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Socio-Ecological Visual Analytics Environment “SEVA”: A novel visual analytics environment for interdisciplinary decision-making linking human biometrics and environmental data

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Abstract. Current architectural design practice is limited in its consideration and understanding of life-cycle energy flows which comprise multiple phases, from material resource extraction, construction, building occupation within the built environment, and after demolition. Furthermore, bioclimatic environmental flows interact with the buildings, particularly at the building envelope, making it a rich interface for shaping energy flows towards buildings that are energy self-sufficient with clean on-site energy resources. The buildings we inhabit directly affect the greater built environment which is an inherent part local ecosystems that compose part of larger ecologies at global scales, ultimately affecting the overall biosphere. As a result, the buildings we construct, directly and indirectly, affect our economies, the health, and well-being of our societies and our natural environments. This paper explores the development of a computational framework that allows designers to visualize, understand and evaluate their design choices in terms of their environmental implications and ecological efficacy. The framework for design analysis offers a more comprehensive ecological analysis than existing sustainability assessment tools by collecting live environmental and human biometrics towards considering the entire comfort cycle. Working with SEVA, Socio-Ecological Visual Analytics, platform a web tool designed to allow for interactive feedback in real-time. This research is proposing to investigate the visualization of human data as a metric to analyze the well-being of the environment, which is an inversion of received perspectives. This paper will use a case study, assessing a built environment unit tracking the environmental conditions, building systems performance and the user human biometrics, demonstrating the qualitative and quantitative environmental impacts of the building design on the users.

1. Introduction: An interdisciplinary approach to facilitate decision making for Human Health and Built Ecologies through a novel visual analytics environment

Current architectural design practice is limited in its consideration and understanding of life-cycle energy flows which comprise multiple phases, from material resource extraction, construction, and building occupation within the built environment. Furthermore, bioclimatic environmental flows interact with the buildings, particularly at the building envelope, making it a rich interface [1] for shaping energy flows towards buildings that are energy self-sufficient with clean on-site energy resources. The process of constructing and operating buildings often leads to environmental outcomes that are not nourishing to either physical or social ecosystems [2]. Due to the siloed structure of the building industry and the endemic lack of environmental awareness among building professionals and



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the industry as whole, the process of delivering built environment systems has played a significant role in the decline of Earth's ecological health [3]. Our built environments [4] are in fact built ecologies [5, 6], in that they are part of a larger interdependent global ecosystems and they, directly and indirectly, have significant effects on our populations' health and well-being, our economies, and on global biodiversity [7, 8].

This research involves the development of a novel visual analytics environment to investigate the built ecology as a closed loop with interactions between the built environment and its inhabitants. Frederick Kiesler in 1939, used the term "correalism" to describe the dynamics of continual interaction between man and his three different environments: natural, technological, and human [9]. These systems and environments, directly and indirectly, affect or influence each other therefore directly affect human health and well-being, and in turn the human condition can be understood as a potential measurement device, or indicator, of aspects of the ecosystem as a whole. The proposed SEVA environment is an attempt to provide analytical links between the human social environment (H), the built environment (T), the bioclimatic flows (N) and the human biomedical data (M). Building technology history has been focused on human health comfort by mostly being centered on how subjects perceive their environment. This research is proposing to investigate the visualization of human data as a metric to analyze the well-being of the environment, which is an inversion of received perspectives. Since two people will never react exactly the same way to the same environmental conditions, such studies rely on epidemiological and population scales. We are surrounded by diverse feeds of data resulting from the recent developments of human wearables, buildings, and environment sensors, thus providing new opportunities to identify and visualize these interrelated feedback loops on a much larger scale and with deeper and more diverse data types, thereby providing an environment to constantly shift perspectives, based on new information which would put the former data into another context.

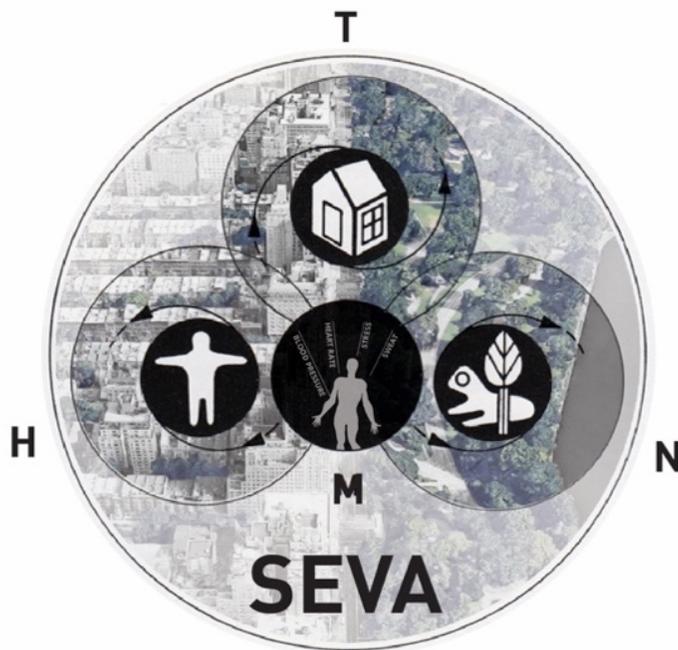


Figure 1. SEVA proposes an environment whereby multiple data streams allow for a comprehensive analysis of our built ecologies, human systems, natural environments, technological environments, as well as human biomedical data. The research focuses on enabling the visualization of feedback loops between the all these systems and environments, directly and indirectly, as they affect or influence each other. (diagram readapted from [9])

This research offers a novel approach to the visualization, sharing and analysis of a much more extensive array of data types and models than has previously been possible, from structured data and knowledge management to live streaming. Critically, the contextualization and semantic annotations of data quality and significance are automatically integrated into the uploading of information to the visualization environment, so that vital contributions to the analysis of meaning and the inference of knowledge are preserved with the provenance of the data. The Socio-Ecological Visualization Analytics (SEVA) environment was designed to incorporate multiple techniques with a focus that allows the user to explore, analyze, and share the data and knowledge findings.

Between 1950 and 1990, the urban population in developing countries doubled and is projected to contain over half of human populations within the next decade. This urbanization process, the demographic transition from rural to urban, is changing the ecology of the living environment. These changes are directly reflected in the change in climates and major climatic events. This is creating a less comfortable environment, which leads to a vicious circle in which people rely on mechanical systems using more fossil-based energy. This leads to many interdependent environmental problems; the primary issues being water quality and quantity, air pollution, and energy generation, and they are cross-linked. Therefore, the built environment has caused a negative effect on the built ecology and the earth ecosystem [10]. The built environment process (BEP) is responsible for more than a third of all of the materials that are harvested, extracted, mined, and treated on the planet; however, almost a third of all of the waste that is buried, burnt, and dumped is resulted from construction and demolition activities (UNEP, 2007). Since the ecosystems we inhabit are essential for survival, understanding the impact of these activities, not just in terms of energy use or pollutants (including the emission of carbon), but also in relation to complex and interconnected networks of ecosystem services [11] on ecosystems services and disservices, is vital for the betterment of the built ecology. One way to reduce or to reverse the negative environmental impact of the BEP may be to create or redesign such environments so that they provide, integrate, or support ecosystem services, mitigate the disservices, and therefore, sustain the regenerative capacity of the ecosystem.

This research aims to develop a computational environment that supports an understanding of the impact of design decisions for the built environment, principally for energy, water, and waste management by allowing for accessible information and feedback. By developing a novel visualization framework that allows for energy, ecologically, and human information feedback to occur. The intention is to facilitate the development of a new paradigm by providing a diverse array of stakeholders', from architects to building owners, feedback about the environmental and ecosystemic impacts of the design decisions throughout the building life-cycle [12].

2. The need for interdisciplinary visualization frameworks to address current ecosystemic problems within built environment and human health

Visualization is the communication of information using graphical representations. Before the formalization of written language, pictures have been used as a mechanism for communication. A single picture can contain a wealth of information and can be processed much more quickly than a comparable page of words. This is because image interpretation is performed in parallel within the human perceptual system, while the speed of text analysis is limited by the sequential process of reading. Pictures can also be independent of local language, as a graph or a map may be understood by a group of people with no common tongue.[13]

Studies show that many multi-scalar research problems cannot be easily addressed from the confines of individual disciplines for they require the participation of many experts, each viewing the problem from his or her unique disciplinary perspective. The bringing together of disparate experts or fields of expertise is known as interdisciplinary research. The benefit of such an approach is that discourse and collaboration among experts in distinct fields can generate new insights to the research problem at hand. With this approach comes massive amounts of multivariate data; different understandings of the possible relationships between variables and their corresponding relevance to the problem is in itself a challenge. One of the most valuable means through which to comprehend big data and make it more accessible is through data visualization.

Studies show that a single discipline is not solely able to adequately address specific multi-scalar research questions in a comprehensive manner [14-17]. In order to answer complex questions, solve complex problems, and gain a coherent understanding of complex issues, interdisciplinary collaborations are formed. This trend has been driven by a rise in funding for multidisciplinary projects [18]. Each expert conducting his experiment will produce a remarkable amount of data. Sharing these results transparently within the interdisciplinary cohort is vital for the participation of many experts, each viewing the problem from his or her unique disciplinary perspective, and potentially leading to the emergence of novel insights. Thus, the presence of multiple data sets and large numbers of elements add

to the complexity. An interdisciplinary concept consciously integrates separate disciplinary data, concepts, theories, and methods to produce an interdisciplinary understanding of a complex problem or intellectual question.

In addition, there is a need for sophisticated analytic systems which enable large-scale, interactive, and insightful analyses. These analytical systems, which use the computer's ability to process large-scale data, integrate the human through the use of visual analytics [19]. Furthermore, in an interdisciplinary context, the need to reveal relationships between constituents presents a complex representational problem. A successful visualization can make the relationships between datasets comprehensible, offering a shorter route to help guide the decision-making process and become a tool to convey information critically [20]. Studies show that the difficulty of interdisciplinary work is often disciplinary in nature, in that a discipline is seen as an identity or boundary condition of specification not differentiation [13]. It is maintained here that in order for truly interdisciplinary work to occur, such boundaries or stereotypes need to be broken. Therefore, to help break these boundaries and allow researchers to understand better how their knowledge can enhance the interdisciplinary process by assisting in the completion of a holistic evaluation of an interdisciplinary problem, studies in this area suggest the need to visualize and diagram interdisciplinary practice [21]. Our approach, through the design of a web-based user interface, attempts to produce an aesthetically engaging, understandable, meaningful, and accessible data visualization environment which facilitates a more in-depth multilevel and multi-focus insight to the analyst through simultaneous analysis of datasets in their overall context.

3. Characterizing complex data for design and research decision making

In the coming decade, the world will generate 50 times the amount of data as in 2011, and 75 times the number of information sources (IDC, 2011). Being able to use this data, proposes enormous possibilities and transforms these opportunities into reality, people need to use data to solve problems. The building process is slow, expensive, and risky. Dealing with data is quick, inexpensive, easily reachable and seemingly suggests offering new levels of certainty on interdisciplinary problems. However, a widespread paradigm shift has occurred in design thinking whereby performance requirements have far greater influence on the decision-making process, except access to reliable and extensive data during critical phases in the decision making has been challenging to achieve. In architecture, the use of generative computational frameworks can support systems design exploration in such a way that expands the solution space for a multitude of formal iterations while satisfying and optimizing performance requirements [22]. This paradigm has also offered the promise to the designer the power to work through generative systems processes through parametric computation potentially. This approach is known as 'Generative Performative Design' whereby both form and performance requirements drive the generation process [23]. The use of building performance simulation tools by design professionals has become a fundamental way to support design decisions for energy efficient buildings.

Recent studies have discussed the potential benefits of better integrating environmental analysis and building simulation into the design process [24]. Weytjens has demonstrated that the interface and input method should be intuitive and thus proprietary modeling rules must be avoided. Also, energy analysis tools should be in harmony with architects' typical working methods to add value to the architectural design process. Architects used to be limited by what they could calculate. With the use of new computational tools, architectural practices can model, understand and simulate the flows. Currently, the development of such tools is booming. However, since the built environment with its complex matrices and fluxes is a giant information-rich interface, the resulting outcomes have become overwhelming. These databases present several challenges for visualization, interaction, and participation for the designer and the public. For example, a significant amount of effort and time is often spent organizing the data before extracting any analysis to infer new knowledge from them. This research proposes an environment to allow architects to handle, visualize and interact with the spatiality and complexity of current and new buildings.

Emerging tools are enabling integrated modules and scripting environments that are narrowing the gaps among architects, engineers, and computer programmers. The rapid feedback method can use

optimization to create a design space to select materials and technology options while balancing cost vs. percent of energy savings. Building upon this first step, the mass optimization process enabled the generation and analysis of orders of magnitude more design alternatives, thus allowing the exploration of designs that were substantially more energy efficient than those typically evaluated using current methods, at negligible additional process cost. This can yield highly accurate and useful results with an accurate and diverse cost estimate.

4. The Socio-Ecological Visual Analytics (SEVA) Environment Design Methodology: Towards a Novel Visual Analytics Environment

With the help of an interdisciplinary team at Rensselaer Polytechnic Institute spanning the departments of Math, Architecture and Computer Science, the concept and framework for SEVA the novel interactive visualization environment were developed. SEVA aims to facilitate the acquisition of unanticipated and disruptive insights and discoveries, by enabling the comparison across a far greater range of heterogeneous data types and analysis techniques across multiple scientific and socio-demographic categories and scales — from metadata to microdata. Through the development of an interactive dashboard, users can juxtapose and recombine the data and data analyses across diverse studies, variables, methods, and participants. The goal is to facilitate inquiries to provide answers to the Why, How, Who, and What questions by reconciling, integrating, and visualizing data and facilitating interaction with data. In keeping with the ethos of the semantic web, SEVA aims to provide a common toolkit to enable data to be shared and represented across multiple types, formats, applications and pre-existing frameworks.

SEVA environment, the interactive data visualization web interface, was designed to allow for the (re)presentation and exploration of data and data analyses from human biometrics and built environment datasets. The proposed data visualization toolkit will integrate conventional data visualization tools and formats with novel visualizations developed for the analysis of such data. DJ aims to facilitate a clear understanding and overview of the relationship between the built environment and its inhabitants. The ultimate aspiration is to inspire the building of intuition and insightful synthesis across large and diverse teams and disparate data sets. The primary goals are to see and show data within its context: to capture, annotate and share data stories, and to allow the users to integrate their own interactive data visualization tools. SEVA was developed to integrate innovative tools customized for the understanding of the complex built ecology alongside industry-standard interactive formats. In particular, pre-existing data formats can be compared from individual data units across studies with aggregate data expressed in the summary form, in order to query significant metadata characteristics across studies such as comparative statistical power across studies, or potentially important gaps in the knowledge base.

A particular feature that we are building for SEVA that distinguishes it from other existing visualization resources is the capability to query and compare very different types of data and data formats within a single dashboard format, with an emphasis on building towards the capacity for comparisons between biometric, and demographic data alongside environmental exposures.

5. Towards a novel visual analytics environment titled Socio-Ecological Visual Analytics (SEVA) to facilitate interdisciplinary decision making

The SEVA data visualization and analytics environment are designed to help multiple stakeholders to see and compare extensive amounts and types of data sets that were not previously accessible or readable. It is intended to support researchers and the general public to explore and communicate scientific results in new and more extensive ways. SEVA is aimed to support domain experts and data scientists to communicate more fluidly by allowing for easier comparison across multiple studies and analytical techniques simultaneously. Within a single dashboard, the visualization seeks to help stakeholders from different disciplines to communicate their ideas better and share results clearly.

This environment is developed to allow architects and designers to understand the performance of the built environment better, and to learn from previous computational data as well as sensors data deployed in the built environment. The web-based visual analytics platform addresses the existing disconnect between the outputs of multiple environmental claims, simulation tools, and performance

metrics by providing a platform to visualize these resulting outputs for different design options simultaneously. In order to do so successfully, an interdisciplinary approach has to be adopted where each discipline can be represented by an expert. The SEVA environment is leveraging the power of the visual to allow all the different stakeholders to make their findings clear successfully and to build a collaborative story. The built environment is complex, involving multi-scalar, dynamic processes that need to be clearly identified in order to provide comfortable shelter for its users. With the current smart building approach and the vastly deployments of sensors with big data and Internet-of-Things applications. Also, the public has adopted wearable biometric devices in search of healthy conditions. These streams of data are used to enhance quality, performance and interactivity of building services, to reduce costs and resource consumption, and to maintain comfortable conditions for human health and well-being. This environment is proposing to close the loop between these streams by allowing for an inter-disciplinary approach using complex visual analytics techniques. SEVA framework is composed of three layers (**Error! Reference source not found.**). The first layer is the inputs as data feeds, from computational models and/or physical experiments. This layer is proposing an automated ingestion process that aligns the data with its appropriate metadata and semantics with the incorporation and alignment of critical assessments/annotation into the data. The data access layer enabling technologies is based on the semantic knowledge overlaying and the use of knowledge management/data management tools. This is where the data is semantically stored and managed. The presentation access layer techniques: the visual analytics approach access and representation of data the presentation access layer, the visual analytics web interface, where the user can search, visualize and analyze the data (top).

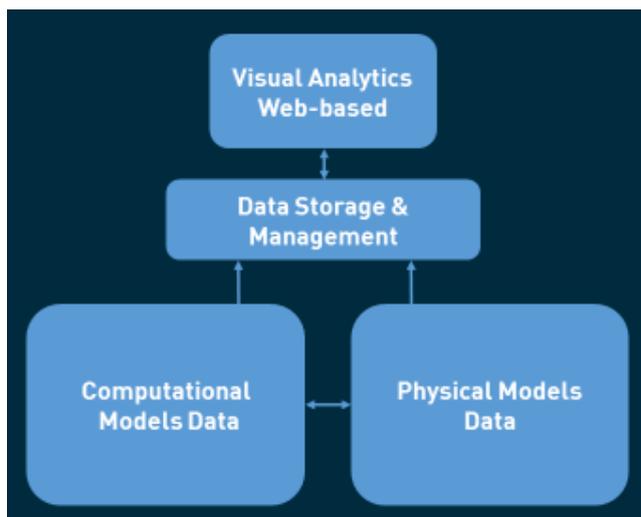


Figure 2. The proposed SEVA framework is composed of three layers: 1) The inputs (data feeds) from computational models and/or physical experiments (bottom). 2) The data access layer where the data is semantically stored and managed (middle); and 3) the presentation access layer, the visual analytics web interface, where the user can search, visualize and analyze the data (top).

6. Testing SEVA framework usability: The Ecological Living Pavilion use case

To highlight the need for innovation in the face of rapid urbanization, UN Environment and UN Habitat collaborated with partners led by the Yale University School of Architecture and the Yale Center for Ecosystems in Architecture (CEA) – in collaboration with Gray Organschi Architecture – on an exhibition of a new eco-housing module. The 22 square-meter Ecological Living Module (ELM) sparked debate and proposed new ideas on how to redesign the way we live, through a Built Environment Ecosystem Framework which addresses the following:

1. Resilient and adaptable construction techniques
2. Renewable, locally-sourced materials and resources
3. Secure on-site solar energy
4. Safe sustainable water capture and purification
5. Indoor air quality remediation
6. Waste management integrated with distributed micro-farming

The first demonstration unit, located on the UN Plaza in New York City, during the 2018 High-Level Political Forum, contained features relevant to the local climate and context of New York.

The exhibition did demonstrate the use of a sensor network for live, real-time monitoring. The data is visualized in SEVA (Socio-Ecological Visual Analytics), a web-based interactive platform that quantifies and displays environmental performance and human health data in real time. The sensors deployed within the exhibition was streaming live data about the environmental conditions (Temperature, Relative Humidity, CO₂ levels, VoCs levels, Sound levels, Lighting levels, and air pressure levels); about the systems performance; as well as human biometrics (Heart Rate).

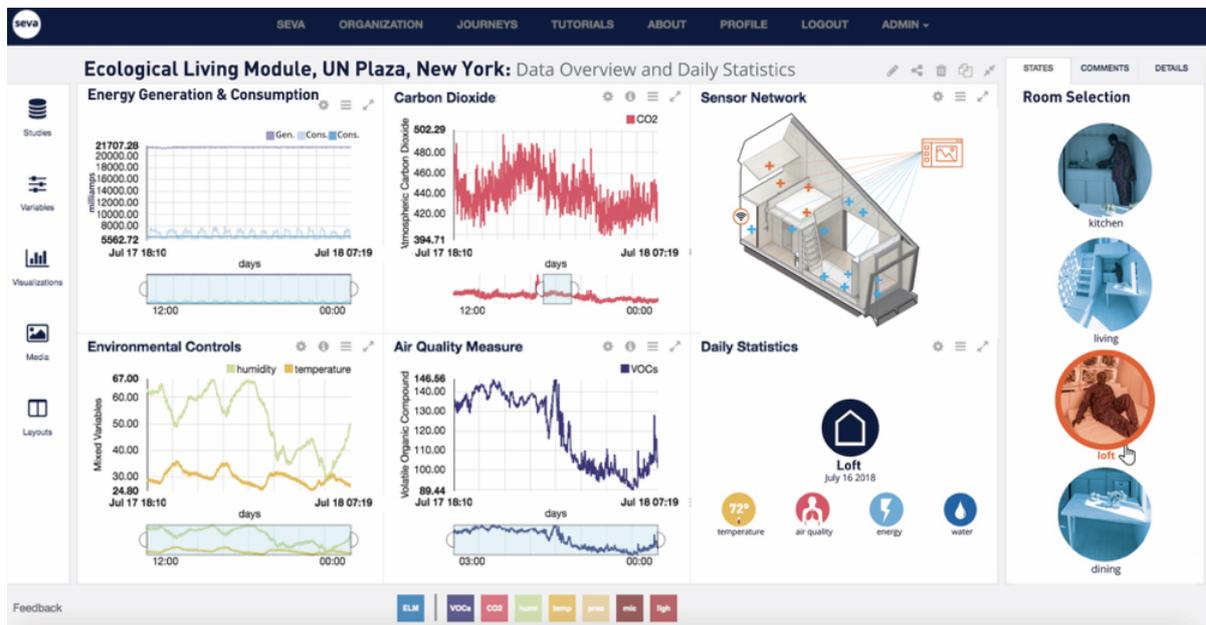


Figure 3. Dashboard view of the SEVA (Socio-Ecological Visual Analytics) web-based interactive visual analytics platform that allows for the displaying real-time data about the conditions within the exhibition.

7. Conclusion and discussion: Towards a Socio-Ecological Visual Analytics (SEVA) environment to facilitate interdisciplinary decision making linking Human Biometrics & Environmental Data

This paper adopted an interdisciplinary approach which is key to nurturing better solutions. Through this document, we presented the novel interdisciplinary environment titled “SEVA” as a mean to bring designers, scientists, researchers and policy-makers to the table with an extended array of potential participants. The environment is proposing solutions permitting more stakeholders with diverse approaches to participate in the process of developing novel solutions for global health and built environments through the comprehensive but accessible presentation and exchange of the pertinent data and models, that can be curated, shared and played with. This research offered a novel approach to the visualization, sharing and analysis of a much more extensive array of data types and models, from structured data and knowledge management to live streaming, After respecting security and privacy policies in place. The workflow proposed took on the contextualization and semantic annotations of data quality and significance by facilitating the automatic integration of functions for data providers to upload information to the visualization environment. This approach proved useful in that vital contributions to the analysis of meaning and the inference of knowledge are preserved with the provenance of the data and can be queried by subsequent users in order to inform future designs.

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