (Serres 1980) by the French philosopher and mathematician Michel Serres (1930 -), where he is searching for a passageway, which leads from the exact sciences to the arts and humanities. While both are looking to explain the world with their own methods, they are turning their backs on each other. The shipping passage in the North of Canada connecting the Atlantic and the Pacific serves him as a metaphor for the complex thought-space linking, connecting and dividing these two explanations of the world. This text deals with connections of places, which seemingly are separate: rigidness and fantasy, myths and exactness, quantitative and qualitative knowledge. The Northwest Passage serves here as a metaphor for the complex design process between disciplines needed to produce and perceive sustainable urban environments. Based on this understanding the paper establishes four overarching theoretical frames crossing between data and perception, narrative and policy, atmosphere and urban typology, technology and behavior, thus befriending quantitative and qualitative methods of design thinking.

The investigation into the difference between urban climates and rural climates is at least 250 years old. Luke Howard, for example investigated London's urban heat island effect already in 1818 (Ng 2016) providing an argument for the Garden City movement initiated by Ebenezer Howard as social and green infrastructure concept. The often-cited book *The urban climate* by Landsberg (last published in 1983) made the topic known to a larger audience and finally established the field of urban climatology. Yet, urban climate is too rarely been considered in recent urban design and development (Ng, 2015). However, the goal to develop sustainable urban neighborhoods brings the topic of urban heat islands in a warming climate to the center of attention. Designing spaces for sustainable urban neighborhoods requires the integration of disparate fields of knowledge. The way spaces are designed with social interaction patterns as practiced by space syntax analysis strategies (Hillier and Hanson 2005) need to be considered in conjunction with urban climatology and urban morphology (Ng, 2015). Urban spaces designed for natural ventilated buildings and outdoor pedestrian comfort require refined understanding and predictability of urban microclimate (Passe and Battaglia 2015). Therefore, research needs to investigate the natural and social forces shaping the urban form and function as a constant exchange of energy and material through human activity (Ng 2015 / Shove and Walker, 2014).

Human habitation has changed the surface of the earth so significantly, that recently earth and social scientists introduced the concept of a new geological time period, the "Anthropocene". "This most recent period is human-influenced, or anthropogenic, based on overwhelming global evidence that atmospheric, geologic, hydrologic, biospheric and other earth system processes are now altered by humans. The word combines the root "anthropo", meaning "human" with the root "-cene", the standard suffix for "epoch" in geologic time. The Anthropocene is distinguished as a new period either after or within the Holocene, the current epoch, which began approximately 10,000 years ago (about 8000 BC) with the end of the last glacial period" (Doucet et al 2017). In order to research urban climate in the Anthropocene as an exchange of energy, material and human activity, urban climatology research needs to be connected and integrated with the discourse about "social practice" (Shove and Walker 2014, Schatzki 2009). The relationship of energy and social practices are reflected in the back and forth between demand and consumption and thus becomes an intrinsically related part of the social life of communities. In other words, energy is needed not for its own sake, but to accomplish social practices, for example heating and cooling homes. This combined thought process aims to uncover behavioral patterns in urban residential environments, which relate to microclimatic spatial types. Research indicates (Harlan et al, 2007) that shade, which can reduce the impact of urban heat island effects, is an advantage of affluence and thus heat island effects have to essentially also be treated as an environmental justice issue, not just merely an energy or climate issue. As shade can mediate the urban climate, which can already be multiple degrees warmer than rural climate, the impact of a changing climate on urban population will affect non-affluent urban residents even more.

Air conditioning as response to overheating is not just a climatic technology to achieve cool comfort, but as Marsha Ackerman in her dissertation *Cool Comfort: American romance with air conditioning* (2013) pointed out, a social and economic issue. Air conditioning technology was only established in United States residential construction, after marketing and public relations campaigns, which were fought against strong resistance from natural ventilation advocates. Many non-affluent neighborhoods, especially in the USA, still cannot rely on air-conditioning for cool comfort. Thus, improving the microclimate through shading is becoming an energy and social justice practice.

Designing sustainable urban environments will thus need to integrate climate and microclimate research with community related work and connect research on urban natural forces with human behavior research through scientific investigations integrating observation, measurements, simulation with community co-design. Achieving this integrated investigation requires the combination of inductive and deductive methods of reasoning. While pattern discovery in data will lead to the development of new scientific theories, bringing human behavior into the center of investigation will enhance the microclimate development. In order to lay the ground for such interdisciplinary research, this paper will mediate between natural and social theories and the observation of the world.

Data and Perception

Urban climate predictions require a rigorous data collection and data simulation workflow. Urban microclimate research requires a refined collaboration between climatology, ecology, urban design and architecture due to their dynamic relationship over time. Therefore, an architectural approach and position to these workflow procedures becomes essential. Currently, mainly computational data scientists and engineers drive the discourse forward. Yet, the vital aspects need to come from the application domain, in this case architecture and urban design.

Weather and climate are intrinsically related to the development of cities and human perception (Hill, 2013), but few architectural theoretical discourses consider climate as a form giving condition. Climate influences human mood, but is rarely considered in architectural discourse beyond a technical requirement for human thermal and visual comfort.

Michel Serres, in the *Passage du Nord-Ouest* analyzes how literature addresses the exact science of meteorology as a theme. He titles the introductory chapter: “Exact and human” and starts the discourse on the relationship between the exact sciences and the humanities with a meteorological description of an urban weather experience: Boston, 17th of January 1950, sky 38% cloudy, cirrocumulus (Serres 1980, p. 35). Serres is further referencing Robert Musil, who uses a very atmospheric descriptions of August weather in Vienna to set the stage for his major novel: *Man without Qualities* written from 1930 to 1943. Highlighting these different ways of describing basically the same physical phenomena once in the language of science, then in the language of a novelist, Michel Serres establishes the schism between the two approaches of investigation, which are looking at the world from two different side: exact science and humanities.

Sustainable urban development has to bring these worlds together in a meaningful way to enable the development of climate and behavioral strategies, which reduce the impact on the environment as a whole. Architecture and urban conditions are mapped as objects with spatial relationships, but innovations are needed to understand the urban world as a dynamic climate system. Designers need to draw knowledge from computational simulations, which are utilized to combine space and time sequences with mathematical relationships about the physical processes constituting climate. Integrating these time dependent data simulations with spatial strategies would provide the dynamic background for climate-responsive urban design. The philosopher of science Eric Winsberg (2010) states: "let us suppose, that we are confronted with a physical system of which we would like to gain a better understanding: a severe storm, a gas jet or the turbulent flow of water in a basin." A computer simulation of this physical system then uses "Partial differential equations (which) provide great deal of information about the system, but do they represent the system in full, and where the system boundaries are?" Following this thought, the storm just needs to be replaced with the airflow pattern around and within an urban neighborhood to reveal and describe a similar complex data science challenge. Therefore, the framework to describe urban climatic conditions will require a multi-layered approach to multiple frames of reference or boundary conditions.

Even without considering the uncertain influence of human interaction, the dynamic of the urban microclimate system is already complex and challenging. Winsberg continues that it is "mathematically impossible to find an analytic solution to these equations - the model given by these equations is said to be analytically intractable." Every simulation requires a certain amount of approximation and does thus include uncertainty. Therefore, it is questionable, that architects and designer can trust computer simulations or develop reliable computer simulations themselves, if even the data scientist, mathematicians and simulation experts consider them impossible. In order to quantify uncertainty, simulation experts thus develop approximations and adjustment coefficients, Also the urban architectural climatology will need to develop strategies for approximation adjustments. This approximation is then conducted by simulating a mathematical equation in various discreet intervals of space and time. Computational Fluid Dynamics (CFD) for example separates the moving volume of air into a grid of finite element points. Each point is connected to a physical equation. However, the development of a grid as fine as possible to achieve results as close as possible to a true representation of the real condition requires lots of computation time. Simulating the "real condition" resembles a philosophical question, such as narrated in the story of Xenon, who tried to walk the exact boundary between water and land and never reached his destination (Serres 1980). Thus, the current scientific inquiry into the possibility to combine computational fluid dynamics simulation with large eddy simulation with the urban context on a scale larger than a building and for a longer time-period than a snap shot requires data driven approximations. Approximations then lead to inquiry how and when approximations can be validated. Thus, the development of an urban climate model combines a mathematical equation to predict the processes in a complex system with time and space variables and maps them into a geometric, topographical and architectural system. This system model needs to be validated with observed data in order to be trusted.

Theory and observed data are also both approximations of the physical system of urban climate. We have come to trust the measurements of thermometers, but still they provide uncertainty (Chang, 2004). It has been established amongst computer scientists, that a model can represent observed data based on the exactness of the mathematical approximations and a trial and error refinement of the fineness and coarseness of the grid points. The next question addresses the exactness of the validating measurements. The scale of degrees Celsius or Fahrenheit is an abstract system representing the movement of molecules in "reality". This information sometimes matches human perception, but not always, therefore "felt" temperatures are often also reported.

Thus we cannot just ask "what is real?" but need to ask "what is real enough?" The newly developing theory of computer simulation asks, if the simulation needs to be true to theory or true to observed data? Ideally, a common ground has to be established, where both can be satisfied. Urban climate research projects need to investigate, how the mathematical representation of a physical system can be validated through a simulation of a climate prediction to obtain reliable results on which design decisions can be based.

Furthermore, it needs to be tested, if the human response to a climatic condition can be represented in agreement with the human perception of that same condition. Human relationship to environmental conditions is usually only evaluated using the concept of comfort, especially thermal comfort, which drives the design and sizing of environmental systems (ASHRAE 2013). Only very recently (Parkinson, de Dear

2017) have experts started to discuss physiological reactions to thermal environments beyond the neutral comfort standard, such as alliesthesia. They acknowledge, that “thermal perception is more than an outcome of a deterministic, steady-state heat balance.” And they continue that “thermal alliesthesia is a conceptual framework to understand the hedonics of a much larger spectrum of thermal environments than the more thoroughly researched concept of thermal neutrality. At its simplest, thermal alliesthesia states that the hedonic qualities of the thermal environment are determined as much by the general thermal state of the subject as by the environment itself. A peripheral thermal stimulus that offsets or counters a thermoregulatory load-error will be pleasantly perceived and vice versa, a stimulus that exacerbates thermoregulatory load-error will feel unpleasant.” Yet, spaces for these types of experiences are rarely designed beyond the thermal bath or the Finnish sauna.

While visual perception, vision and light are established topics of critical phenomenological thought, the thermal perception has received very limited attention in the realm of perception theory. Lisa Heschong’s *Thermal Delight in Architecture* (1979/2002) uses human delight and interaction as a key indicator for the thermal environment and laments the loss of social spaces around fireplaces and cooling garden fountains with the advent of air conditioning. Otherwise, climate and weather are not direct topics of phenomenology, but often remain part of the energy efficiency discourse and enter the architectural discourse only through engineering set points.

Urban climate performance and prediction are thus intrinsically related to the uncertainty we are able to endure and the sensitivity certain systems have to fluctuation in actual numerical values. In order to move forward with the development of sustainable urban environments, architects, engineers, city planners and residents need to collaborate to determine ranges of data accuracy for prediction in the urban design process. In addition, the range of reliability is required and requested for the intended purpose. Therefore, future research needs to address sensitivity analysis in order to understand, what difference what type of change makes on the urban level considering social and climatic practices? Thus, scientists need to investigate the impact of ranges of data versus specificity of data for the physical phenomena (storms, heat islands etc) under investigation using human sensitivity and perception as guidance.

Narrative and Policy

In order to develop guidelines and align design decisions with sustainability goals, cities and neighborhoods need to develop urban climate assessment strategies, which can be implemented during the urban and architectural design process. Up to now, maps with steady state and historical data have been used to provide environmental data for these types of decision workflows. Urban energy models such as the urban modeling interface (*umi*) developed by Reinhart et al (2013) now promise to predict expected changes dynamically based on design iterations. While a map only visualizes data spatially, an urban climate model provides the simulation of physical phenomena of varying spatial resolution and creates data. In order to inform policy, the scale of map and scale of data becomes important as they combine the observation of climatic conditions through measurements with human responses to such conditions using surveys, narrative storytelling or other engagement techniques. These more immersive strategies aim to go beyond mere thermal comfort as a neutral stage to provide human-bio-meteorological (human responsiveness to weather) information for the effect of weather on human activity.

For the sociologist Elizabeth Shove and collaborators (2014), energy and social practices are reflected in the back and forth between demand and consumption and thus intrinsically related. In other words, energy is needed not for its own sake, but to accomplish social practices. They draw on Theodore Schatzki’s “Wittgensteinian approach to social practices and social life” (2009). With respect to urban climate, energy is used to keep comfortable through heating and cooling, ventilation or clothing. These social practices are influenced by many factors. First of all there is the achievement of thermal comfort. Building inhabitants do not want to shiver in winter and do not want to sweat heavily in summer. Thermal comfort is considered a neutral state. The initial human response to heat is sweating. The excretion of a liquid onto the skin to extract heat from the body through evaporation. Vernacular cooling techniques often cooperated with this human response to overheating, while current western social norms require business attire and the avoidance of sweating as means of cooling (Humphrey, Nicol, Roaf, 2016). Therefore indoor temperature set points remain fairly low even in summer as response to social practice. Thus, changing energy demand requires the change of social practices, not just individual behavior. In summary, in order to instigate significant change of the climate-related energy performance of urban neighborhoods, bundles and complexes of climate related social practices and not merely individual human behavior will thus provide the basis for the simulation of human energy and climate related behavior. This will enable a more accurate integration of human behavior into urban energy models, for example through agent based modeling, where agents and personas can be simulated with values and actions.

Atmosphere and urban typology

Environmental discussions in architecture tend to focus on either the practical or the poetic, (Hill, 2013). Similarly, the creation of an atmosphere can relate to the poetic or the scientific meaning. Atmosphere can indicate the sensorial qualities of a space (Zumthor 2015) as well as the literal atmosphere, the layer of gases around the planet Earth. The aim here is to consider atmosphere both literal and spatial. Urban heat island effect is a physical phenomenon, combining the impact of weather on urban form with social and economic issues. It has been noted, that urban heat islands are most impactful in low-income neighborhoods. This section is an attempt to develop a theory of urban climatic form and to provide a basis for the elements, which constitute the urban climate with respect to urban atmosphere and spatial typology. While humans are directly affected by the dynamic of weather, the long-term prospect of climate is more challenging to grasp. The perception of space though deals also with the atmospheric qualities. A space with a draft is regarded as not comfortable in connection with a prescribed use, like working or doing any sort of physical activity, but a breeze nevertheless can make natural ventilation possible and can be very pleasant.

Environmental characteristics have a huge impact on the development of spatial language, symbols and icons as culture is manifested through atmospheric and climatic properties. Humidity, dryness, heat, cold and light intensity have left their mark on the built form, roof type, surfaces, and openings of buildings. Buildings position themselves in relationship to the direction of the sun and the prevailing winds. The need for vision, light, heating and cooling is based on the interrelation between the climate outside and internal needs (Passe 2011). Yet, contemporary urban strategies have mostly omitted the relationship to the environmental forces. One of the last urban layouts responsive to solar access was most likely Cerda's plan for Barcelona. He turned the grid about 45 degrees to enable equal access for all apartments to the sun.

Urban climatic conditions can only be represented as approximations in time and space as stated in the previous section. Many researchers, writers and philosophers have asked the question, how to represent what one cannot see. One relevant example is Alessandro Nova's investigation of the artistic representation of wind (2011, p. 195). Thus, an urban energy model could be compared to Umberto Eco's attempt to analyze, how to develop the "1:1 map of the world" and the stunning conclusion after many attempts, that indeed "a 1:1 map always reproduces the territory unfaithfully and the moment the map is realized, the empire becomes unreproducible" (Eco 1998). Thus, the goal cannot be a "true" 1:1 model, but an approximation.

Historically the visualization of climate started with weather forecasts based on observation adding symbols depicting wind velocity and wind direction as well as low- and high-pressure zones on top of geographic maps. Nova (2011) states: "It was Humboldt, who indicated to other scholars of his time a way to record deviations in temperature in different zones of the globe empirically, producing in 1817 the first map of annual isotherms."

Also according to Nova, Loomis, a meteorology pioneer, prepared thirteen maps for the year 1842 that exceeded previous practices in detail and sophistication. He was the first to utilize colored signs to differentiate the different layers of cloudy sky and precipitation and thus refined the isotherm diagrams invented by Humboldt. He recorded data about air pressure, and above all introduced arrows of different length to indicate the direction and force of the wind. Since then meteorological data has been recorded and forecasted in this manner. Soon afterwards, the intensity of the phenomenon wind was introduces to the symbol with 6 notches, one for two degrees on the Beaufort scale. This system with 12 scales from 0 (calm) to 12 (hurricane) was developed by Admiral Beaufort in 1806 and is still used today.

Prior to the scientific advances of meteorology, Wind Gods have played a significant role and position in mythology of most cultures and played a significant role in artistic representation (Nova 2011). Wind Gods had characteristics and temperature, maybe best noticed by the relationship of the two words temperament and temperature. One major features of the urban climate is the wanted or unwanted channeling, exchange and circulation of air. Like all maps, *Urban Climatic Analysis Maps* (Ng 2013) or urban energy simulations are abstractions of natural phenomena in space. The aspect of time can be notated in manifold ways to integrate air path corridors and spatial proportions. Spatial density of built form is thus the main architectural influence on the urban climate. Jonathan Hill (2013) considers the weather as an architectural author that influences design, construction and use in a creative dialog with other authors, such as the architect and the user. Relating this statement to the urban climate condition, it can be concluded, that the urban climate influences the inhabitants in the same way as the inhabitants influence the climate.

In recent years, increased computing power has enabled the integration of maps and climate models as 2- or 3- dimensional spatial representations combining mathematical simulations with geometric objects (Reinhart et al 2013). While Ng (2013) still complains about the missing link in the planning profession between climatic knowledge, and knowledge to design for urban climatic improvements, these new tools have the potential close to this gap to enable climate-responsive urban design.

The urban climate model will have to have specific requirements on the regional, neighborhood, block and street canyon scale to bridge the large spatial and time scale differences. The urban morphology (building volume, ground coverage percentage, and the proximity of openness) influences the microclimate and vice versa. Thus, visualization of air movement in the urban context is currently moving from maps to models and simulation. And, it will be only a matter of time until urban microclimate will be simulated utilizing computational fluid dynamics (CFD).

Technology and Behavior

Prior to the development of mechanical air-conditioning as major technology, vernacular architecture used passive, building-integrated strategies of spatial composition to induce natural ventilation in combination with thermal storage as an integral part of their cooling concept. House typologies like the bungalow were adapted for the United States by integrating colonial experiences from British India with timber construction technologies developed in New England using shade and natural ventilation as major spatial technologies to mitigate the humid summer heat of the North American continent. The main feature of this spatial typology was the porch or stoop, a transient space, which acted as a main social gathering space, a shading device in summer and a sunspace in winter increasing seasonal comfort. Since the development of mechanical air conditioning in the U.S. building industry of the 1950's (Ackermann 2002), devices for heating and cooling have been separated from the design process and the porch as a climate device has disappeared from most new residential neighborhoods (Passe 2011). This change in spatial patterns also removed a major social feature of the neighborhoods, where community became spatially embedded in social practice. This change in the urban environment mirrors a change in interior circulation patterns within residential buildings as noted by Robin Evans in *Figures, Doors and Passages* (Evans 1997), where he traces the development from multi-connected rooms in the Renaissance to the corridor-circulation in late 19th century residential spaces, where individual privacy had become a social requirement. Lisa Heschong (1979/2002) analyses a parallel development with respect to the thermal connectivity in homes around a fire place versus the opportunity for privacy with individual room-specific air-conditioning units.

Technology is thus instigating social behavior; behavior is instigating technology. Air conditioning and urban climate are intrinsically related. Heat is merely moved from indoors to outdoors, thus by cooling the interior space, the urban space is warming up creating urban heat islands. By removing in between spaces like the porch or stoop, the opportunity for social interaction also declined.

Occupant behavior and related environmental controls are a major driver for building energy consumption and thus research needs to go beyond the design and performance simulation to investigating occupant behavior and control strategies. The resulting data will inform the urban simulation. For example Hong and Lin (2013) simulated energy impact of how occupants set comfort criteria (including thermal, visual, and acoustic) and interact with building energy and services systems, and studied how occupant responses to environmental discomfort directly affect the operation of buildings and thus their energy use. They developed behavior categories for three workstyles: 1) austerity – occupants are proactive in saving energy and manipulate set points after their arrival and ahead of their departure, 2) standard – average occupants manipulate set points only for times, when they are not present and 3) wasteful – occupants do not care about energy use and never roll back temperature set points. Most buildings are operated to satisfy the 'standard' occupant, while more austere occupants might be needed to operate buildings in a sustainable neighborhood. Similar patterns could be developed for residential buildings.

Discussion

The Northwest Passage acts as metaphor in Michel Serres critique of the divide between the humanities and science. This paper uses the same metaphors of a passage between technology and humanism to show how the divide can potentially be overcome with a novel interdisciplinary design approach for urban environments.

Along with Ng (2013) and many other researchers (Reinhart et al 2013) Passe et al (2016) are working towards an improvement of the integration of climate data with urban design and urban planning. As design and planning processes are conceptual- and knowledge-based (Ng 2013) the thinking process of professionals is based on images, metaphors and concepts, not mere technical-rational. Therefore, it will be important to avoid information overload when developing data driven design and decision making tools.

Urban building energy modelling apply physical models of heat and mass flows in and around buildings to predict operational energy use as well as indoor and outdoor conditions for groups of buildings (Reinhart et al, 2013). Yet, it is currently extremely challenging to integrate more detailed and specific data about human-building interaction into these models. Thus, the dynamic relationship of human-building microclimate interactions is the focus of multiple research studies Kalvelage et al (2015). Once the investigation of human-building microclimate interactions have revealed feasible and repeated patterns, data science can support the effort to connect these behavior patterns into numerical patterns. Then these behavior models could be connected with the thermal – physical models. Furthermore, vegetation and urban tree coverage are viable mitigation strategy to offset the energy loads of built environments and reduce heat island effects. Trees can lower surface and air temperatures by providing shading and contribute evapotranspiration. Therefore new urban modeling interfaces need to combine CFD simulations of the microclimate impact of trees with inhabitant behavior. This can be achieved by combining agent based models with the thermal physical model in order to provide a basis for neighborhood development strategies in the near building environment. (Passe et al 2016). Those then need to be communicated to the designing architect and urban designer. Thus, visualizing human behavior related data in a simulation interface will become significantly important. This interactive interface will enable the integration of social practices with design, energy and resource scenarios.

Conclusion

The development of sustainable urban neighborhoods still faces many complex challenges. This paper presented the theoretical framework for interdisciplinary research into sustainable neighborhoods to bridge the perceived or apparent gaps between data and perception, narrative and policy, atmosphere and urban typology as well as technology and behavior to develop performance-based design strategies and tools which expand the field of sustainable design from a mere environmental data driven application to a social practice. This is particularly important as communities (both nationally in the US and globally) are experiencing more frequent and extreme weather events such as drought and floods which acerbate existing environmental issues such as urban heat island effects.

The stresses caused by extreme events particularly on the not- so affluent highlight the critical need for novel practices and policies to address these challenges. Community engagement and co-design between community members, scientists, designers and humanists could in the future facilitate direct transfer of scientific and socio-technical advances into urban planning processes. These teams need to collaborate directly with communities immediately affected by the rapid changes in our environment and provide input data for models, which can support future community decision making.

The conceptual outline of an organizational structures for urban design teams will remain a task for further research into interdisciplinary team strategies, but it can already be stated from experience, that without a changed decision structure in the design team, true sustainability, where aspects of humanity are addressed interwoven with aspects of science will not be achieved. The design practice of the design and planning professions, such as spatial layout to create social places related to topography, sun orientation and climate through its composition and beauty need to be part of standard planning approaches. Measured performance needs to become part of standard design evaluations. Thus, bridging the gap between quantitative and qualitative data, between technology and humanism.

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