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Design Out of Necessity
Architectural Approach to Extreme Climatic Conditions

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Abstract

This paper is the culmination of the first phase of research in the development of adaptive surface conditions which can mitigate extreme climatic scenarios, specifically air pollution. How can the discipline of architecture address worst-case climate scenarios within inhabitable structures? The question asked throughout this case study and research project was essentially based on a critique of the architectural community's utilization of sustainable technologies in design, and whether current design initiatives were in fact aggressive enough in their approach to "green" building. While assessing the probable environmental changes likely to affect the architectural discipline in the future, this research project developed computational simulations of polluted atmospheres in order to develop surfaces which would respond formally.

Keywords: Adaptive; Behavioral; Responsive; Ecological; Generative

Introduction

In 2013, the Intergovernmental Panel on Climate Change released its fifth Assessment Report on the state of global climate change. Backed by evidence submitted by scientists and specialists from 195 countries, the fifth report opens with an Executive Summary outlining the environmental consequences of the exuberant consumption of post-industrialized society. A rapidly increasing global population, diminished natural resources, unsafe air and water, rising sea level and global temperature fluctuations are having a significant impact on the ecosystem. These conditions have reached a critical precipice where inaction, or delinquent progress toward curbing environmental changes, will have irreversible effects on the climate (IPCC, 2013).

Taking heed of the encroaching environmental crisis, it is vital that architects explore the conflicts and complexities of the future by embracing the synthesis of computational design and the natural world. Static and stagnant tendencies in architectural design processes are becoming increasingly obsolete in order to adapt to the ever changing needs of the built environment. Software tools are now able to simulate the dynamic attributes of environmental conditions and integrate this data continuously into design models. The constant feedback of information throughout each iteration allows for a reliable and robust work process. Computation in design has brought into question the effectiveness of current approaches and practices, in particular the profession's approach to climate change and the appropriateness of the popular term, "sustainability" in the context of design.

Design out of Necessity is a case-study examining how adaptive architectural design processes and advanced fabrication methods are best suited to counteract worst-case climate conditions. This paper focuses on research conducted in 2013-2014, beginning with a critical analysis of current approaches in green design within the context of climate change. Localized atmospheric conditions, specifically extreme air pollution, were highlighted during the first phase of this project and were utilized to illustrate computational techniques which produce environmentally adaptive structures. Though the study is still in its beginning stages; the first phase represented in this paper identifies approaches to adaptive design, specifically context-specific constraints, fabrication and assembly, material selection and life cycles. Formal research was conducted in order to test the synthesis of these topics and evaluate how they operate as a new approach to envelope design.

Sustainability in Context

The idea of sustainability, in regards to environmental policy, was coined in the mid-twentieth century as the necessary response to a rapidly changing environment directly impacted by industrial and ecological activities. Quickly adopted into use by the architecture and design community, the term bled into the public consciousness as an ideal approach to maintaining, and sustaining, modern society as it progressed toward a distant utopia. Yet nearly 60 years after the term grew into popular use, the profession is still grappling with meaning of sustainability (Steele, 1997).

The definition of what constitutes a sustainable and environmentally conscious product is a mutable notion. "[T]he concept of green building is a social construct. This is not to say that the range of environmental innovations are not valid—socially, commercially, or technically—in their own terms." (Guy & Farmer, 2001, p. 140). The dilemma lies in the magnitude of the issue, the increasingly dire projection for the future, and the sluggish advancements in design and planning that cannot keep pace with a progressive problem. What are the sustainable methods architects, planners, and builders will use to propel us into a future of ecological dynamism? Should the term "sustainability" be considered synonymous with "progressive", "enduring", or "adaptable"?

Nowhere in the current paradigm of *green* building is there a realistic discussion about what the climate and environment will look like in the coming decades or distant future. Design proposals that address the future of climate change often do not deal with the realistic climatic conditions that are likely to be present. The contemporary strategy of sustainable design assumes an optimistic outlook, with little consideration for the immense economic, environmental, and political hurdles that must be breached in order to make this outlook a reality. The discipline needs to examine and redefine the methodology behind green design and assess the potentially negative outcome if the existing inflexible approach is maintained.

Many preferred green building practices are not only unsustainable but also limited in the effect they will have on a broader scale by underemphasizing the possibility of future catastrophic environmental conditions (IPCC, 2013). An example can be seen in the long term effectiveness of a strategy such as passive ventilation versus the energy needed for mechanical ventilation. Passive ventilation is only effective under ideal environmental circumstances. The growing effects of air pollution create new conditions that fall outside of the parameters for which passive ventilation was engineered or designed. Natural ventilation is also lessened by the reduction of operable windows in urban contexts where noise and air quality are already active concerns. How can architects begin to integrate various environmental and energy concerns within a holistic, adaptable design solution?

The Effects of Air Pollution

While it is difficult to assess the toll environmental changes will have on future generations, air pollution has emerged as one of the most pressing challenges due to the immediate and visible effects it has on the population (Fussell and Kelly, 2011). Air pollution is a global problem; it is not stagnant, but circulates the atmosphere effecting both local and distant populations. Air pollution permeates the barrier between what is considered acceptable pollution, such as a refuse landfill which has a low degree of influence on a population, and unacceptable pollution, such as toxic drinking water which has acute effects on a population. Polluted air is everywhere, invisible, unrelenting, and often ignored.

The health impact of air pollution on populations was highlighted in 2010 by the World Health Organization's report, "WHO guidelines for indoor air quality: Selected Pollutants". In the report, attention was given to the adverse health effects manifested by exposure to particular chemicals present in indoor air. These chemicals, such as carbon monoxide, formaldehyde and nitrogen dioxide, are only a few of a number of toxic elements that remain unfiltered in many indoor environments**.** (WHO, 2010; Fussell and Kelly, 2011) Therefore, it is clear that the enclosures we rely on to protect us from invisible pollutants must be critically reviewed and better prepared to respond to this dynamic and complex variable (Klooster, 2009). To prevent acute breathing complications, among other health concerns, building envelopes should be equipped to handle varying levels and thresholds of pollutants over the course of the building lifespan.

There are few built contemporary architectural projects that respond to and counteract high levels of air pollution. The Torre de Especialidades at the Hospital Mauel Gea Gonzalez in Mexico City is a significant example. The project has influenced progress within the design and construction industry towards combating poor air quality through ecological design and smart engineering. Conceived by Allison Dring and Daniel Schwaag of the firm Elegant Embellishments and completed in 2013, the façade is comprised of modules with pollution-fighting technology. Elegant Embellishments developed the Prosolve 370e technology where the modules within the façade are coated with a layer of superfine titanium dioxide ($TiO2$) that effectively breaks down and neutralizes air pollutants, such as nitrogen oxides, when activated by ambient daylight. The integration of formal complexity, material development and finishing techniques has led to a design solution which responds to the specific constraints of place; in this case, the atmospheric conditions of Mexico City (Lovell, Bottger & von Borries, 2008).

Surface Ecology

To address atmospheric conditions, the context must first be recognized as an environment comprised of changing variables and extrinsic forces. Atmospheric forces, such as wind speed and air pressure, will act on a building surface over time from a variety of directions and at varying intensities. To respond to such a multiplicity of factors, the design process must engage with processes of feedback (Lynn, 1999). To this end, form finding design methods utilizing the self-organization of complex material systems test the intrinsic relationships between form, material, behaviour, and context. The focus of ecological relationships within architectural design can be traced back to Johann Wolfgang von Goethe's observations of how the material characteristics of plants are responsive to their environment (Goethe, 1790). The same principle informs the computational simulations of the case study.

It was important for the *Design out of Necessity* project to utilize the inherent logic of the natural world. The case-study experiments employed a software which could mimic the natural physical behaviours of air and atmosphere and could reliably simulate surface adaptation to test the behaviour of both the hypothetical material and particle. Using dynamic curves in Maya, a primitive surface geometry was defined. The geometry was dynamic in the fact that it could simulate physics and natural phenomenon. This aspect of the dynamic curve software was a critical factor in the project because it responded in a simulated environment in the same way a physical model would have responded in a built environment. The primitive, preliminary geometry was not bound to one static form but instead could respond to natural forces within its context over time.

With each iteration and unique set of contextual parameters, there was a change in the primitive geometry's formal silhouette (profile, definition, form, and shape). Due to the flexibility of the modelling software, a range of forces and conditions could be tested at varying intensities, both on the interior and exterior of the surface. Qualitative conditions were set to simulate particulate matter and gaseous chemicals.

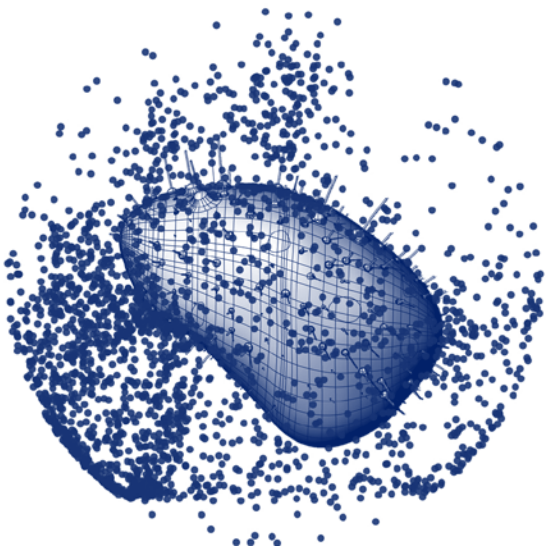

Figure 1: Qualitative particle simulation of air pollution.

As the study progressed, experimentation with surface textures was initiated utilizing rule-based definitions in the software to further test how the surface envelope could become more adaptive. These conditional statements embedded an additional level of adaptation and response between form and environment. The material thickness and surface texture of the form changed, or adapted, based on two variables: 1) the degree of curvature of the material wall and 2) the intensity of simulated particle bombardment against the surface. The scripted definitions applied to the surface area were determined by the ability of the surface to deflect, gather, or distribute the simulated particles. Surface area, texture, and porosity were the primary elements that could be fine-tuned in each iteration based on the contextual conditions. The texture manifested as a series of bumps and curve normals. These textures could act as a visual register or map demonstrating which areas on the form were most affected by the levels of simulated particle pollution. Higher levels of pollution caused a greater response from the envelope and resulted in a highly textured condition.

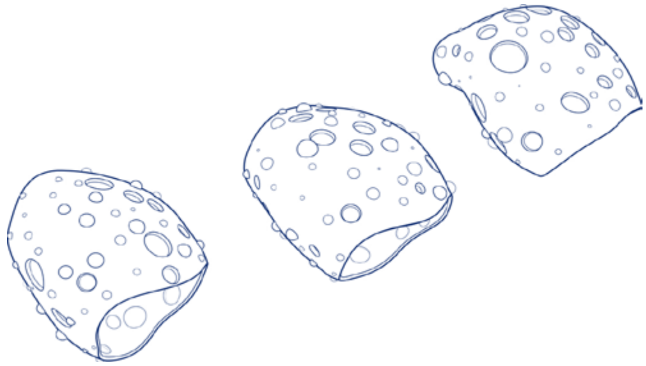

Figure 2: Texture studies on various surface iterations.

The scripted definitions applied to the surface iteration were the final element determining the mitigation of air pollution. Each type of iteration represented an ideal resultant form composed from the synthesis of material resistance, external forces, and intrinsic forces, creating a "smart" wall system.

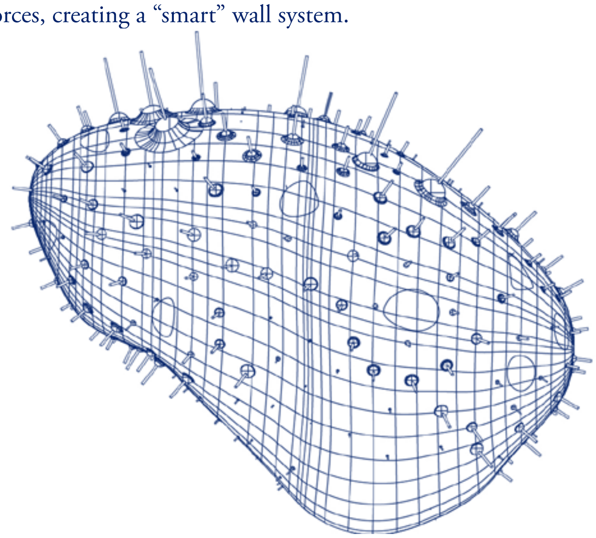

Figure 3: Side elevation of final primitive geometry.

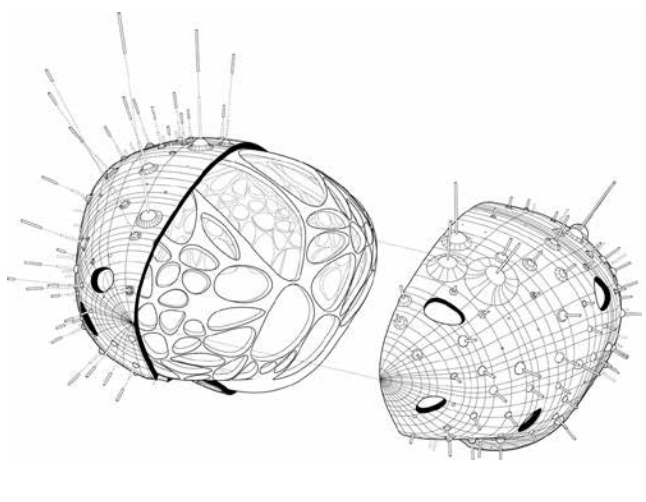

Figure 4: Exploded view of final primitive geometry.

Future development of the case study will begin by applying the methodology behind the surface refinement to a structure within an existing geographic location, specifically a traditional American suburban single family house typology. The dwelling will be retro-fitted with a new skin which will decelerate air movement around the structure and will also restrict the amount of air that comes in contact with the existing façade. This scenario will allow for quantitative performance testing of the exterior building envelope by implementing site specific environmental data. The comprehensive results will not only aid in the prototyping of full-scale surface panels but will also aid in the selection of materials for trial and will help determine the fabrication method of the final design.

The ultimate goal is to develop a building envelope capable of adapting and responding to varying levels of air pollution through an embedded material intelligence. Smart materials capable of responding to the passage of air and light will lead to structures which can self-reliantly acclimate to their surroundings.

Conclusion

In the spirit of Buckminster Fuller and the Dymaxion House, architects must seize current technologies and resources in order to push the paradigm of the profession into a new era of technological advancements. Fuller looked to the advancements of other industries as a direction for updating and replacing the house. Similar to a tool or instrument, buildings could also receive constant refinement as a result of continuous research and development, leading to the abandon of past styles (or the generation of new design). Buckminster Fuller's attempts to address technological advancements, social and economic change and dynamic environments through his design projects may not have been realized, but the precarious current conditions and uncertain future make it more appropriate to revisit the essence of his vision (Neder, 2008).

Although *Design out of Necessity* borders on the examination of science fiction, a worst-case climatic event, it will encourage a discussion and investigation into the realistic future of an architectural process. The current case study will be evaluated quantitatively in comparison with contemporary exterior enclosure systems and developed further through fabricated assemblies. With extensive testing and with the integration of new materials, the possibility of addressing worst-case air pollution can be realized by retro-fitting existing buildings with adaptive outer layers. The project overall addresses the need for a re-examination of the dialogue between architects, students and professionals, as to the viability of sustainable proposals which assume an idealistic collaboration between government, public and private sectors. In contrast to sustainable design, strategies rooted in adaptability and longevity aggressively challenge the effects of climate change by emphasizing the conservation of materials and the importance of being prepared for worst-case conditions.

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