Assessing a Community-Engaged Decision Framework for Increased Urban Neighborhoods Resilience in a Warming Climate

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Successful urban systems-related climate-action-support tools enable urban stakeholders to communicate and collaborate across and beyond their respective disciplines to identify innovative, transformative solutions to increase urban infrastructure resilience and sustainability. The actions of humans within buildings and the relationship of buildings to their near-building environments (aka microclimate) constitute one understudied urban system with significant impact on urban energy use strongly impacted by a warming urban climate. This interdisciplinary research team lead by an architect at a large research university collaborates with local community partners to identify evidence-based approaches for the integration of human behavior data, building energy use characteristics, future climate scenarios, and near-building microclimate data. The team has built a prototypical model, which integrates urban trees into urban energy models based on a large-scale inventory and probabilistic occupancy data based on a neighborhood wide energy use survey. To ensure that these urban energy models are equitable, however, the needs of marginalized populations must be included- especially those most vulnerable to the consequences of a changing climate. The paper reports on two intertwined research strands. First of all, the team's best practices for gathering data from individuals facing marginalization as well as the application of this residential occupancy data into neighborhood energy models. The second strand addresses trees in urban landscapes and their capacity to modify temperatures in the near-building environment, which is important for reducing summer heat loads on building surfaces. Preliminary results for an urban neighborhood strategies are reported.

INTRODUCTION

> The Glasgow Climate Pact only keeps 1.5C in sight if countries take concerted and immediate action to deliver on their commitments. This means phasing down coal power, halting and reversing deforestation, speeding up the switch to electric vehicles and reducing methane emissions. (COP26 2021)

Written right after the Glasgow Climate Pact highlighted the need for urgent global climate action, this paper presents research grounded in architecture and building science, with specific emphasis on integrative design strategies for sustainability assessing natural energy flows in buildings and neighborhood. This integration of building science with design is driven by the hypothesis that architectural space is a technology to integrate form and performance.[1]

Expanding sustainable design research into urban environmental modeling and simulation derived from the acknowledgement of two long-term research questions as boundary conditions for design: The urban micro-climate, especially urban surfaces used for trees and vegetation around the buildings, and the interaction of occupants with the building, especially when passive operation strategies are present. These research questions led to the development of the Sustainable Cities Research Team at ISU.[2] Developing this team expanded on previous interdisciplinary research and collaboration with engineering and thermodynamics such as Passe & Battaglia (2015)[3] as well as a deep understanding of architectural design thinking, history, and theory.[4] Data-driven science and computational simulations are integrated with design thinking to develop new knowledge with a direct impact on a holistic understanding of sustainable architectural design.

Human life on earth is endangered by global climate change and depleting fossil fuel resources.[5] Changing the ways in which we design and build buildings, neighborhoods and cities is an important part of the solution, because buildings use close to 40% of the energy consumed in the United States and in most other developed countries.[6]

As climate change threatens human habitation with rising temperatures and more frequent extreme weather events, communities struggle to make decisions related to the built environment both to adapt to changing conditions and to mitigate future impacts through energy conservation and community actions. Much data related to this issue exists, but its vast quantities and multiple formats make it challenging for decision-makers to integrate and use effectively as they seek to create more livable, resilient cities. In addition, qualitative information about interactions between humans and the built environment is lacking, so systems are frequently designed without attention to the perspectives of those who live in them. Developing integrated models that residents and city officials can use to foster sustainable urban ecologies, the research project contributes to the advancement UN Sustainable development goal 3 (Health), goal 7 (Energy) goal 11 (Sustainable Communities)[7] The research projects expand disciplinary data analysis capacity for less established data collection aspects and develops methodologies for model interpretation to expand data transfer, data analysis, and data exchange between physical and socio-economic models utilizing mathematical models. Methodologies for reliable data access are established and assessed to build, validate and calibrate urban system models. Finally, data visualization techniques will "close the loop" between data collection, data analysis, and model interpretation to enable stakeholders to make and communicate data-driven decisions. The project is currently ongoing to accomplish the integration of human behavior data into urban energy models to test urban surface use scenarios and develop detailed modeling frameworks for integration of vegetation characteristics and urban heat island (UHI) characteristics derived from remote sensing strategies. Computational fluid dynamics (CFD) simulation capacity will support cities and communities in complex sustainable development decisions. Funded by multiple agencies over the past five years, this paper assesses of the currently available results and the potential of the project to be scaled up to enable significant impact and potential to mitigate and adapt.[8]

Urban climatic conditions as local physical phenomena can only be represented as approximations in time and space. 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".[9] Thus, the goal cannot be a "true" 1:1 model, but an approximation.

THE FRAMEWORKS TO ESTABLISH ARCHITECTURE WITHIN INTERDISCIPLINARY TEAM COLLABORATIONS

Two frameworks guide the presented research based on interdisciplinary and transdisciplinary research teams, one is theoretical and the other methodological. The theoretical framework has been presented by Passe in 2017[4] with the premise, that architecture has always occupied a thought space at the boundary between technology and humanism. The theoretical base supporting this work is Hermès V Le Passage du Nord-Ouest[10] 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. Based on this understanding Passe (2017)[4] established 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 understanding of design impacts on building energy balance demands the collaboration of architects and engineers, bringing together deeper scientific and engineering knowledge with design knowledge and experience. Interdisciplinarity is embedded in architectural practice, no research method intrinsic to architecture, but borrowing from many other disciplines.[11] This synergistic capacity of architecture provides architectural researchers with the ability to form large scale teams and integrate multiple disciplines crossing the Northwest passage. These collaborations have provided significant knowledge and shared expertise, their energy, and the work they contributed to the overall effort.

The methodological framework was developed by Passe et al in 2020[12] as a research and computational modeling framework which integrates the activities and interactions of people with their buildings with the modeling of the building-environment interactions. Based on community surveys an agent-based modeling has been proposed to integrate occupant-building interactions with an energy model. This will then provide the integration of the environment and tree data and land surface temperature data from satellite with building data. These models can then be tested for the impact of future climate models on the urban environment using data such as the future typical meteorological year data set developed by Rabideau et al in 2012.[13] This neighborhood model is then able to support the stakeholders to make decisions on retrofit initiatives on cooling center initiatives on alert initiatives in those neighborhoods.

SELECTION OF A STUDY AREA

The study area of our team is the Metropolitan Statistical Area of Des Moines in Iowa, USA. Within the city the team has been collaborating with a neighborhood called Capitol East which is situated very close to the state Capitol. Located at 41.6°N latitude and 93.6°W longitude, it was chosen because civic officials had expressed a commitment to development of a sustainable, equitable city. This resource-vulnerable neighborhood is considered representative of many mid-sized US city neighborhoods that are affected by climate change. The Polk County Health Department (PCHD),[14] with jurisdiction over Des Moines and adjacent suburban/rural communities, has indicated a need for improved knowledge about vulnerability of residents to extreme heat in these areas. The neighborhood is comprised of predominantly older single- or multi-family residential properties, some occupied by more than one household.[15]

The climate of Des Moines is characterized by hot, humid summers with design conditions of 32.4°C dry-bulb / 23.8°C wet-bulb temperatures[16] and harsh cold winters. Extreme heat conditions can be as high as 38°C. The Third US Climate Assessment predicts that extreme heat events will increase markedly in the US Midwest.[17] Lack of central air-conditioning[18] and the impact of urban heat island (UHI) effects[19] caused by urban density and limited tree canopy can create dangerous indoor living conditions. This phenomenon is also linked to areas in many US cities that have a history of redlining, racial segregation, and disinvestment, which often overlap with areas of highest UHI effect as noted by Hoffman et al in 2020[20] and least tree canopy as noted in the City of Des Moines 2020 Urban Forestry Plan.[21] Thus, temperature reduction in the urban environment is crucial to reduce cooling loads for residential buildings. For a standard house in the urban core, active heating and cooling energy systems are required throughout the year to manage internal comfort. However, the existing residential building stock in Capitol East typically have little insulation, older windows, and leaky building envelopes with very low R-values. Additionally, up to 50% of homes in the most vulnerable neighborhoods, and 25% in the case of the Capitol East neighborhood specifically, do not have functional central air conditioning (AC) systems and thus rely only on natural ventilation in summer possibly enhanced by fan use as mapped by the Polk County Health Department in 2019.[14] This setting offers unique, often underestimated challenges related to climate change especially for increased frequency and intensity of heat waves. To assess the impact of vegetation and land use surface, a tree inventory was conducted in the neighborhood in collaboration with the community. Thus, the team has has access to a tree inventory which includes yard trees.[22]

These issues are exacerbated by the so-called Urban Heat Island (UHI) effect which is higher in denser neighborhoods such as Capitol East.[12] Thus, the neighborhood is already warmer than more wealthy locations and facing increasingly warmer conditions with the least resources to counteract these challenges for the residents. climate policies and strategies need to be established now for improved resilience and preparedness.

INCLUSION OF COMMUNITY MEMBERS

Based on the noted framework, data collection was conducted about residents—building interaction with neighborhood residents. Surveys and demonstration projects were included in community meetings. Those demonstration projects highlighted strategies how to retrofit buildings. Furthermore, the team collaborated with school groups on issues of urban heat, on issues of vegetation and on issues of local food production.[23]

The first step in developing community engagement practices with this neighborhood was a manual using five major best practices guides.[24/25] The development of partnership became a key aspects as was multilingual communication. The energy use survey has been conducted in Spanish and English. Images were designed to be familiar with community members. The interview and activity schedules were developed in accordance with cultural norms and of course also offered useful gifts related to the residents. Human behavior data collection has been conducted at various community events over multiple years to integrate data about neighborhood dynamics and needs: an extensive youth program merged sustainability, technologies (geographic information system (GIS) information and ABM), and action projects.[12] The lack of methods to integrate location-specific occupancy schedules for neighborhood energy simulations led to the development of an Institutional Review Board (IRB)-approved energy-use survey administered to 1,000 Des Moines households. The survey asked questions about the building properties and the energy patterns and the energy use characteristics of buildings and developed a energy model.

The schedules were then correlated with the American time use survey (ATUS) which indicates when people are at home and what they do at home (presence rates) and those values were then clustered based probabilistic distribution of base schedules by weekends and weekdays into the energy model.[26] The data was furthermore integrated into multiple sensitivity analysis including UHI data with the result, that a more localized representation of occupancy indeed influences the results of predicted cooling energy consumption with up to 10%.[27]

URBAN MICROCLIMATE AND URBAN ENERGY

The second strand addressed trees in urban landscapes and their capacity to modify temperatures in the near-building environment, which is important for reducing summer heat loads on building surfaces. Trees can reduce energy use and improve indoor and outdoor comfort for cooling in summer by casting shade and providing evapotranspirational (ET) cooling. Tree morphology and building data have been integrated in a three-dimensional energy model using the urban modeling interface (UMI) to estimate cooling due to interception of sunlight as reported by Hashemi et al (2018),[22] and Passe, et al (2019),[28] later those were integrated with a sensitivity analysis to assess UHI impact using satellite data compared to rural weather data when trees are present resulting in a 21% increase of cooling loads when heat island is considered and reported by Ghiasi et al in 2021.[29] 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.

Integrating the trees only as radiation blockers for the buildings shows already significant impact of the vegetation on cooling loads. Savings were computed as high as 20% in case of well shaded building.[22] Trees do not fully shade at all times of the day and year as they are porous and often partially transparency, thus in a next step the leave on and off-season spring and fall needed to be integrated into the urban energy model. Malekpour at al thus developed a Rhino-grasshopper based tool which included species and, tree geometry and seasonality tree leave coverage into UMI in 2021.[30]

Tree shade effects on building energy use are attributed to tree configuration, building characteristics, and/or climate. The major characteristics of trees that affect energy demand of buildings are tree height, position relative to the built structure, tree canopy shape and density, tree species, and duration of the leaf-on period. The challenges encountered for developing a high-resolution urban energy model with tree geometries that accurately represent the actual setting were significant. Their preliminary results indicate a relatively modest effect of trees on potential cooling savings, but the model and simulation does not yet include evapotranspiration, which is likely to increase the effect of trees on building energy dynamics, the main goal for developing high-resolution tree geometries for trees was related to increasing the fidelity between predicted and actual energy consumption of buildings in urban energy models. Further explorations related to microclimate around residential buildings was conducted with the evaluation of the impact of evapotranspiration using computational fluid dynamics (CFD) computing the humidity transpiration from the trees and related impacts on heat flux on buildings were significant.[28] The framework is currently expanded towards a probabilistic model of tree-building-interactions into the overall modeling interface.

Generally, under different climatic assumptions, heating loads are expected to decrease in the projection period, while cooling loads are expected to increase. These changes depend on the magnitude of climate change-induced ambient temperature increases over the next five decades. Looking at the simulation results from 2017, the impact of longer periods during which there is greater need for cooling can already be observed in energy consumption of the buildings modelled. Overall, including trees in the model results in a general decrease in cooling loads and a general increase in heating loads As noted above with the most significant variable being the UHI inclusion and tree location. These results suggest that an accurate and reliable prediction of cooling loads with simulation tools is not possible without including high-resolution tree geometries. Such geometries need to account for both general geometric properties and shade factors throughout the period of study.

DISCUSSION AND COMMUNITY FEEDBACK

This result of the multiple ongoing research project of the Sustainable Cities team integrating refined human behavior and occupancy data with improved integration of trees and vegetative surface covering for buildings. A potential drawback of this framework is the amount of effort required to conduct local energy use surveys and build comprehensive tree inventory dataset. Although many municipalities have some data for street trees, there are relatively few comprehensive urban forest inventories that include so much information on canopy dimensions, the degree to which the canopy is filled with leavers, and fewer still include such data for trees on private properties. Therefore, the ATUS-based occupancy schedules provide estimations, which allow for refinement without excessive detail. While each of the individual studies reported modest accuracy improvement, the most significant issue remains the impact of urban heat on cooling loads in residential buildings of less prosperous neighborhoods. It may be that the development of specific empirically based date collection will allow calibration of models using other available data (such as LiDAR imagery with detail for tree canopy shape and size) in the future to support communities with local tree-planting mitigation strategies.

CONCLUSION

The COP26 Glasgow Climate Pact requires immediate action in order to prevent catastrophic warming of the planet and staying within the 1.5 C global warming goal. The development of sustainable urban neighborhoods still faces many complex challenges. Based on a theoretical framework for interdisciplinary research into sustainable neighborhoods laid out by Passe et al 2017[4] and 2020[12] to bridge the perceived or apparent gaps between data and perception, narrative and policy, atmosphere, and urban typology as well as technology and behavior performance-based tools were presented, which can support more refined 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.

Next steps will require the application of this knowledge into full city analysis and enable residents to participate in creating an interface for the city and policy makers to explore and install real change. Residents will be able to enter their activities into the data base and receive close to immediate results how their actions result into community energy impact. 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. Further cross-variable simulations are planned to explore and refine these preliminary outcomes.

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 which bridge the gap between quantitative and qualitative data, between technology and humanism. Thankfully, measured performance has now become part of standard design evaluations with the AIA Excellency Framework[31] and climate action plans are being established in communities across the world. The hope is that the presented research will support communities to make informed decision and scale up the integration of this work will provide a design manual for urban neighborhood retrofits and for the development of climate change mitigation strategies.

ACKNOWLEDGEMENTS:

This preliminary work was funded by the 2016 Iowa State University Presidential Interdisciplinary Research Initiative

(PIRI) on Data-Driven Science as well as the University of Iowa Center for Global and Regional Environmental Research. The Iowa Urban FEWS team is supported by the National Science Foundation, Award # 1855902 (PI: J. Thompson, ISU). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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