Translating ecological systems models into generative, real-time, form-based visualizations

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ABSTRACT: This paper outlines a new methodology for generating and representing site driven biogeochemical forces as dynamic formmakers utilizing Grasshopper 3DM, and its plugin Kangaroo, as translators of ecological systems models (ESM's) into parametric modeling protocols. It also discusses the critical nature of communicating the impacts of these dynamic forces in human cone-of-vision perspectival visualizations that are legible to designers, scientists, and the general public so that they may be utilized as part of larger planning decision making processes.

Within today's context of anthropogenically driven climate change architects cannot ignore the increasingly dynamic environmental conditions on our sites, and those forces extending out from our sites that produce effects at scales from local to global. ESM's are highly useful tools that communicate relationships between stocks and flows of energy and materials through time. Multi-scalar, complex ecologies have been successfully modeled and quantified utilizing this methodology since the 1950's resulting in a new discipline within ecology and critical new understandings of the pathways through which resources organize, flow, and ultimately generate and maintain systems. This understanding of how systems are structured and function (Archer 1994) often determines their form; however, ESM's are not spatially explicit, rendering them problematic tools to incorporate into our spatially explicit processes and products. Because Grasshopper 3DM's programming language syntax has reciprocity with the syntax of ESM's, these models can be translated relatively straightforwardly by partitioning natural and anthropogenic processes into operational strata. This strata structure establishes a framework into which systems models from various disciplines and of various scales can be translated including: ecology, hydrology, oceanography, geology, biochemistry, landscape architecture and architecture, while simultaneously facilitating communication between the disciplines necessary for successful generation and calibration of the model, and ultimately the designed site intervention itself.

KEYWORDS: Ecological systems models, parametric modeling, visualization of dynamic landscapes

INTRODUCTION

1.0. The Built Environment in the Dynamic Landscape

In places such as the Southern Louisiana Delta, where landscape change previously experienced at a geologic pace is now experienced in a generation, architects can no longer conceive of sites as static conditions on which to place buildings that primarily deal with gravitational and envelope loads. Because built and natural systems behave as one system across the surface of the lithosphere, both the natural and manmade factors that influence coastal development must be considered in tandem as critical components of planning decision-making processes. Coastal development in the Gulf is subject to powerful natural forces that are largely beyond human control, so an understanding of the potential behaviors of these forces can facilitate more accurate projections; hence, design that is sympathetic to the weathering of anthropocentrically re-structured environments. Therefore, we must find new methodologies for understanding, representing, and designing with diversified yet site specific dynamic forces that effect how the built environment mitigates, adapts to, and modifies today's increasingly dynamic environmental loads.

Coastal Louisiana's current land loss crisis is a result of the interaction between human resource extraction, human settlement patterns, and dynamic natural forces, many of which are largely invisible within planning scales of space and time. Recently, in response to dire future predictions, communities have started to question the sustainability of their long-term planning strategies, to challenge their understanding of habitation on fast changing wetland ground, and to explore more resilient options. An understanding of how ecological systems are structured and function (Archer 1994) often determines natural form, and the weathering of the built environments within them; hence, it behooves us to increasingly incorporate them as critical components of the design processes of buildings and infrastructures sited within dynamic geographies. Critical to the re-disciplining of architectural practice, this has led us to develop a new methodology for representing and calibrating site driven biogeochemical forces as dynamic formmakers utilizing Google Earth, Rhino, Grasshopper 3DM, Kangaroo, and Photoshop.

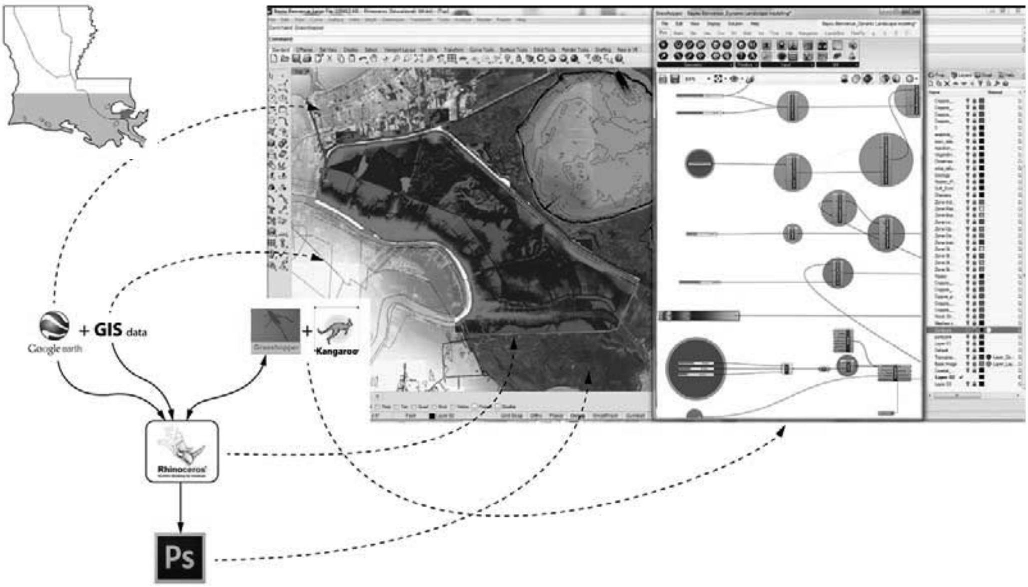

Figure 1*: depicts the methodology workflow which utilizes data from Google Earth and GIS to construct base topographies in Rhino that are then subjected to dynamic forces and quantification through Grasshopper 3DM and, its plug-in Kangaroo. Still images from the model may be brought into Photoshop for post-processing, in order to generate photorealistic renderings that incorporate existing site conditions and communicate look and feel within the modelled landscape, which can be viewed in plan, section, axon or perspective. Above, the Grasshopper 3DM definition is manipulating and displaying water levels in the Central Wetlands Unit in New Orleans, Louisiana. Source: (Rodriguez 2013)*

1.1. Modelling Environments of Ecologies

Grasshopper 3DM's programming language syntax has reciprocity with the syntax of ESM's in that Grasshopper's dynamic programming definitions are comprised of parameters, components, and connections which are structured similarly to the symbols and flows of the *Energese Generic Systems Symbols* language developed by Howard Odum in the 1950's (Odum et al. 2000). Grasshopper 3DM's interface requires that parameters and components, which are similar to Energese symbols, are created on a blank canvas and connected by workflow connectors, which are similar to Energese flow arrows. A series of Grasshopper 3DM definitions appear strikingly similar to ESM's in terms of their visual structure and organization. This syntactical reciprocity facilitates a more straightforward translation of existing ESM content and structure into Grasshopper 3DM's language, particularly for designers who are visually acute.

The next step is to translate ESM's into parametric definitions that drive Grasshopper 3DM's outputs. We have found that through the translation of existing ESM's, via functional regrouping and partitioning operations, into natural and anthropogenic processes (we have identified five operational strata specifically), at a range of scales from intra-ecosystem, inter-ecosystem, to whole biosphere functional levels, the accurate translation of the ESM is possible. The five operational strata developed are: astrodynamic (planet-scale), terradynamic (biogeochemical landshaft function), anthrodynamic (human influences), hydrodynamic (biogeochemical hydrological function), and aerodynamic (biogeochemical atmospheric function). This strata structure establishes a framework into which ESM's from various disciplines and of various scales can be effectively reorganized for input into Grasshopper 3DM.

This paper details the preliminary model building methodology developed over a summer at Louisiana State University. By imputing existing topographic and 2012 Master Plan data from the Central Wetlands Unit in New Orleans, Louisiana as a baseline, and utilizing it to generate performative meshes that evolve in response to physics and agent-based commands such as charges, pulls, and fields we can manipulate the output form parametrically. Model calibration is facilitated by natural system parameter ranges of inputs that are derived from measured behaviors (from scientific data), and quantified and controlled primarily by toggles, sliders, and gradients within the Grasshopper 3DM/Kangaroo/Rhino interface. Through the manipulation of these toggles and sliders, landscape form is modified in real-time renderings which facilitate predictive modeling across continuums of time. Research has shown that visualizations which combine GIS data, sketching/rendering, and photorealistic depictions of planning scenarios are more effective at facilitating a "…common language to which all participants technical and nontechnical can relate…" (Al-Kodmany 1999, 38) thereby resulting in the building of consensus, more access to local knowledge, and ultimately a more informed and appropriate design and planning process. This dynamic four-dimensional visualization and design tool is so critically needed today because designers and communities must be empowered to make increasingly complicated planning decisions in the face the dramatic and unpredictable circumstances driven by climate change and land loss.

1.0. LEVERAGING THE AGENCY OF ECOLOGICAL SYSTEMS MODELS

Over the last 70 years, the earth sciences have fragmented into two philosophical camps. The reductionists trended toward an increasingly disciplinary pursuit of knowledge which has resulted in the generation of numerous specific models and platforms corresponding to the specific expertise and discourse of each discipline, which track specific behaviors within larger ecosystems. These models are quantitative and often not output visually. This has resulted in a fragmented body of Earth Science knowledge that can prove somewhat illegible, even to other earth scientists in related fields, let alone designers and the lay people who inhabit the environments being modeled. Simultaneously, integrative, multi-scalar, complex ecologies have been successfully modeled and quantified utilizing ESM's, resulting in a new discipline within ecology and critical new understandings of the pathways through which resources organize, flow, and ultimately generate and maintain systems. The father of the discipline of ecological systems modeling, Howard T. Odum, developed and describes optimal organizations of whole systems, and the interactions of their components, as systems diagrams. These diagrams organize complexity via a language that

> …should follow naturally from verbal thinking while showing system structure, processes, and flows. A systems diagram should help the mind visualize relationships and infer system behavior from the configurations…[of] energy or material flows. (Odum 2007, 25).

ESM's assist in the understanding of conditions that affect the physical environment, and are excellent tools for testing relationships between system structure, function, and the resulting evolving behaviors. They often inherently link scales from local to global which can prove difficult in design, facilitating the study of complex ecosystems which "by definition…cannot be understood by study at one scale." (Odum 2007, 167) This type of understanding is critical for sustainable and resilient design processes.

The other critical ecological understanding for designers is the disturbance regime. Disturbance regimes, which can be dramatic events like storms, or slow steady processes such as land loss, can stress stable ecosystems, and often render human habitation challenging. While these regimes may have predictable patterns, in recent years scientists have recorded increasingly unpredictable behaviors now attributed to global climate change. Walker et al. identify and describe catalysts of uncertainty, as:

> "1. Key drivers, such as climate and technological change [that] are unpredictable. Many change nonlinearly, 2. Human action in response to forecasts is reflexive. If important ecological or economic predictions are taken seriously, people will react in ways that will change the future, and perhaps cause the predictions to be incorrect, 3. The system may change faster than the forecasting models can be recalibrated, particularly during turbulent periods of transition, so forecasts are most unreliable in precisely the situations where they are most wanted." (Walker et al. 2002, 14)

Because of the variability associated with uncertainty, scenario building becomes a critical tool for ecologists to conceptualize coupled human-natural systems, which can also be employed by planners in the forecasting of future environmental conditions (Peterson et al. 2003). Details of the relationship between planning and scenario building will be discussed in more detail in the "VISUALIZATION FOR PLANNING" and "CONCLUSION" sections. Here it is critical to note that ecology and ESM's facilitate the inclusion of uncertainty in addition to the behaviors of flows of energy (in particular) and materials through time.

While very effective at taking snapshots of a whole system through time, ESM's are not necessarily spatially explicit, in that they do not accurately represent adjacencies, distances, and scales, which can make them difficult to incorporate into the design process. Nonetheless, they are an important tool to facilitate communication between designers, planners and natural scientists, because they reveal relationships between energy and material flows visually, relationships that designers often do not consider.

2.0. MODELING METHODOLOGY

For us, in order to model the physical behaviors that drive dynamic forces in spatial and temporal continuity, it was first necessary to investigate the behaviors of natural dynamic forces and their resulting processes, which was greatly facilitated by studying ESM's of our test geography: the Central Wetlands Unit in New Orleans, Louisiana. Despite the fact that ESM's are designed to facilitate communication, we found we needed to develop a framework to facilitate the translation of the models into a more intuitive understanding of ESM's for designers, who may not have a comfort level working with their structures, functions, and the scientific nomenclature developed to notate these relationships.

2.1.1. Operational Strata Modelling Framework

We have created a programming protocol of organizing guilds (functionally related constituents) and pathways. Pathways connect individual units or whole guilds, together via transfers of energy which may contain or not contain materials. (Odum 2007, 15). Ecological Guilds are defined as a "…group of species that exploit the same resources, often in related ways." (Simberloff and Dayan 1991, 115) We are not using Guilds in their strict ecological definition, but adapting this system of grouping related units that perform as a whole, which we have defined as five *operational strata*: astrodynamic, terradynamic, anthrodynamic, hydrodynamic, and aerodynamic. This strata structure establishes a framework into which systems models from various disciplines and of various scales can be translated spatially including: ecology, hydrology, oceanography, geology, biochemistry, landscape architecture and architecture, but also facilitates communication between the disciplines necessary for successful generation and calibration of the model. In this way, we facilitate ease of programming of natural processes by designers, who may not have extensive prior knowledge of these systems, i.e.: designers can locate pre-existing ESM's for specific ecologies, and plug them into our modeling protocol.

2.1.2. Astrodynamics (planet-scale)

Astrodynamics facilitate the programming of forces that affect a site that exist at the planetary scale such as the sun's relationship to the surface of the earth (sun angles/solar radiation/seasonal change), the moon's relationship to large water bodies (tides), etc. Astrodynamics are critical for the modelling of change through time and primary production (plant growth).

2.1.3. Terradynamics (biogeochemical landshaft function)

Terradynamics facilitate the programming of land-based processes such as geology, soil formation, subsidence, pollution, etc. Terradynamics are the formmaking processes that determine the shape of land through time.

2.1.4. Hydrodynamic (biogeochemical hydrological function)

Hydrodynamics facilitate the programming of water-based processes such as wave action, erosion, deposition, pollution, etc. Hydrodynamics are critical for the creation of the complex configuration and behaviours of confined (protected areas behind levees) and unconfined (wetland) hydrological units, and land-formmaking processes as the land-water interface.

2.1.5. Aerodynamic (biogeochemical atmospheric function)

Aerodynamics facilitate the programming of atmospheric processes such as wind, weather, pollution, etc. Aerodynamics influence the programming of storm surge, precipitation, pollution, etc.

2.1.6. Anthrodynamic (human drivers)

Anthrodynamics facilitate the programming of human driven factors that affect the environment such as settlement patterns, resource extraction, waste disposal, etc. In our test geography, Anthrodynamics are critical for the programming of levee building and other hardscape modifications to Terradynamics and Hydrodynamics that influence land-formmaking through time.

2.2. Modelling Software Workflow

Through the utilization of the State of Louisiana 2012 Coastal Master Plan Project List, site visits, and Google Earth, our test geography was scoped and defined. Once relevant ESM models were identified, they were translated through the operational strata in order to extract their prevalent structural and functional characteristics. This determined not only that three of the five Operational Strata would be deployed (terradynamics, hydrodynamics, and anthrodynamics) to organize the Central Wetlands Unit at the meta-scale, but also the necessary data to be captured from Google Earth, GIS, and scientific papers. This data was then translated into a Rhino base topographical surface projection of the areas being studied (terradynamics). This base layer evolved through the construction and application of topo-surfaces (meshes), subsidence/erosion/deposition, surface visualization layers, and soil depth, and became the 3-D space on which functions of time and natural forces (including gravitational forces, etc.) were then applied via programmed Grasshopper 3DM parametric modeling protocols and definitions and the plugin Kangaroo physics. Kangaroo is a Live Physics engine for interactive simulation, optimization, and form-finding that allowed us to generate geometries that change through time, according to the physical behaviors of the material properties of the ecosystem and the human interventions within it. The visualization produced by Kangaroo allowed us to modify inputs based on actual parameters and feedbacks, and automatically calibrated the behaviors of the forces to produce animated visualizations of the resulting changes in the landscape.

On top of the terradynamics, we overlaid anthrodynamics which included levee building and built hardscape modifications. On top of the more solid hybrid system of terra-anthrodynamics, hydrodynamics were overlaid, which included the creation of confined (protected areas inside levees) and unconfined (wetland) hydrological units, and formmaking processes at the land-water interface (see figure 2).

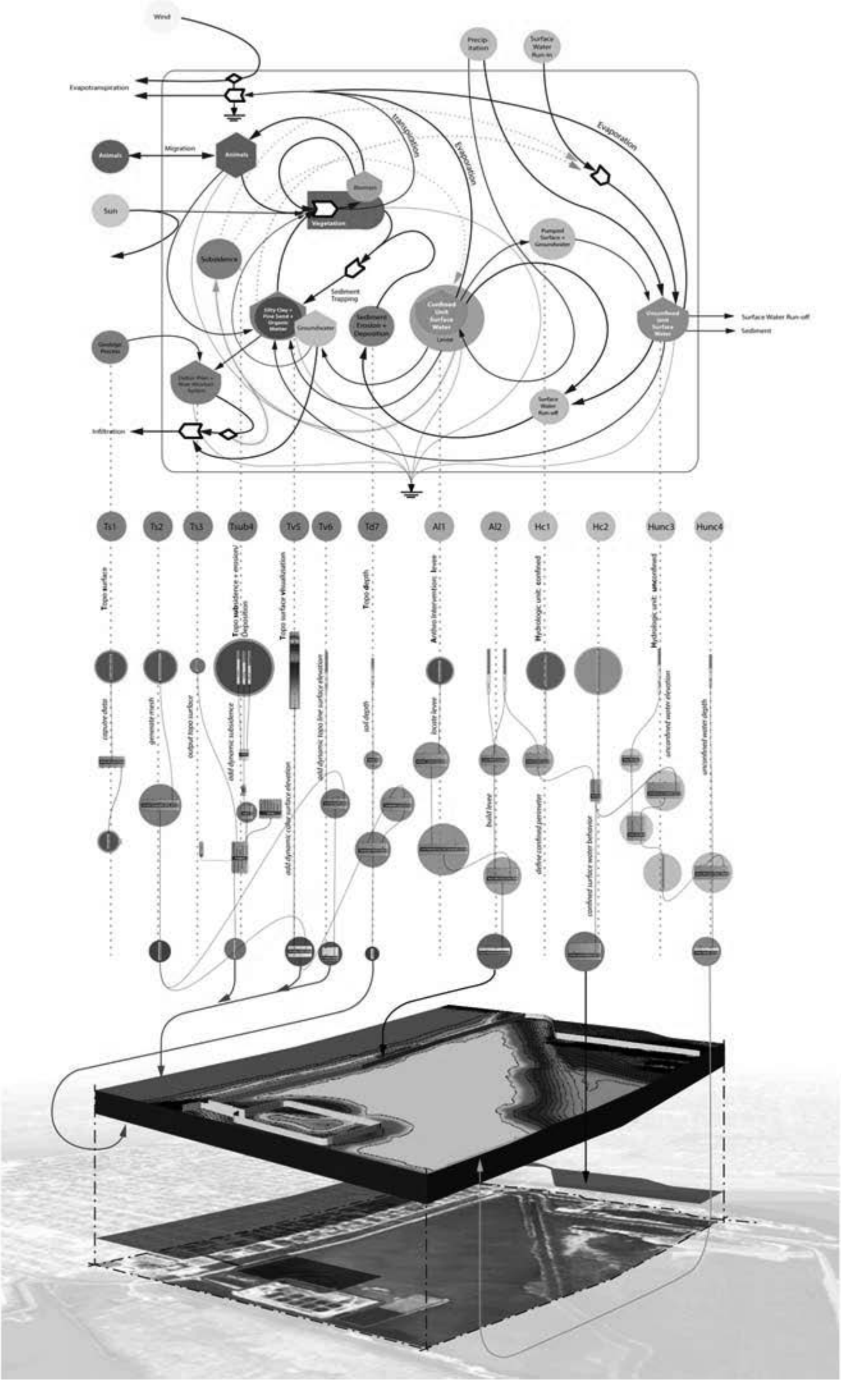

Figure 2: *the construction of site through the synthesis of coupled human-natural systems. Working from the top down, first is the ESM, which is translated next to the modelling script. Below that are the Grasshopper 3DM definitions, which create the visualized dynamic landshaft at the bottom. Central Wetlands Unit and Bayou Bienvenue, New Orleans with terradynamic, hydrodynamic, and anthrodynamic forms mapped. Source: (Rodriguez 2013)*

3.0. RESULTS

Our preliminary results show that it is possible to successfully model coupled human-natural components of larger ecological systems according to the methodology described above. In addition, through a second round of "streamlining" modeling we were able to strategically manipulate the code to increase efficiency and workability as we learned about tool limitations. We found scalar linking and bracketing to be difficult in the translation of ESM's into landscape forms at varieties of scales. Ultimately, we had two different models of the Central Wetlands Unit, one smaller and at a finer resolution than the other in order calibrate file sizes with computing power limitations. In the end, we found that multiple models of the same geography at different scales assisted model calibration.

We were heavily reliant on plugins for Grasshopper 3DM, primarily Kangaroo, to successfully model many of the more sophisticated physical processes that require gravity, etc. We found that some forces/behaviours are significantly more straightforward to model than others. We are still working to resolve the successful modeling of aerodynamics, water velocity, suspended sediment deposition, and other ecological drivers governed by fluid dynamics. At this time there is not an effective fluid dynamics plugin.

Ultimately, the 3-D quality of the model allowed us to explore the results in different scales, views and cuts, including plan, section, axonometric, and perspective. We also have the ability to represent data with multiple graphic conventions, according to the type of data, scale, and other visualization opportunities including: color, gradient, lineweight, etc. Such a variety of view outputs are not possible outputs in most scientific modeling packages today.

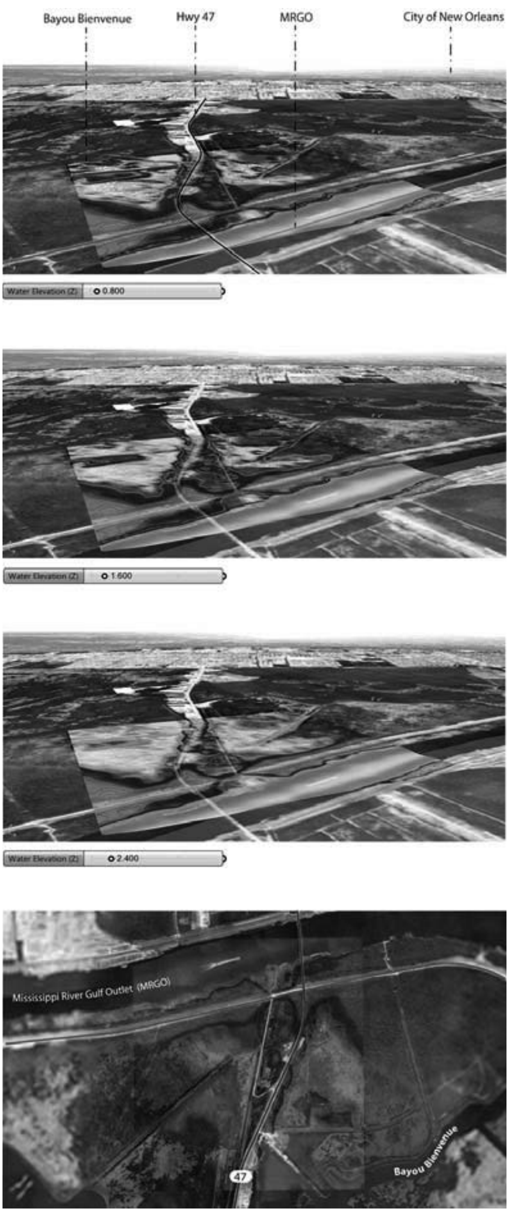

***Figure 3**: The effects of 8" interval water level change on land and plant growth potential. Central Wetlands Unit and Bayou Bienvenue, New Orleans. Source: (Rodriguez 2013)*

4.0. VISUALIZATION FOR PLANNING

> "Traditional planning is frequently based upon the belief that the application of professional expertise to achieve well-defined goals will ensure efficient and effective management. However, such plans often fail to consider the variety of local conditions or the propensity for novel situations to create extraordinary surprises (Scott 1998). This blindness to variety and surprise, which is often accompanied by a false certainty about the efficacy of management, can lead to costly failures (Holling & Meffe 1996)." (Peterson et al. 2003, 359)

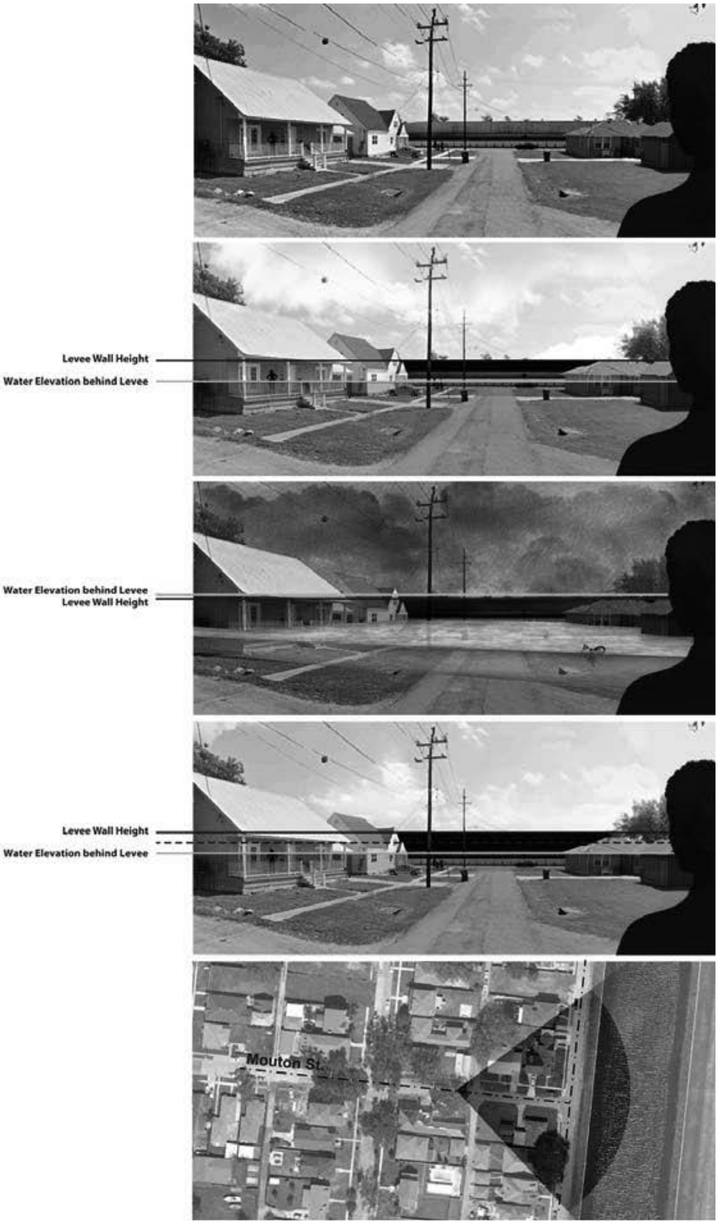

***Figure 4**: A perspectival view depicting the water level on the opposite side of a residential neighborhood levee, and the process of overtopping. Source: (Rodriguez 2013)*

In 2005, during Hurricane Katrina, the levee that separated the 9th Ward in New Orleans from the Central Wetlands Unit / Bayou Bienvenue failed, sending tons of high velocity water into a residential neighborhood, at the expense of lives and property. That levee failure is dramatic evidence of the costly false certainty cited above. We hypothesize that risk is more clearly understood when it is visualized. Only then does it has the potential to operate as a critical informational tool in design and communication necessary for our evolving understanding of the effects anthrodynamic interventions into dynamic environments subject to increasing rates of climate change.

These visualizations are particularly critical in facilitating more effective and integrated public planning processes, particularly those that team specialists from diverse disciplines with local residents. The ability to depict the impacts of largely invisible yet incredibly dynamic forces through human cone-of-vision perspectival images is particularly critical. By placing the human eye into the viewport of the image, perspectives mimic how we perceive and navigate the world daily, and are hence more legible to designers, scientists, and particularly the general public. Historically, much planning work is done utilizing plan drawings, which are often read abstractly by policy makers and community members. We believe that perspectival images, which can be generated by Rhino models, may be utilized more effectively as part of larger planning decision making processes.

CONCLUSION

5.0. Architectural Implications of the Operational Strata and Methodology Deployment

In architecture, nested scalar relationships and the fourth dimension have historically proven difficult to incorporate into visualizations, and therefore, ultimately the design process. The five Operational Strata facilitate the programming of biogeochemical ecological systems into dynamic forms. They also structure spatial-scalar hierarchy, and facilitate a seamless continuum between past, present, and possible future site conditions through the synthesis of coupled anthropogenic-natural forces in a manner more congruous to their operation across the surface of planet. Through the visualization and communication of a myriad of forces previously less legible to designers, architectures and infrastructures have the capacity to be designed and tested against site forces in new and innovative ways that are more native to the designer. Again, through the multiple scenario modelling and visualization process, weak links between constructed environments and the dynamic forces that play upon them become evident and available topics for further architectural research.

Currently, the role of risk mitigation, in the form of designing and sizing architectural and infrastructural components for pre-determined acceptable levels of risk, is typically relegated to engineers. As architects, we can increasingly take back this scope of services, through a deeper understanding of site forces facilitated by the methodology, we have an increased potential to successfully design softer and more integrated approaches to risk management. Hence, we have the potential to further influence sustainable design strategies and assessment frameworks that currently tout their effectiveness primarily through the *reduction* of material and energetic environmental inputs without satisfactorily linking those reductions to ultimate global environmental performance. Through the integration of multiple sets of disciplinary knowledge, the Operational Strata have the potential to frame a more sophisticated understanding of sustainable and resilient performance of hybrid human-nature environments through time and at multiple scales which is so critical to the synchronization of the built environment with natural environmental forces.

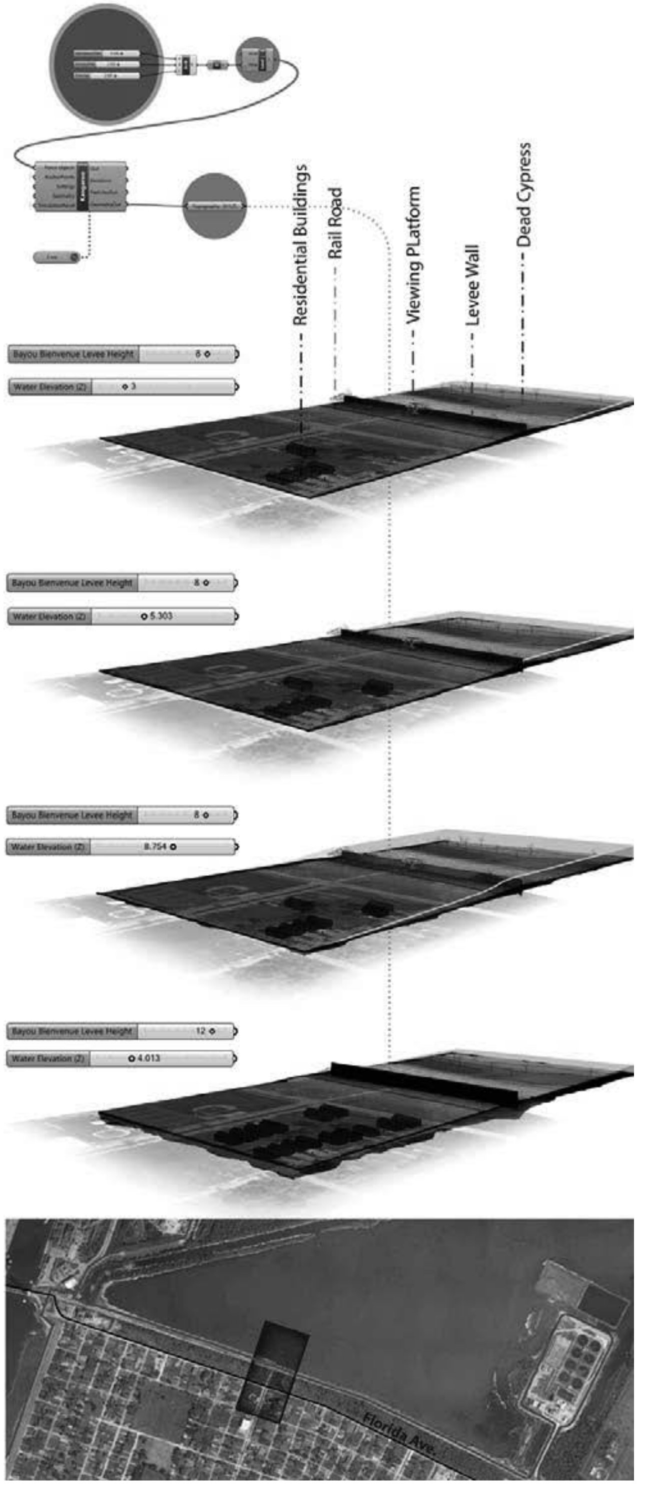

***Figure 5**: Depiction of the dynamic behaviors of settlement patterns, sea level rise, storm surge and subsidence at the levee which separates the 9th Ward from the Central Wetlands Unit/Bayou Bienvenue, New Orleans. Source: (Rodriguez 2013)*

Ecologically responsive architectures that result in built environments that respond to natural forces, rather than resist them, in the end will prove to be the most resilient and sustainable solutions. Perhaps the significance of this modeling methodology's potential is stated most succinctly and poetically by Master Po in Season 1 of the 1970's television series Kung Fu: to paraphrase,

> In a heart that is one with nature, though the (building) body contends, there is no violence. And in the heart that is not one with nature, though the (building) body be at rest, there is always violence.
> (Master Po to Kwai Chang Caine (otherwise known as Grasshopper!) in Kung Fu TV show Season 1, 1972)

5.1. Applications to Scientific Research

In addition to visualization for design and planning purposes, our methodology may also further scientific research through the facilitation of communication between diverse scientific disciplines and the visualization of multiple scenarios:

> Some paths of domestication will result in improved ecosystems both for people and for other species; other paths of domestication will result in ecosystems that are clearly better for humans but not for other species; and some paths of domestication will result in ecosystems that are too degraded to benefit people or other species. The key scientific goals for the study of domesticated nature are to understand what tradeoffs exist between the promotion or selection of different ecosystem services and to determine to what extent we can change a negative tradeoff to a positive one by altering the details of our domestication process (see Fig. 3). With this understanding will come a science of nature domestication that might guide human activities to minimize the negative aspects and accentuate the human benefits…A second possibility would entail an examination of tradeoffs, perhaps even switches to alternative ecosystem states after some threshold is crossed. Tradeoffs are most likely to create problems when they occur as an abrupt change, with little warning. Because managers and researchers have tended to focus on impacts rather than tradeoffs, there has been no systematic examination of tradeoffs in a way that leads to a useful theory. Without a solid understanding of tradeoffs among ecosystem services, we can expect conservationists to rely on protecting nature from people as the primary form of stewardship. (Kareiva 2007, 1869).

5.2. Applications to Sustainable Development Planning Processes

As previously mentioned, the methodology's greatest impact may be through the facilitation of sustainable development planning processes. By merging interdisciplinary knowledge through the modelling and communication tool of the ESM, and visualizing the resultant forms, multiple scenarios can be effectively vetted by all planning process constituents thereby revolutionizing the community-based planning process. Peterson et al. have identified six interacting stages of planning that can be explored through series of workshops / charrettes:

> 1. Identification of a Focal Issue, 2. Assessment, 3. Identification of Alternatives, 4. Building Scenarios, 5. Testing Scenarios, and 6. Policy Screening (Peterson et al. 2003, 360-2)

Our methodology seamlessly facilitates these first 5 stages in order to ease transitions toward more performative environments that enhance human welfare in the face of climate change. Sustainable development in the delta relies on striking an integrated balance between natural systems, human needs (resources), technological advancement, and scientific knowledge. As we continue to adapt and create more functional systems for risk reduction and restoration for sustainable coastal development we advance and refine methodologies, including this new methodology of visualization, which may be integral to the development of better planning and design strategies. Our visualizations may facilitate a better understanding of human relationships to the environment's dynamic processes in as society that is eager to explore sustainability and resiliency. By defining a better methodology for the visualization and communication of Louisiana's dynamic landscape, and the anthropogenic processes that are so integral to this managed environment, we further our understanding, challenge the way we visualize the future impacts of our actions, and plan for a more sustainable future.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support of the State of Louisiana Board of Regents, the Gulf of Mexico Research Initiative 2013 Summer Research Program, and the Louisiana State University Schools of Architecture and Landscape Architecture. The authors wish to thank David Merlin, John Mouton, Andy Nyman, Carol Wicks, Andrew Tweel, David Morgan, Matthew Siebert, and Bradley Cantrell. This paper was presented at the 2014 ARCC Spring Research Conference. The contribution of the current and previous ARCC conference organizers and committees is hereby gratefully acknowledged.

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