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Computational Modeling for Climate Change: Three-Dimensional CAD Visualization of Coastal Storm Impacts on Shoreline Erosion

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Abstract. This research describes the creation of a quantitative three-dimensional visual modeling workflow to simulate the impact of sea level rise and coastal erosion on storm surge and inundation. Using GIS data, Photoshop software, and CAD 3D modeling and animation software with particle fluid simulation, the researchers were able to simulate erosion, dynamic waves, and sea level rise, visualizing the impacts these climate-related events would have on human habitation and ecosystem biodiversity. Aspects of the impact on visualization simulations on human perception of climate change are discussed, with a focus on the utility of this research specifically to design professionals. The benefit of this workflow is shown by creating visual animations of coastal storm events interacting with sections of digital coastline terrain, accompanied by an analysis of the level of disturbance which could occur. The outcome is a preliminary workflow which demonstrates that the complexity of interrelated natural and man-made forces can be simulated in 3D using both standard and emerging computer-aided design tools.

Keywords: landscape, CAD, GIS, modelling, animation, geospatial, algorithm, erosion, climate, ecology
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1 INTRODUCTION

Computational modeling for climate change necessarily requires the participation of landscape architects, yet the discipline of landscape architecture does not currently have a satisfactory set of software tools to address the unpredictable parameters of coastal flux and sea level rise. When functioning at its highest level, design software enables the rapid site analysis of existing conditions, allowing the designer to execute design ideas with ease. Between these two stages of analysis and design, the landscape architect works to understand the natural forces that may act upon the design site at any point in the future and respond accordingly with an adaptive design strategy. The complexity and uncertainty of climate change has multiplied the factors which the landscape architect must attempt to analyze, thus necessitating the development of new workflows which meet this 21st-century challenge.

This project involves the creation of a workflow intended to simulate coastal conditions using 3D modeling and geographic information system (GIS) software, in an effort to develop new methods of accurately simulating interrelated natural phenomena. These phenomena – including wind, erosion, water movement, and the spread of vegetation – can generally be understood as acting within a range of natural variation and predictability [6]. Yet when combined as an ecological system, they may dynamically interact in ways that elude digital capture and simulation.

1.1 The Need for New Software Workflows

Twenty-first century landscape architects face challenges of enormous complexity that demand increasingly sophisticated software workflows. Rising population density in coastal areas, coupled with an imperative to design resilient landscapes which can tolerate extreme weather events, requires adaptation of traditional design processes [9]. This adaptation necessitates technology which can quickly respond to complex parameters and illustrate their potential outcomes in visually meaningful ways which can then be interpreted by designers. Considering the large number of variables and algorithms embedded in the behavior of coastal ecological systems, a single software application is unlikely to capture their behavior in its entirety. Rather, a digital workflow is needed for these tasks, a series of digital processes which passes information from one piece of software to another in a prescribed manner.

Digital media in landscape architecture has historically provided computer-aided design (CAD) workflows which establish formal elements within the design such as spatial dimensions, materials, and quantities. 3D modelling software has augmented this process and enabled further rapid iteration of spatial design ideas. The introduction of GIS software has broadened the CAD workflow to include geospatial aspects; currently, there is a strong and established workflow interoperability between CAD and GIS software [5]. This interoperability facilitates analysis of existing conditions as well as testing of three-dimensional design ideas, for example performing a viewshed obstruction analysis with ESRI's Spatial Analyst. Landscape architects also now have access to tools which enable reconstruction of terrain from LiDar and aerial imagery. These tools enable us to document existing site conditions and test very simple design interventions to understand their impact from a visual perspective.

However, 3D modeling software for spatial designers is most commonly geared towards architects, with landscape architects adopting this software for their needs. This is largely due to the comparative size of the landscape architecture profession, which is a significantly smaller market share than that of architecture. According to the 2016 Survey of Architectural Registration Boards, there are 109,748 architects in the United States; in that same year the U.S. Department of Labor identified 24,700 employees in the landscape architecture field. In addition to the comparative size of these two professions may be a significant factor in the focus of commercial software development on architecture. An additional reason why 3D modeling software does not adequately represent the needs of landscape architects may be the inherent complexity and breadth of the natural environment. Landscape architects model sites of significant physical size, with high levels of differentiation and variation in surfacing, materials, and form. Landscapes are naturally dynamic, with design implementation and maturation which can take decades. It stands to reason that 3D modeling software is not currently suited to enable adequate representation of the characteristics that landscape architects seek to model. This territory is often taken up through adapting software intended for modeling specific natural assets for CGI animation in film and video game design. Examples include SpeedTree, an industry standard tool for creating realistic trees and plants, and Terragen, software used to create large-scale photorealistic natural environments. In recent years many landscape architects have begun using Lumion, a real-time renderer which integrates with most 3D modeling software and has a large and accessible library of trees and other vegetation.

1.2 Advances in Digital Simulation

Advances in three-dimensional simulation have focused on modeling the flow of water on terrain. Work in digitally simulating riverine flows has produced valuable ideas regarding robotically controlled computation infrastructure to manage sedimentation [3]. Other research uses engineering software to simulate riverine water flow using geospatial analysis, computational fluid dynamics, and parametric software, providing output which has expanded the designer's ability to guide natural processes that are difficult to detect through immediate observation [7]. Landscape architecture firms have also contributed to this arena through the design and visualization of projects which address climate change and coastal sea level rise, often producing powerful graphics. One project, Oyster-tecture by SCAPE, addresses rising coastal waters in urban areas through aquaculture. According to the SCAPE website: "envisions an active oyster reef that diversifies aqueous marine life and recreational potential in the New York Harbor. The project was commissioned by the Museum of Modern Art in 2009 for the Rising Currents exhibition, an initiative to develop adaptation strategies for New York City in the face of climate change and sea level rise." Another project, Arverne by Balmori Associates, aims to address rising tides through the recreation and protection of dunes. According to Balmori's website, the project's is described as follows: "Water drainage becomes the leitmotif for its reinvention. Even its dunes, nearly destroyed by misuse, have to be recreated and protected. The houses were placed on stilts facing the street with only a garage at the ground level. At their backs, they were lined up along a swale (or small stream) that filtered and drained gray water, as well as any flood water, from the site. These swales were used as backdoor public gardens (in addition to their drainage function). They vary in length and planting throughout the seasons."

Technical advances in LiDAR and Photogrammetry capture workflows and devices, including unmanned aerial vehicles (UAVs) and submersible capture devices have enabled higher precision of digitally-captured environmental data. Using UAVs to derive points from vegetation canopy and integrating it with GPS field surveys, it is now feasible to map terrain which us under dense vegetation canopy. This provides a solid technique for using UAVs to perform topographic mapping in coastal areas which are located underneath dense vegetation [10]. LiDAR remote sensing from aircraft enable high-definition digital mapping of low-lying areas which are susceptible to sea level rise, and can enable the capture and assessment of geomorphic change along barrier islands or other sandy coastal areas resulting from long-term sedimentary processes or short-term storm events [2]. These tools can provide dynamic, evolving data sets of high accuracy, and are less susceptible to errors which occur due to inherent limitations of capture methods used in fixed datasets.

Design clients – especially cities and towns - are increasingly demanding evidence of design performance outcomes in the form of digital simulations, which have historically been the territory of engineers. However, landscape architects will need to develop their own processes to overcome software shortcomings that do not address the complexity and irregularity of landscape geometry or the agency and flux of the natural systems where interventions will be applied. Research has shown a crucial need to position digitally proficient designers at the outset of a project to address these factors, creating 'toolmakers' who enable software proficiency to inform all stages of the landscape design process [17]. Some computational design researchers have begun to address this territory, developing algorithms that emulate and visualize the behavior of natural systems. An early precedent is The Algorithmic Beauty of Plants, which presents fractal assembly methods that effectively simulate plant growth and variation [13]. More recently, several volumes mark significant increases in application of this knowledge. The Nature of Code provides a framework for software simulation of natural forces such as gravity, friction, and velocity, enabling the designer to visually program these elements and understand how they act upon a three-dimensional field using Processing [14]. Generative Art, a book on creative workflows, covers methods of visualizing fractals, growth, and emergent properties of groups of organisms [12]. And in Dynamic Patterns: Visualizing Landscapes in a Digital Age, several digital projects explore these phenomena through generative computational design approaches to the field of landscape architecture, with an environmental site-based approach to emergence, patterns, interaction, and feedback [8].

While each of these projects addresses a specific aspect of simulating natural systems within the built environment, landscape architects are still in need of additional tools. Some projects address natural phenomena from a digital art and design angle, while others address it with a purely scientific approach. The goal of this project was to create a workflow that folds in both approaches – the visual and the scientific – to enable landscape architects to simulate future conditions of a site and create a responsive design proposal.

2 PROJECT OVERVIEW

A core goal of the project was to develop a digital workflow flexible enough to be applied to a broad range of coastal sites and conditions. Designing such a workflow required initial research to understand the range of software programs used by design professionals. Given that the project's aim was to create a workflow primarily for landscape architects, but also one that was accessible to architects and urban designers, the team felt that the project's simulations should be created with tools most commonly used within the spatial design professions. The analytical techniques used in this research fall into the category of visual computing, which is based on the visual representation of data favoring large and complex systems of heterogeneous data. These techniques result in representations of three-dimensional digital environments through agent-based simulations of large and complex information, which can be interacted with and controlled to produce visual responses that can generate new knowledge [4]. In Colin Ware's book, "Information Visualization: Perception for Design" (2013, 2nd ed.), he argues that visualizations – a graphical representation of data or concepts – have multiple advantages: an ability to comprehend huge amounts of data; the perception of emergent properties that were not anticipate; the realization of problems with the data itself, the revealing of the way data is collected; and the facilitation of understanding of both large-scale and small-scale features of the data. He also argues that there are four stages of visualization: the collection and storage of data itself, which is often the most-lengthy stage; the preprocessing designed to transform the data into something we can understand; the display hardware and the graphics algorithms that produce an image on the screen; and the human perceptual and cognitive system (the perceiver) [18]. It is important to note that this research focuses mainly on the second and third steps. The first stage - collection and storage of the data itself - has already occurred, and therefore the integrity of the workflows depends on the investment given to the collection of data. With regard to the last stage, although this research acknowledges the perceptions and reactions of the viewing public, the research is less focused on a broad audience and more towards design professionals who are likely to monitor their response to visual simulations. Therefore, the middle stages of visualization – processing and image production – comprise the main elements of this research.

The methodology created through this research is intended to accomplish two goals. The first is to provide a realistic animated simulation of coastal ecological conditions. The second is to evoke a visceral emotional reaction in the viewer, as such reactions may enable the designer to more deeply understand coastal complexities, to visualize the irregularity and spectrum of natural forces, and to foment design inspiration. Through this methodology, we sought to add three-dimensional depth to systems that are often displayed two-dimensionally. This depth allows ecological systems to make use of a familiar visual language – that of the three-dimensional world – that is routinely utilized for understanding spatial relationships. We have considered whether this workflow contributes to scientific knowledge; we believe that this is not quantifiable, yet it may occur. This research offers a structure for applying scientific information to generate possibilities for climate adaptation and mitigation through improved use of information in creating design outcomes which address climate-related impacts. The visualizations which result from this workflow may be studied and critiqued by scientists, therefore offering the potential for increasing scientific knowledge. Although this is not the primary aim of this research, it will be important to analyze whether these visualizations provide any useful scientific knowledge about the agency of landscape architecture in addressing climate change scenarios.

The methodology was designed to align with scientific principles and research on the topics of sea level rise, erosion rates, and storm surge conditions. However, this methodology should not be interpreted as a system that can predict or forecast with exactitude how these coastal systems will evolve under acute and long-term climatic stresses, which is beyond the capability of current digital tools. Digital and physical modelling are integral to how designers perceive environments, test design strategies, and understand spatial representations. The intended audience for this project is the design professional, such as a landscape architect or planner, who can use these simulations to advance their design decisions with more specific information about the behavior of coastal systems. These graphics essentially fulfill the heuristic function of a 'decision-making tool' [16]. When simulated images are used to convey specific conclusions made by climate change scientists, the viewer tends to retain the expectation that a successful picture conveys knowledge at first sight [11]. Our intent is that the 'viewer' of these simulations be a professional who is allied with the discipline of spatial design, and we suggest that this 'viewer' – being neither scientists nor laypeople - be considered in possession of some broad scientific knowledge, but also prone to certain assumptions about images which are made by the general public. We advise that spatial designers and allied professionals carefully consider that visual simulations, such as the visual output from this research, show possible futures derived from climate model simulations are not forecasts but rather probabilities or potential scenarios [15].

2.1 Assumptions

The team made some key assumptions in order to make the methodology more accessible and streamlined. These assumptions allowed us to focus on developing certain key aspects of the workflow without becoming overloaded with numerous variables which ultimately were outside of the range of predictability. Such variables included future changes to the physical composition of the landscape due to development of infrastructure and real estate; the occurrence, timing, and magnitude of future storms, and ecological changes such as the introduction of invasive species or changes in water temperature. We believe that these assumptions do not hinder the integrity of the process and the final outcomes despite the uncertainty of so many future factors that could alter outcomes such as sea level rise, storm frequency, ocean warming, and coastal development trends. Yet the introduction of these factors may be useful in moving the research in a specific direction, and therefore in future phases of the project, some of these assumptions may be revisited and explored further.

The first assumption we made was that erosion rates would remain constant throughout the timeframe explored. Though it is known that erosion rates change frequently, to simplify the process an erosion rate spectrum was created by using a low erosion rate of 0.25m/yr and a high erosion rate of 0.5m/yr, both of which are greater than the average recorded rate in that area since 1939 [1]. These rates were selected to account for the variation of erosion rates throughout 50- and 100-year time frames. The erosion rates were also selected because of the uncertainty about sea level rise rates over the next 100 years. Rising seas are predicted to increase erosion rates due to a wave's ability to erode higher elevated materials and to maintain its force before breaking because of a lower seabed. Given these variables and the uncertainty of how they will play out in the real world, the team defined a single fixed erosion rate.

The second assumption was that the material composition of the coastline would remain fixed. Though existing coastal reinforcement in the study area suggests that further construction could occur as a measure to control erosion, the team felt that there was too much uncertainty about when and how such measures would occur. Coastal nourishment programs that restore naturally eroded coastline are undertaken either to mitigate chronic erosion or in response to a severe storm. Because of the high cost of nourishment programs and the uncertainty of severe storm systems, the presence of coastal nourishment programs was not considered as part of this project. However, it is possible to account for planned nourishment with the current methodology.

The accuracy of the project's methodology is to some degree limited by these assumptions. Because of this, the methodology should not be used to highlight individual real estate at risk of inundation or foundation erosion. The methodology also does not demonstrate how wind would impact the ways that water would disperse on land during storm events, and therefore it should not be used to describe the full extent that water could navigate throughout a site. Rather, it should be used for making broad inferences and discoveries about coastal ecological systems and their impacts on design sites, and to test initial adaptation and mitigation efforts.

3 METHODS

To effectively simulate coastal erosion, sea level rise, and storm surges to create future scenarios, we initially gathered a current topographical model that could be the base for further augmentation. We acquired a digital elevation model (DEM) from the United States Geological Survey's (USGS) National Map Viewer. The DEM of Misquamicut, Rhode Island was imported into in ESRI's ArcMap GIS software. Using orthoimagery provided by ESRI's online database, we determined site extents and trimmed the DEM to the extent of the study area. It is important to note that these baseline data sets have certain limitations due to their fixed nature which captures a single moment in time, as well as the inherent potential for technical problems associated with the data capture methods themselves [18]. Regardless, at this point in the project we felt it sufficient to begin with a fixed data set, with a future goal of working with more dynamic data representing the evolving morphology of the coastal environment.

To create erosion scenarios for future conditions, we researched past erosion rates for the site, located in Misquamicut, Rhode Island. We examined the Rhode Island Geographic Society's historic erosion rates since 1939. From those rates, we created high and low erosion scenarios. We decided on a low erosion rate of 0.25m/yr and a high rate of 0.5m/yr because they represented the two extremes experienced on the site. Though 0.25m/yr was not the lowest erosion rate in the historic data, we selected it because of the effects of climate change. We assumed that future erosion will accelerate beyond past rates as a result of higher sea levels and increased storm severity. The high erosion rate scenario of 0.5m/yr is conservative for the same reasons. We used these erosion rates to create 50- and 100-year scenarios for both the high and low erosion rates.

We then imported the DEM of Misquamicut, Rhode Island into Adobe Photoshop using a plugin named Geographic Imager. This tool allowed us to 'translate' the coastline of the DEM in response to the distance determined by the erosion rates and the timeline. We accomplished this translation using Photoshop's clone stamp and its measure tool, which allowed a fixed distance to be maintained as the coastline was modified. Using these tools, the coastline of the DEM was retreated to create basic erosion scenarios (Figure 1).

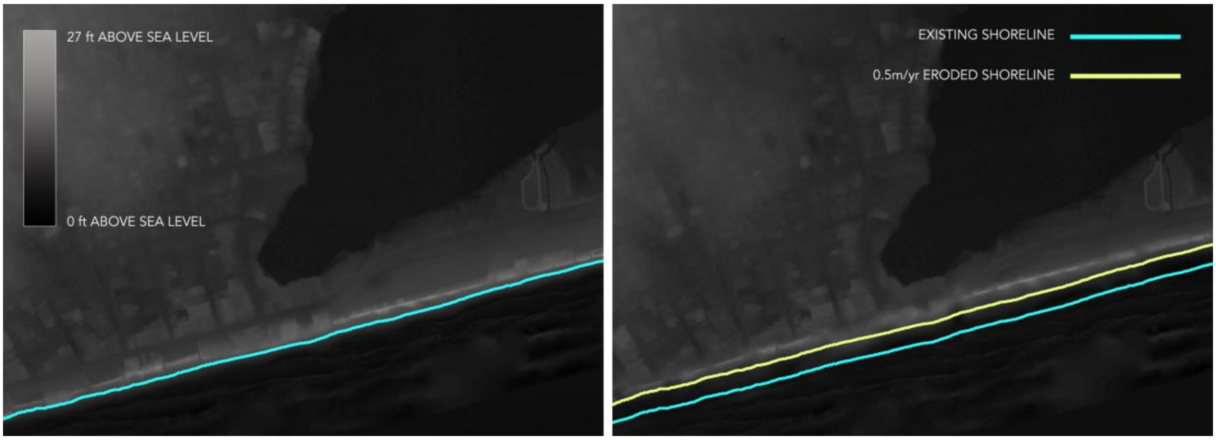

Figure 1: Original DEM (left) and modified DEM (right) using Geographic Imager Photoshop plugin to adhere to historic erosion rates.

Our first translation attempt involved simply cloning the dune morphology at set distances away from the current location. However, our second attempt also included changes to the dune morphology which more closely reflected the shifts in height and angle of repose which naturally occur as a result of littoral dune movement (Figure 2).

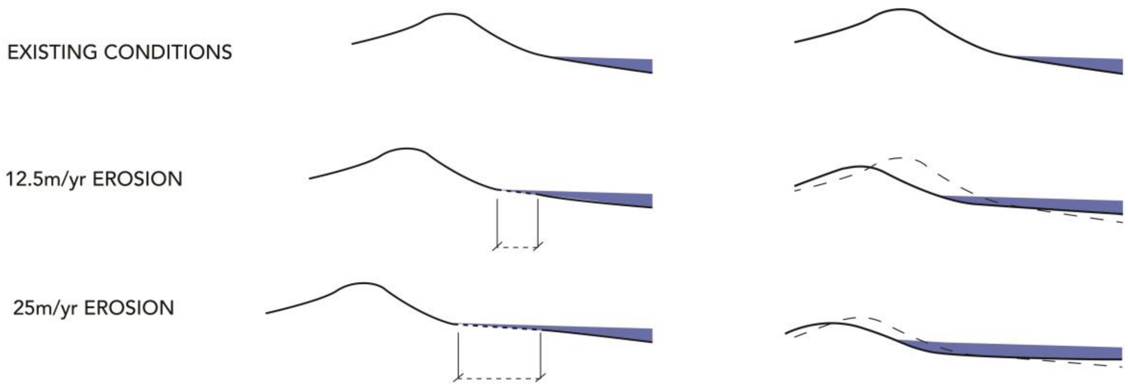

Figure 2: Cross-section of two digital erosion strategies used to modify the DEM. Left: clone dune by replicating it at set distances. Right: clone dune while simultaneously modifying morphology.

We exported these modified DEMs from Geographic Imager back into the GIS software ArcMap. Due to the ability of Geographic Imager to retain the geospatial position and scale of each modified DEM, the DEMs successfully imported layered one top of one another, representing different stages of erosion. From Arcmap, we tested several strategies to export heightmap information and import into McNeel's three-dimensional modelling tool Rhinoceros (Rhino). We found that because of the complexity and large scale of the imported data, Rhino's tools could not accurately create a terrain mesh from the DEM. When attempting to create a terrain mesh using built-in Rhino tools such as the Patch command, the result was a smooth and simplified surface that did not follow the true elevation of the ground plane. We then evaluated several approaches using plugins and scripts to create a terrain mesh, with positive results (Figure 3).

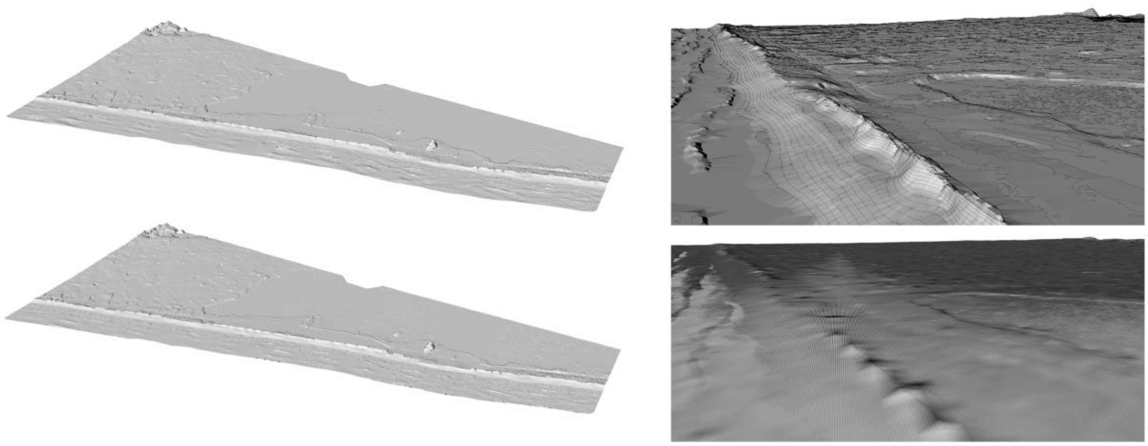

Figure 3: Top: terrain created using contour lines. Bottom: terrain created using ASCII point grid.

The first approach involved creating a terrain mesh from contour lines. To accomplish this, we created 1-foot contour lines from the DEM in ArcMap using the Contour tool, then exported these contour lines to Rhino. In Rhino, we created terrain using a custom plugin called *TerrainMesh* which created a triangulated mesh of high detail with a total of 1,800,000 vertices. The second approach involved creating a terrain surface from ASCII points. To accomplish this, we created a grid of points from the DEM in ArcMap using the Raster to ASCII tool, then exported these points to Rhino. In Rhino, we used a Python script called *ASCIIGridImporter* to import the points which created a NURBS surface of high detail with a total of 9,500,000 vertices. the large-scale view of the terrain models does not indicate any significant difference in output between the two techniques, the macro view clearly shows that the first approach yielded a greater level of detail. Ultimately, we decided to use the surface generated by the first approach because of its higher level of detail for small-scale animations. For for large-scale modeling of coastal change we recommend the second technique due to the smaller file size of its model output. With this terrain model, we created a flat plane representing a simplified measurement of sea level height, at 2ft, 4ft, and 6ft above current mean tide where it intersected with the terrain model. The visualizations of these increasing sea level heights show dramatic changes in the coastline (Figure 4).

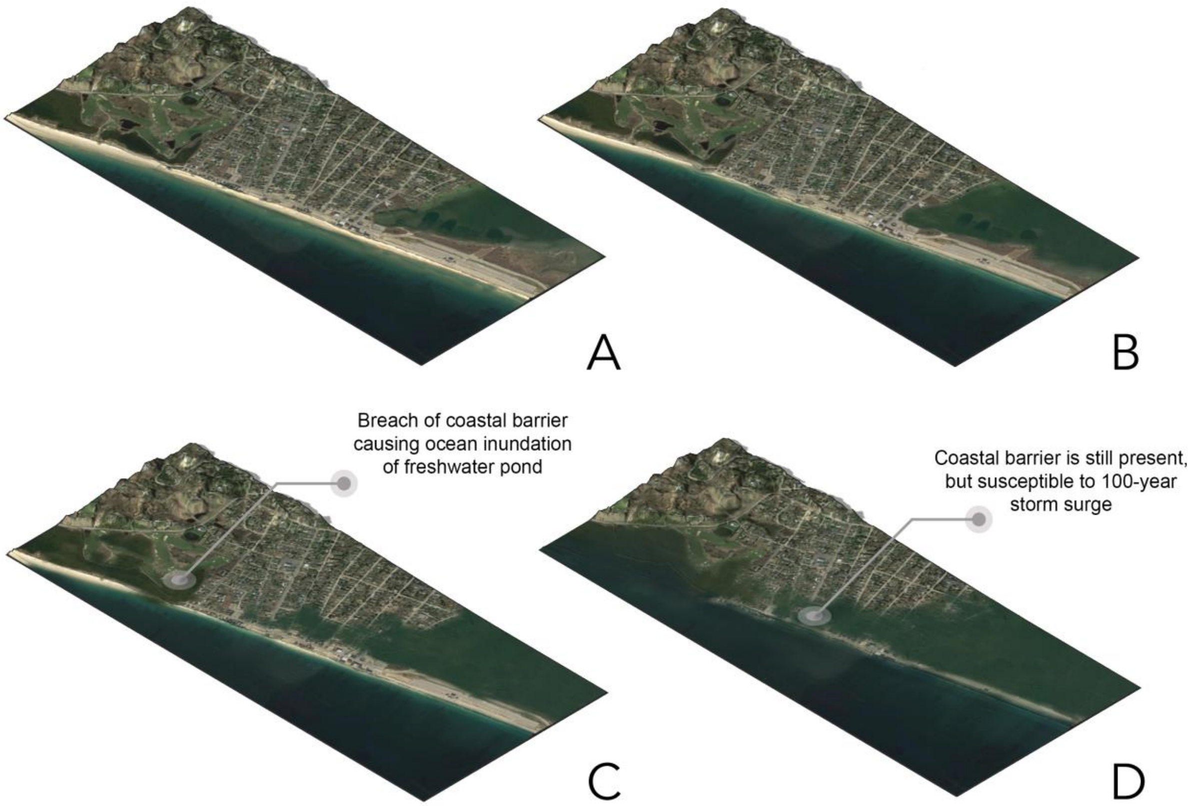

Figure 4: Three-dimensional visualization of coastal inundation derived from DEM heightmaps and raised water planes imported into Rhino: (a) existing conditions, (b) 12.5m erosion + 2 ft. storm surge, (c) 25m erosion + 4 ft. storm surge, and (d) 50m erosion + 6 ft. storm surge.

To simulate moving water within these modeled scenarios, we decided to integrate Autodesk's three-dimensional animation modelling program Maya and its water modelling simulator Bifrost. Maya and Bifrost are more frequently used by the animation industry than by the building industry but they have value as modelling tools because they can create hydrological simulations that use physics-based fluid computations. This is done through Bifrost's fluid implicit particle solver for creating animations of various fluid types and scales. We understood the potential of these tools to create a large-scale body of water that could behave like an ocean, enabling us to generate more realistic storms systems and sea-level rise scenarios. To create this digital water body, we chose a storm surge scenario. The first step in modelling this scenario was to understand the potential height of such a storm surge. For this, we used the Sea, Lake, and Overland Surges (SLOSH) model from NOAA's Hurricane Modelling System to provide storm surge ranges for the site's general vicinity. We used a category 1 hurricane to estimate the height of a storm surge. We chose a category 1 hurricane because of its higher probability of occurrence. Because of the computational power required to produce the animations, we divided the site into smaller sections. We exported each section from Rhino and imported it into Maya. We created a polygon to fill a basin representing the site's bathymetry and scaled it to touch a plane that represented the height of an 11ft storm surge – the SLOSH program determined that this height was possible. We transformed the polygon into the Bifrost liquid that would propel the water towards the beach in a fashion similar to waves in a storm. We used deformers to modify the geometry to create regular, semi-unique wave forms of customizable heights, shapes, and frequencies that would roll in a prescribed direction over time. We could increase or decrease their influence to modify their effect on the fluid. To create the kind of periodic irregularity that would occur in swirling winds and turbulent waters, we added a paddle to the rear of the basin to create occasional fluctuations in the storm surge's height. We animated the paddle to oscillate along the x-axis at a speed that matched the waves. We programmed an expression into the paddle's amplitude to add a cross wave as it oscillated. This helped to create a more dynamic effect within the ocean waves. To observe the impact of erosion on a storm surge, we imported the erosion terrain models to replace the existing terrain model (Figure 5). This enabled many possibilities: we could re-run the animation to visualize the difference between the two conditions under the same storm surge or modify the process to depict a higher mean tide to simulate sea level rise or a more forceful storm surge to depict a stronger hurricane or Nor'easter.

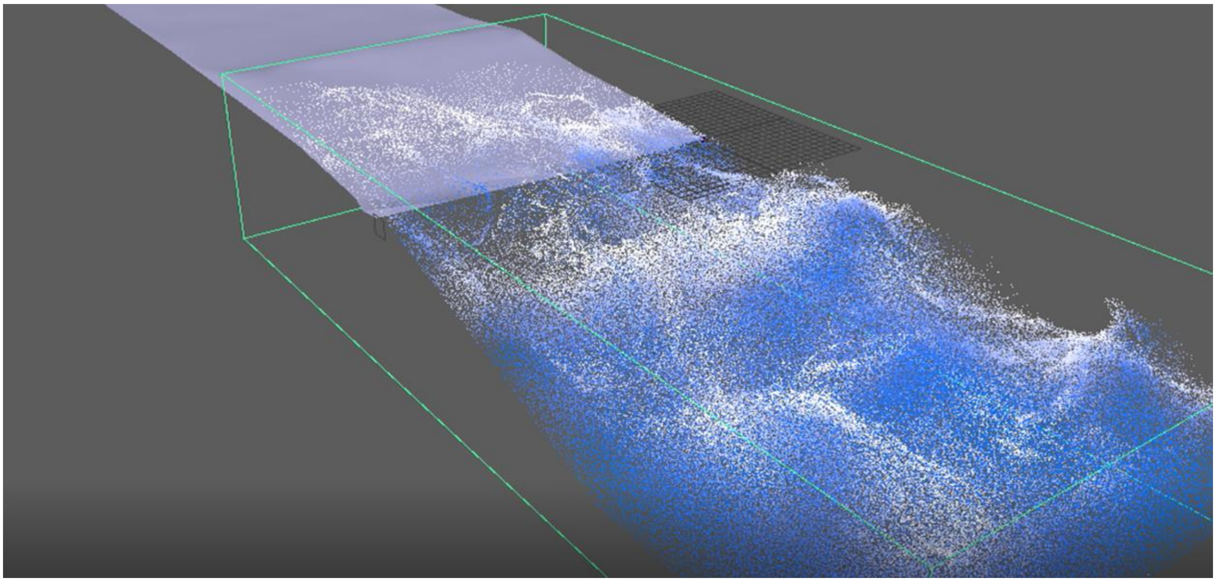

Figure 5: Animation of waves in Maya, showing 50m erosion + 6 ft. sea level rise combined with a 100-year storm event.

4 FINDINGS

The use of Bifrost in conjunction with our topographic models began to demonstrate how the ocean could interact with coastal conditions at varying degrees of intensity. Once we simulated a storm surge, we could see water breaching coastal barriers, posing a risk to infrastructure, settlements, and vulnerable ecologies. The simulations were able to demonstrate how both human and natural ecologies might become more vulnerable to periodic, semi-regular, and chronic inundation. Further development of this simulation model would add structures and natural systems that would further interact with the water as it breached the natural and human barriers. For our site, this would entail adding nearby ponds and the buildings that occupy the coastline. Because the digital tools used in this research enabled a multifaceted understanding of the impacts of coastal storm events, environmental areas that appear most likely to be impacted can now be considered as zones where preemptive mitigation may occur.

This methodology helped us create quick representative models of coastal change and process that improved our understanding of the coastal systems' complexities and irregularities. On a personal level, we discovered that the process of creating these animations was as meaningful and informative as viewing the final animation. Creating physical iterative models of coastal systems can be challenging because of the difficulties of generating accurate fluid simulations, especially at scale. Yet the process of modelling is an essential explorative method in analysis and design formation, a "tool people use to organize their mental perceptions of perceptible, phenomenal reality" [5]. Through engaging in this process of digital modelling, the dynamism of the coastline becomes more observable and intellectually and emotionally understood.

The workflow itself involved several stages using different geospatial mapping, image editing, 3D modeling, and animation software, with each piece of software handing off information to another in a relatively lossless format (Figure 6). The final animation that we created highlighted the strength of this new methodology as an iterative process. Because we acquired data and transformed it independent of a single software program, it was simple to identify problems at any stage of the workflow and make the necessary changes. We were also able to reuse the workflow for different sites: for example, because we modelled the fluid simulator independently of the coastal topography, we could change locations and scenes or augment the landscape to see how these changes would influence the interactions between the various modelled factors.

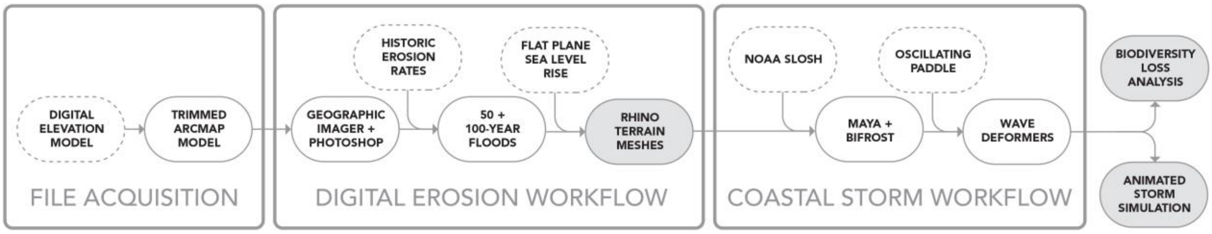

Figure 6: Diagram of digital workflow used in the project.

5 DISCUSSION

While it relied heavily on scientific data, this process contained significant trial and error. This was due to the continual translation of scientific principles that dictate natural systems for software workflows. Especially in the later stages of the project when animations were generated, results were often unexpected and surprising. To verify accuracy, the team would watch videos of coastal storm events to understand whether the exported products of our methodology shared similar properties with real-life events. Although the final animations match the visual behavior of similar water bodies, some technical discrepancies can be expected. The team believes that with the consultation of an oceanographer and a digital artist who is an expert in Maya and Bifrost, a more precise model could be created.

Through this process, we understood that there was potential to add error when retreating a coastline within Geographic Imager and Photoshop. However, because there is inevitable flux in actual erosion rates over time, we did not consider the minor distance variation a drawback to the methodology. Although the first iteration of this workflow is complete, the team has been unable to test it at the full site scale due to limitations in computational power. While we do not believe a large scale will alter our core methodology, we cannot say for certain what effect it would have. For now, we are using representative sections of various topographies across the study site.

These challenges in the methodology do not diminish the applicability of this modelling approach but rather invite even greater collaboration. Currently, scientists use many modelling methods to explain natural systems that design professionals do not use. It is our belief that, while it is important that these methods are integrated into the design process, these models are most effective when initiated by the scientific community. We are excited about this methodology's potential to work with tools that are geared toward designers but have input and direction from the scientific community. We believe this process opens a dialogue between the parties to exchange information and methodologies that are more familiar to each discipline, with the aim of further understanding both the natural system and modelling processes.

6 CONCLUSION

These systems, which are typically represented in landscape architecture as static images in plane and section, can be seen as time-based phenomena acting upon the design site. The ability to view water moving into a site repeatedly and to consider this scenario playing out over weeks, months and years may lend the designer a deeper sense of the impact or non-impact that their design could have. On a conceptual level, the ability to view these dynamic natural systems in action elicited a sense of wonder, awe, and even fear in the team. This may signify the potential to augment the designer's mental approach to the tasks and provoke a more fundamental appreciation of the dynamic systems within which they plan to intervene.

A methodology like this can further the dialogue between disciplines to create more visual languages and new perspectives on ecological conditions. This methodology builds off others that are being introduced into the design professions and it is our hope that others will adapt these principles in new ways to improve our analysis and understanding of ecology and inspire new approaches to landscape design. These kinds of techniques have the power to help designers, developers, and politicians make informed decisions about coastal settlements and natural ecologies. It is our hope that such tools will enable effective decision making that can preserve the visual, cultural, and ecological functionality of our coastlines in the midst of great climate change and uncertainty. Adding this methodology to the existing set of computational three-dimensional modelling workflows will help scientists and landscape designers understand the challenges of climate change in the 21st century and beyond.

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