The Third Simulation: Augmented Reality Fluvial Modeling Tool

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Abstract: In recent design discourse in landscape architecture, ecological and environmental concerns have stimulated a shift from rigid formal practice to design of dynamic systems that are constantly in fluctuation. The digital revolution has provided landscape architects with intelligent tools to challenge the determinacy of traditional static simulation and modeling method. However, it has also distanced physical material exploration from the standard protocols of the discipline. This paper presents the use of a small tangible hydromorphology table as a new workflow and method of design for landscape architectural interventions within hydrological systems. By integrating physical hydraulic simulation model with real-time computational fluvial simulation through augmented reality technologies, the new method enables landscape architects to design intuitively with a tangible material process, while simultaneously being informed by computational simulation results.

Keywords: Hydromorphology, Augmented Reality, TUI, responsive environment

1 Background and Related Work

1.1 Dynamic Models in Landscape Architecture

Recent ecological and environmental concerns have put simulation and modeling into the center of landscape design discourse that explores the dynamic and temporal aspects of ecological and urban systems. Emerging modeling techniques combined with computational simulation, responsive and tangible devices have provided landscape designers with advanced tools to challenge the determinacy of traditional static modeling methods. In this context, the making of dynamic models is an essential process in landscape architecture. It requires the designer's ability to exact and abstract the needed features, structures and relationships of the natural systems from the complex physical environments, in order to construct a proper model. The dynamics and indeterminacy of the model is essential in terms of understanding the complex and dynamic processes of nature, especially those that have not yet been fully understood. Models are also regarded as a dynamic medium between human inventions and the physical world, acting as an integral part of the feedback loop between sensing, constructing, manipulating and actuating.

1.2 Physical Fluvial Modeling

In scientific and engineering practice of physical hydraulic modeling, large physical river models are usually built to simulate the weather, floods and to evaluate the effect of flood control measures. Precedents include those large-scale hydraulic models from the 1950s, such as the pioneering work of the Mississippi Basin Model and the well-known San Francisco Bay Model. The physical models not only provide large platforms for collaboration between different professions, but also show great potential for communicating complex and nonlinear phenomena, especially the phenomena which are not yet fully understood and not

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available in the forms of numerical models (CHERAMIE 2011). Besides the scientific speculations, in landscape design practice, physical models are also used to test the performance of designed landforms. For example, in the Guadalupe River Park project by Hargreaves, an 80 feet long scale model was built to test various design alternatives to study the impacts of potential flood flows, sedimentation, and scour patterns. Smaller non-site-specific river tables such as EmRiver Models are also available for more general design and research. They allow more direct and intuitive material manipulations, and thus are widely used in academia and professional river management across disciplines including geosciences, education, government, museums, design, etc.

Although observations of material and dynamic processes are made easier by a greatly compressed time scale and expanded physical scale, there are also limitations to the physical hydraulic models. In the same way as engineering or scientific models, models for landscape architecture should be specific to bring meaning to the types of systems and landscape and inform decision-making. However, it is difficult to determine a proper spatial and temporal scale which is essential to determine similarity of the physical models and the simulated landscape. In addition to scaling issues, both the process of constructing the model precisely, and extracting data outside of the model prove difficult.

1.3 Numerical Fluvial Modeling

With the advances in computational simulation, a variety of numerical fluvial models are available for quantitatively measuring the dynamics of hydromorphological changes. This paper will avoid going in-depth about these engineering models, nor will it try to apply these models uncritically in design use. The aim here is to examine those numerical fluvial models which have potentials to inform design decisions and which have the potential to be integrated with the physical models. Computational Hydraulic Models are used to simulate the complex behavior of water, and the movement and interactions of the related media such as bank, sedimentations and pollution. The most widely used mathematical models for computational fluid simulation include: 1D de Saint-Venant system of equations, 2D Lattice Boltzmann methods and 3D Computational Fluid Dynamics (CFD). Most simulation methods are developed, based on these mathematical models, to meet different specific engineering uses. For example, Boltzmann methods are usually used in the simulation of runoff and flooding, since the intense calculation of 3D CFD method doesn't make it efficient enough for landscape scale simulation. One of Boltzmann methods, SRH-2D, short for Sedimentation and River Hydraulics -Two-Dimensional, can be used to simulate the sediment and flows with in-stream structures, multiple channel systems, floodplains, flow spills over banks and levees, vegetation model for river systems, and so on. This method is used to study the wetland suitability strategies of Delaware River (M'CLOSKEY 2016) in a landscape design research work by Peg Office. By feeding sensing topography data into the computational simulation, and visualizing the result through Grasshopper, landscape designers are able to integrate the simulation into their own design process.

Though there are many off-the-shelf tools available for fluvial modeling, none of the tools are developed specifically for quick prototyping landforms. As for design purpose, we prefer quick prototyping process and direct visualization to high precision of every simulation number. Moreover, in order to fully integrate the numerical model into the physical model, it is necessary to customize our own tool, to ensure real-time feedback and adjustable parameters. The numerical model used in this project was developed by the author based on 2D Lattice

Boltzmann model in Processing, a java developing platform which is compatible for real-time data transmission with most of the design software, such as Rhino Grasshopper.

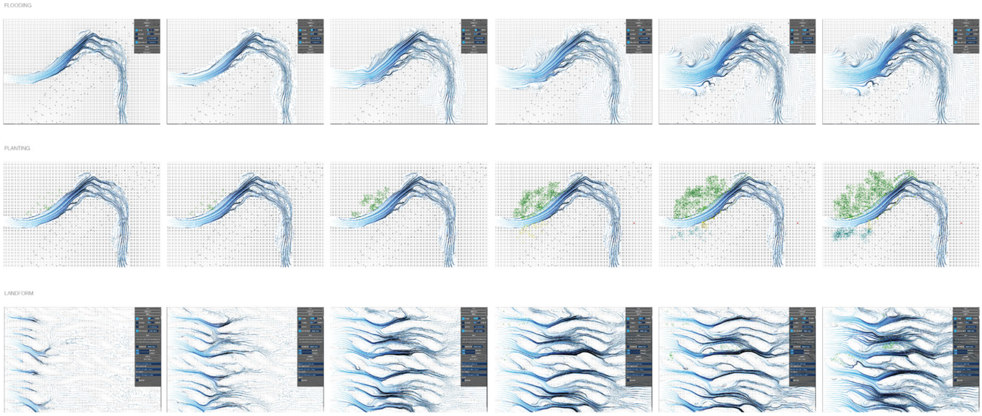

Fig. 1: Customized tool for water flow visualization

1.4 Tangible Model

Tangible user interface (TUI) are increasingly accepted as an alternative paradigm to the more conventional Graphic User Interface. They combine the benefits of physical and digital models in the same representation. More generally, they give "physical form to digital information, seamlessly coupling the dual worlds of bits and atoms" (ULLMER et al. 2000). Some pioneering works on tangible models in design field include SandScape and Illuminating Clay from MIT tangible media lab, which have discussed how tangible interfaces might inform a more effective use of GIS, and to allow non-expert to involve in the discussion and decision-making (RATTI et al 2004). Another pioneering work, Augmented Urban Design Workbench, uses digital augmented tagged physical objects to represent buildings that can be rearranged, and real-time digital simulation of urban space are overlaid into this single information space to support the urban design process (ISSHII et al. 2002).

However, most of the current tangible models have overlooked the inherent material process of the physical model. The coupling of the two models usually regards the physical models as data input and interface for manipulation, while numerical models as the embedded simulations. For hydraulic models, or even broadly speaking, landscape ecology models should not only consider human intervention as inputs, but also nonhuman changes as important input sources. The concept of tangibility discussed in this paper is more than the tangibility of the interface, but the synthetics and composition of the two different simulations: numerical models being used to manipulate while validating physical models, and vice versa. As discussed in detail in previous sections, either of the physical or numerical models are compelling enough for hydraulic models. The physical model lacks precision in construction and modification process, and it is hard to read and extract data out of it. The numerical models lack the inherent features of randomness and indeterminacy of the natural and hydraulic systems, and have set high technical barrier for use in the design field. But through integrating these two simulations, each of them makes up the other's limitations, mutually feeding and adapting towards each other to build the tangible interface.

1.5 Adaptive Control

As sensing technology and computing power advance, the opportunities for real-time extracting model data to adaptively develop numerical models as a process of feedback are considerable. Integrating adaptive controls into the mixed reality systems would allow a more accurate manipulation of the physical model, and also enable a recursive computational design-action process. The adaptive manipulation shows great potentials of landscape design, which is open-ended. In the work of Erosion Machine (PAINE 2005) and the Procedural Landscapes projects (GRAMAZIO 2013), robotic manipulator are used to procedurally inform computationally indeterminate material process. Responsive Landscapes also proposed new workflows of real-time models as critical components within the feedback loop for responding and adapting to circumstances in the landscape (CANTRELL 2017).

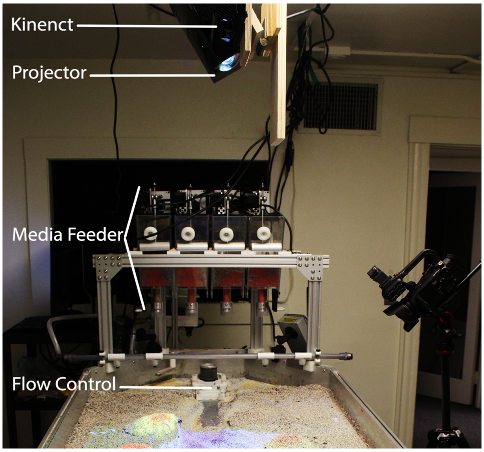

Fig. 2:
Augmented Geomorphology Table

2 The Tangible River Table

2.1 Em River Geomorphology Table

The physical simulation part of this project is built upon the Em River geomorphology table in Harvard Graduate School of Design (GSD) Responsive Environments & Artifacts Lab (REAL). It is a 1.5 × 4 meters metal table with synthetic sediments. This small interactive water table used by professional hydrologists is imported into the field of landscape architecture to help students in design studios to better understand hydromorphological process, and to facilitate the production of responsive design strategies. The inputs of both the sediments and water flow are controllable through four sediments feeders and water pump to simulate the water flow and the behavior of sediment. Each feeder is digitally programmable and contains different media size. The ratio of each media is operated by micro-controller to composite different density of sediments. The slope of the geomorphology table is adjustable both laterally and along the length of the bed, to adjust the speed of flow to accommodate different simulated hydraulic systems. A vertical adjustable cylinder controls outflows and the water level, and outflow water tank is connected to the input water tank to allow reuse of water. The model allows running iterations of the same system with measurable adjustments, as well as testing multiple systems with the same flow and sediment input. The physical model is also equipped with sensing and monitoring devices to real-time gather and post-process extracted data. There have been some experimental projects developed based on this table. Towards Sentience is a project that developed a series of responsive gateway devices that can constantly alter, modify and attune the fluvial morphology of the LA River (ESTRADA 2016). It proposed an alternative understanding of the autonomy of nature, privileging the evolution of ecological processes over static constructions.

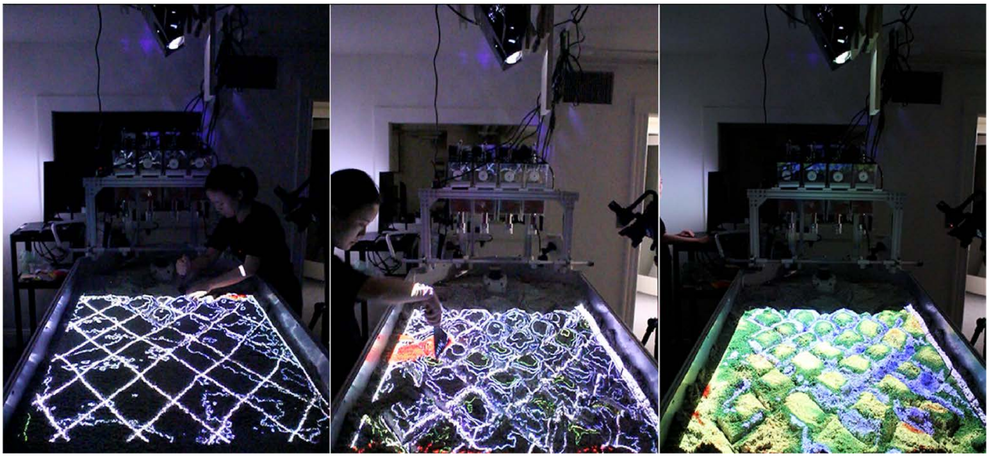

Fig. 3: Freeform Prototyping

2.2 System

At the same time as the physical hydraulic simulation is running, the table is monitored by a Microsoft Kinect overhead to record the imagery and changing surface topography. This approach allows users to quickly create and understand highly complex topography that would be difficult to deal with using mice and keyboards. Besides the designer's intentional reshaping, the terrain is simultaneously changed by the natural processes such as water flow and sedimentation erosion and deposition. The modification can also potentially be automated or controlled by robotic arms and responsive devices, but this is not yet integrated into current project. The customized program uses the sensed topography data as input geometry to compute customized program for numerical simulation of flow, as well as other agent-based simulations such as vegetation distribution, pollution and sedimentation. Topographic changes, landscape morphology, water streamline and patterns of other simulated agents can be abstracted and visualized in diagrammatic representations to aid in decision making. A short-throw projector is attached next to the Kinect to project these results of digital simulation to inform human users allowing for interactive interventions.

2.3 Software

The basic interface is built in Rhino Grasshopper, a visual programming language and environment widely used by designers to build customized design workflow and analysis. In the last few years, lots of plugins for Grasshopper were developed to enhance the landform analysis and manipulation as well as data transmission between other platforms. In this project, The plugin Tarsier is used to import 3D point cloud data from Kinect in real time; Bison is used for the landscape analysis such as slope, aspect, elevation, etc., to replace the conventional hydraulic analyzing process in GIS; HumanUI is used to build the user interface, to allow non-experts and students easily changing parameters and accessing the output 3D terrain data; Horster camera is used to adjust the projection distortion to the 3D surface. Human is used to automate exporting 3D geometries. There are also some self-written components to bridge the real-time flow simulation in Processing and Rhino 3D modeling platform. 3D point cloud data collected in Rhino from Kinect is transmitted to process as Digital Elevation Model (DEM) data. After the real-time hydraulic simulation, the simulated result is sent back to Rhino as vector field data, as well as image sequence for better visualization purposes.

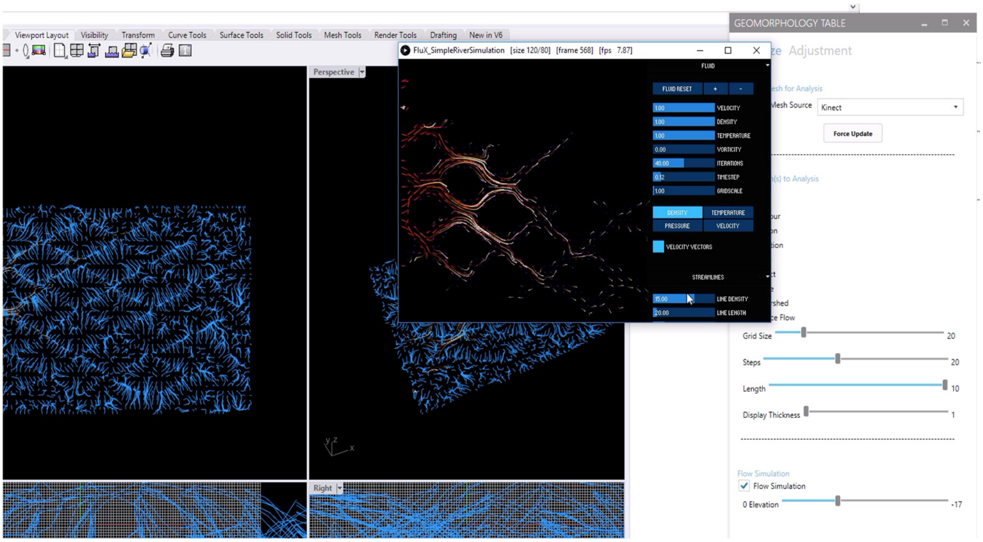

Fig. 4: Software interface

3 Applications

3.1 Tangible GIS and Free-form Geometric Prototyping

The project proposes an intuitive alternative for modeling free-form landscape models, by introducing TUI and responsive modeling idea to the traditional hydraulic modeling. The tactile richness of conventional physical models makes them easy and enjoyable to manipulate. Designers are able to manually prototype the physical model while informed by the

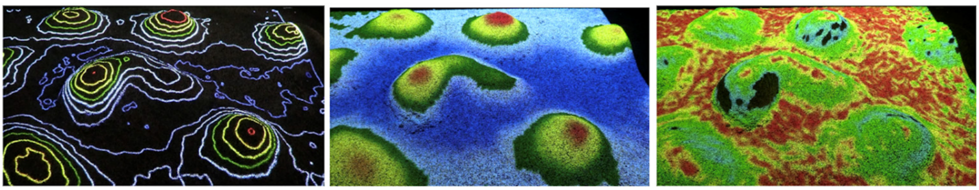

Fig. 5: Augmented GIS analysis

projected information, such as guidelines, contour lines, and cut-and-fill map. The basic GIS analysis is integrated into this platform together with dynamic fluid simulation to better visualize the invisible aspects onto the topography. In the user interface, the user can directly select which aspects to show on the table, and adjust the parameters for visualization and simulation.

3.2 Hydraulic and Agent-based Simulation

The Tangible River Table was conceived as a platform for multi-layered physical and digital simulations and representation. By overlaying previously incompatible simulations at the same place and scale, the project hypothesized that different simulation methods are able to modify and validate each other, to provide a hybrid but seamless information space that lead to a dynamic and indeterminate design process. Different parameters in digital hydraulic simulation, such as flow direction, base flood elevation, flow density/ velocity/ vorticity, are adjusted to match with the physical simulation model, rather manually being set up. In addition to the augmented flow simulation, agent-based simulations are realized through image recognition methods. By manually putting a tagged object in the physical surface, the computer would read it as a position for planting and seeding. These customized computational agent-based simulations such as sedimentation and vegetation propagation are overlaid into the table to reveal additional information which cannot be observed in physical model. In this way, landscape designers can use it to make more comprehensive decisions and planting strategies. They are able to adjust the parameters in the computational model by selecting the plants species and properties, to test where to send them and how many to put. The seed propagating path is based on hydraulic simulation, and ecological succession of different species is based on the plant's own properties and competing capacities with each other.

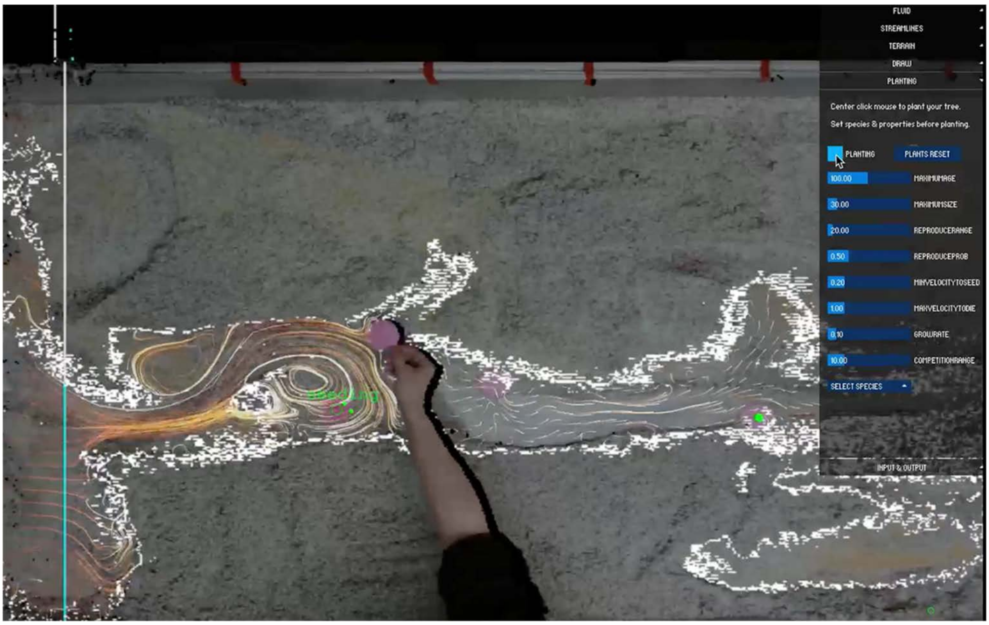

Fig. 6: Agent-based Simulation

3.3 Interaction, Responsibility and Autonomy

This augmented hydromorphology modeling table can be used as a prototyping, modeling, simulating and evaluating tool for landscape designers, as well as an educational tool for community engagement and distribute communication between different stakeholders in practice.

4 Discussion

In this paper, by combining a physical fluvial simulation model with real-time computer fluid simulation through augmented reality technologies, new workflows enable landscape architects and urban designers to design intuitively with tangible material process of fluvial model while simultaneously being informed by computational simulation results. Rather than developing design in a linear progression from idea to computer-simulated model to material manipulation and result, this paper presents a prototypical design process to discuss alternative workflows which allows different elements in design process to play concurrently and recursively.

4.1 Assumptions and Limitations

This tangible river table is not meant to replicate processes in a site-specific hydrological and ecological system. Neither the physical model nor the numerical models have the capacity to scale the model to the real-world scenario. The presumed scale of the model is not built based on a mathematical scaled relationship with real landscape conditions. However, due to its small scale, the river table can still help us understand and visualize the behavior of the hydraulic systems. By regarding this model as its own environment, with its own autonomous and evolving process, it offers the possibility for designers to challenge traditional forms of simulating landscapes. The role of numerical simulation here is not simply used to analyze an environment, rather it is used to visualize, validate and determine the function of the responsive environment. The boundary between physical and numerical model dissolves in the process of feedback and adjustments.

4.2 Future Work

The Third Simulation is in the very early stages of development both as a concept and as a working prototype and is in need of both technical and theoretical improvements. The current simulation platform is built partially in Grasshopper and partially in processing, while transferring the data in near-real-time between these two platforms through customized components. The future version will integrate the flow simulation algorithms and interface into Grasshopper for more seamless simulation and simpler user interface. However, the parameters of these digital simulations are able to be manually adjusted based on the physical model setup, and physical simulation is able to adjust the rate of flow based on real-world digital data input. The idea of two simulations concurrently evolving towards each other is still experimental. The future version will test the machine learning ideas upon these simulations, to allow one simulation to learn from the other, in order to create an initially unscripted third simulation to evolve into a dynamic and indeterminate result. This tool will hopefully be tested in future landscape design studios, to explore alternative design methodology for fluvial environment.

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