Hydromorphosis: A Technologically-Integrated Approach to Fog & Droplet Harvesting

GARRETT HERBST
University of North Carolina - Charlotte

Within architecture there has been an ongoing shift in the architectural process. Each piece of new software allows for a higher level of simulation and calculation within architectural design, allowing for faster output of drawings and increasingly dynamic and complete building analysis. What seems to have taken months or years through analog methods are being completed in days or weeks digitally. But as with all technology it can create users who are compliant, relying solely on technology for its intended purpose and nothing more. To remain relevant in the contemporary discussion, architects have an ethical imperative, not to acquiesce their design process, but instead to ask how to push the utilization of these tools beyond their basic uses. Parametric modeling, environmental analysis, computational scripting; these all have the potential to be powerful pens in a skillful hand, manifesting ideas onto paper in ways the minds of the past could only imagine.

This paper will focus on Hydromorphosis; a morphology of our current technological methodologies within the endeavor for a more hydro-centric approach to design. This research project pushes several pieces of new software beyond their conventional applications to work to help one of the largest global issues that faces us today, potable water consumption. With our growing global population comes an increasing need and subsequent shortage of potable water around the world, and to address this architects need to rethink water collection. Increasing population means denser urban centers, resulting in a higher strain on cities water supplies than ever before. To address this issue Hydromorphosis zooms in at the molecular level, shifting the focus from droplet to vapor, calculating where to apply fog harvesting systems on the urban high-rise. With this shift in perspective, a new implementation of existing software was used to realistically prove the validity of this new methodology.

INTRODUCTION

Over the past several decades, an increase in global population and need for resources is creating a global water crisis; consisting of shortages in areas with increasingly limited access to potable water. The ominous "Day Zero" countdown was implemented in Cape Town, South Africa just this past year, marking the day in which the first modern-day city would completely run out of water. Researchers at MIT "expect 5 billion of the world's projected 9.7 billion people to live in water-stressed areas by 2050" (Roberts 2014). Considering this projected crisis, approaches to water collection need to be reevaluated to better suit our growing needs. Architect's must move past the traditional ideologies of water collection practice, and think of a macro-level solution that will truly have a sustainable impact on the environment.

New methodologies for the accumulation of water vapor and condensation can provide alternative water sources, but with these new methods comes a question of how to prove their validity to the client. Research into the manipulation of material micro-structures and assemblies, along with their strategic placement and execution, offer an additional solution for many cities whose climates require more sustainable water sources. Hydromorphosis focuses this research into the creation of a computational tool that combines 3D modeling, scripting, and environmental analysis software to calculate, analyze, and formulate tactile solutions that can be utilized within practice to increase the amount of non-potable water collected on a building's exterior surfaces.

BACKGROUND

Before beginning to generate a solution to this problem, one must look at the inherent problem with rainwater harvesting within the urban environment today. The location of its collector. Consider a traditional high-rise with a footprint of 75' x 100' at 400' tall. It has only 7,500 square feet of roof surface compared to it's 140,000 square feet of vertical facade. An office building of this size would employ approximately 2400 employees, who would generate a total of 15,128,672 gallons of non-potable water use. With a rooftop collection system, this building would only be able to harvest an average of 100,459 gallons of rainwater a year in the San Francisco area. However with a vertical harvesting system like a fog-catching mesh, there is the potential to increase that number to almost 7 million gallons a year.

Fog harvesting has become a source of collection for potable drinking water in many regions of the developing world, whose climates consist of low amounts of rainfall yet high frequencies of fog. An existing fog harvesting program, FogQuest, reports that a site using a combined mesh area of 5000 sq. m. produced an average of 15,000 liters of water a day, with maximum yields exceeding that of 100,000 liters a day (Schemenauer 2015, p. 7). Looking at the meshes used in these harvesting systems, researchers at MIT analyzed their microstructures and began to implement meshes with hydrophobic coatings to gain a better understanding of their scientific processes and how to improve their efficiencies.

Figure 1: Rethinking Water Collection through Conceptual Facade Iterations

Their analysis determined a varying efficiency coefficient based on wind velocity and droplet radius. Based on this research they developed their own mesh design that resulted in a 500% yield compared to traditional structures (Park 2013). Building upon this research, this paper describes a tool that helps specify the application of these harvesting systems on the urban high-rise.

METHODS: FINITE PARTICLE SIMULATION

Used during the schematic phase of a project, the tool's intent is to analyze and subsequently re-generate an Autodesk Revit Conceptual Mass. The development of the mass utilizes inputs from local weather data to manipulate its orientation and form to be best suited for fog harvesting. Weather data, provided by the National Oceanic and Atmospheric Administration (NOAA), extracts daily records of prevalent wind direction and velocity, fog indication markers, rainfall, and dew point depression to provide a base assessment of water collection for the initial Revit mass geometry. While other factors help to more specifically articulate the potential collection amounts, the existing research indicates that these values are core to providing a relatively accurate estimation and the addition of other variables which can simply be added into the model as necessary.

To achieve this calculation, the desired building mass is turned into a 'conceptual mass' in Revit, simplified to its most significant geometries, which is then imported within the Dynamo environment for analysis. Using the imported NOAA data, days of optimal conditions are extracted based on indicators specifying whether there has been a dense fog, visibility was low, or that it was a clear day.Based on those optimal days of dense fog and low visibility, days are culled even more to only include conditions of wind speeds with a velocity less than 15 MPH and dew point depressions of less than a 5-degree difference. Based on these inputs, the tool can set up a model that can be evaluated in Autodesk's Computational Fluid Dynamics software.

Using the conceptual mass's centroid as an origin, the tool frames the geometry with a bounding box,scaled to generate a rectilinear solid surrounding it. Scaling to 4x its width, 6x its depth, and 1.5x its height; the mass is then used as an air mass in a CFD analysis. The tool then rotates the solid to align the faces designated as the air volume intake and outlet to be perpendicular to the direction of the day's most prevalent wind direction. Having been properly oriented, the solid and mass then export an ACIS solid to be imported into Autodesk CFD for simulation. The average wind speed for that day is utilized as the starting velocity, to accurately simulate the aerodynamics and subsequent impact of the fog traveling around the building's mass (figure 2). The resulting finite particle analysis creates an array of nodes each carrying an XYZ coordinate as well as a specific velocity magnitude which are exported as a CSV file and brought back into the Dynamo environment (figure 3). With the CSV file converted into a point cloud around the conceptual mass, the tool can now utilize the individual node velocities within its initial calculation.

FOG COLLECTION CALCULATION

The Dynamo graph begins by initially subdividing the facade of the mass into a square meter grid of points, which is utilized throughout several areas of the calculation. The tool finds the closest node in the CFD point cloud to each individual point on the subdivided facade, and associates the corresponding velocity magnitude to that point. Using the imported velocity (converted from miles per hour to meters per second) a calculation is performed to acquire how many meters of vapor would be moving past the mass at each location. Each unique velocity is then multiplied by the total number of seconds within a 12-hour period of the day, giving an initial estimate of how many cubic meters of a vapor cloud pass along the face of each square meter. The 12-hour period reflects a more realistic fog accumulation period, with the fog beginning to form in the early morning hours and dissipating by early afternoon.

A cubic meter of fog holds within it a certain amount of water, known as its Liquid Water Content (LWC), with a study being done by NASA to accurately measure the amount of LWC held within several types of fog clouds (United States 1994). By attaching sensors to an airplane and descending into each fog cloud, the study was not only able to determine LWC but also realize an increase in LWC based on the increase in altitude of the fog. Utilizing this data, a specific level of LWC is given to each cubic meter of fog based on its altitude. The water coefficient is then multiplied by the varying number of cubic meters that pass by each point of the subdivided facade. This calculation sums up the total amount of liquid water that will impact each individual point on the facade. Each total is multiplied by an efficiency coefficient generated through a formula, written based on the MIT study, which is dependent on each the individual velocity at each respective point on the facade. As the velocity of the fog moving through the mesh increases, the water collection efficiency of the mesh increases. The tool then sums up each point's potential water collection and outputs the total amount of water expected to be extracted by the mesh.

Importing the 75'x100' control geometry based out of San Francisco, the script identified 174 days that had optimal conditions for fog harvesting based on the imported NOAA data. Of those 174 days and using the MIT metal mesh, the geometry was able to collect an average of 39,500 gallons a day. This brought the total water collected from fog to about 5,154,802 gallons, which using San Francisco - Water Power Sewer fees is equivalent to $49,204.92.

PANEL DEVELOPMENT AND APPLICATION

While the tool can be utilized to inform the user on how much potential water savings can be collected using these fog harvesting systems, the tool can also be used to effectively test mesh implementation onto the facade. While the most efficient and seamless integration of theses systems are within new construction, to have a truly significant impact on the water crisis at hand these systems must also have the ability to be retrofitted onto existing structures. In either case, the architectural implications are crucial to the application of this system as it has significant impacts on the daylight, cost and urban environment of the design.

With this in mind, the tool extracts the average wind speed and wind direction from the refined list of optimal days of the year, and exports an ACIS solid model manipulated by those variables. A CFD simulation is then run to get a mean velocity magnitude for the year to export from the CFD nodes back into the Dynamo environment. The closest point node is used once again to populate the fog's velocity moving past each face of the facade, and the tool visualizes this for the user by associating each point's velocity with a color map with the same relationship as the CFD analysis. This allows the designer to get a sense of where on the building the most optimal locations to install panels for maximum potential collection.

These variables can be used in multiple ways, the most obvious of which is to use it to control the application of a Revit adaptive component. Either by its geometry, orientation, or

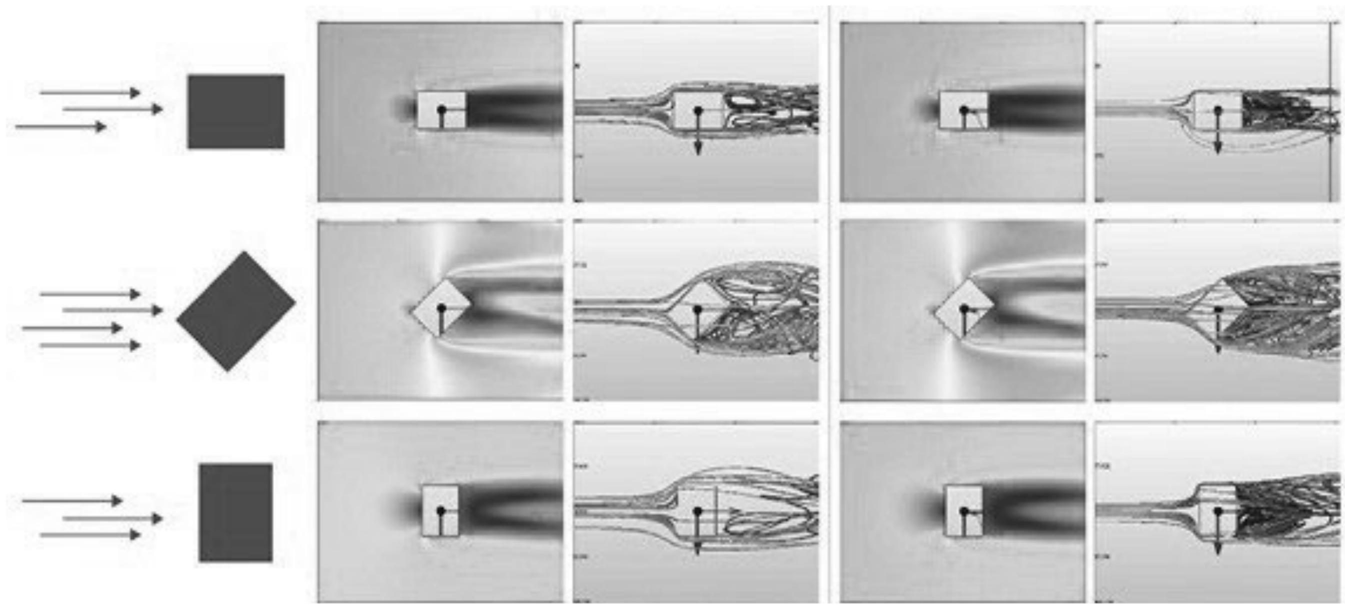

Figure 2: Computational Fluid Dynamics Simulation & Analysis

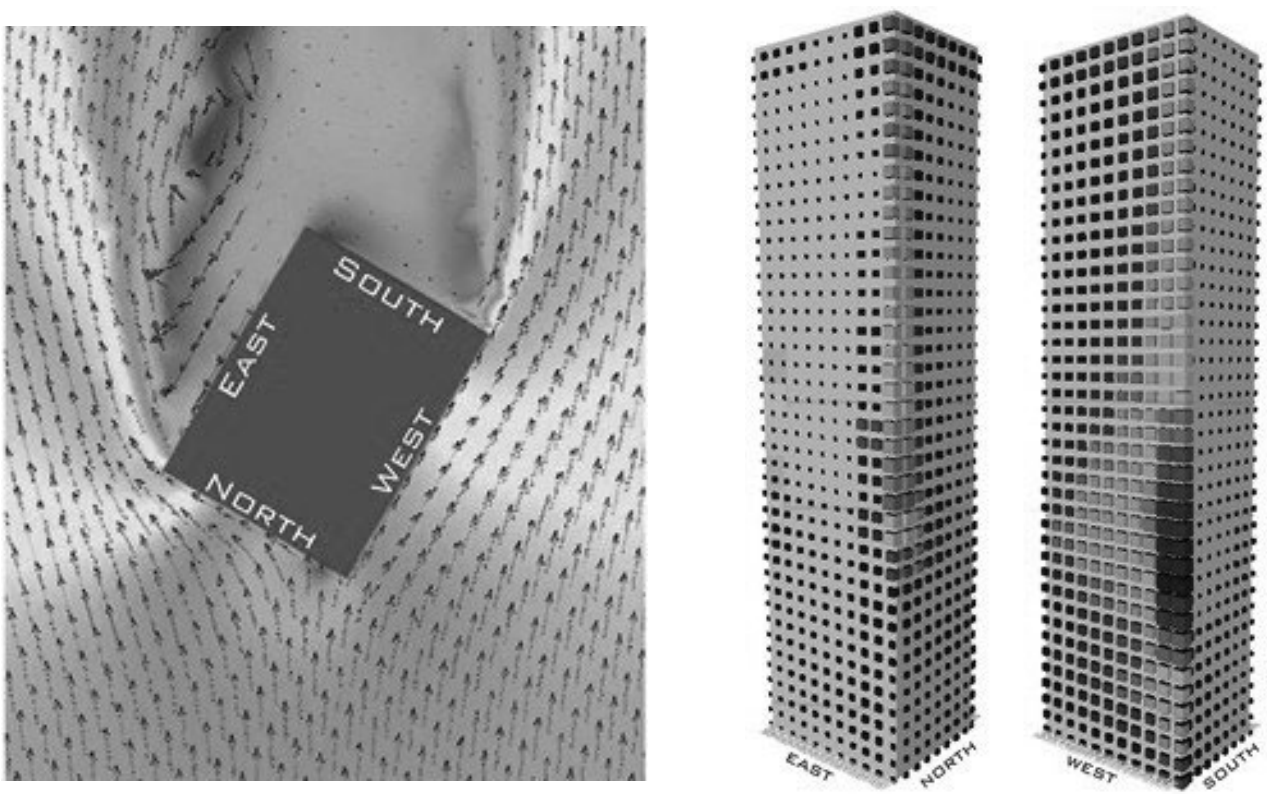

Figure 3: Assocciation of Point Velocities onto the Facade

scale, the controlling variables can be determined by the aesthetic direction of the architecture, the desired functionality provided by further research into maximizing collection, or a combination of both (figure 5).

Based on a predetermined cost per square meter of mesh, the user can also adjust a minimum velocity slider to refine the grid of points to only include those with an associated velocity above that minimum level. The designer can use the tool to visualize the cost per square meter mesh and calculate an estimated total cost, and therefore refine the grid to fit within an estimated budget.

RESULT: BACKGROUND

At a projected 1,070 feet tall, the Salesforce Tower (Pelli Clark Pelli Architects) currently under construction in San Francisco, California will be the tallest super high-rise in the city and second tallest building west of the Mississippi River. The enormity of the architecture's infrastructure will likely prove detrimental to the rapidly growing water crisis of the Southern California area. Based on a report for urban water conservation in California, the expected use of non-potable water (which includes toilet flushing, cooling, and irrigation) for the Salesforce Tower is an estimated 74,506,730 gallons per year (Gleik, Appendix E). With an impact of that magnitude, a look towards an alternative water source provides an opportunity for the testing of the tool.

CALCULATION

Using the building's mass shape and gathering the local San Francisco weather data, an initial calculation of the fog collection potential was run using the MIT stainless steel mesh design. With a total facade area of approximately 53,500 square meters, the average daily collection is approximately 60,716.57 gallons based on an average mesh efficiency of 1.134 gallons of water per square meter of mesh. That provides Salesforce Tower with an annual total of 10.5M gallons of water from fog collection, with an estimated savings of $100,844.70 using San Francisco's current water rate of $7.14 per CCF.

APPLICATION

After providing an initial analysis, the average wind speed and direction was extracted from the 174 optimal fog days in San Francisco to run the CFD simulation needed for determining panel locations. Using this data, several iterations of differing facade typologies were generated with different architectural, aesthetic, performative, and programmatic influences in mind:

- A diamond panel was created as a Revit adaptive component, whose varying scale was determined based on the wind velocity moving past it on the facade. This visually presented the public with the aerodynamic gradient along the entire built form while maximizing collection potential.

Figure 4: Free-form Mesh envelops the Salesforce Tower's peak

Figure 5: Salesforce Tower Facade Iterations: Diamond, Fin, & Free-form

- For maintaining the desired views achieved by the extreme altitude of the building, a vertical fin system was developed that used a refined point grid as controls for creating the vertical elements. This point grid used a wind speed of 2 m/s as its minimum velocity before exporting to ensure application in the most influential areas of facade.
- A final, more free-form facade was developed using the same point grid as the vertical fin system. Unlike the fin system however, the free-form design used the points as controls for a NURBS-curve network. This network worked to cover the most influential areas of facade, layering itself within areas of highest velocity while splitting apart in areas of low velocity to allow for views and daylighting from within.

CONCLUSION

While fog harvesting is the focus of a facade based mesh installation, the highest yield of water collection is from rainwater. An existing Dynamo tool (Damiano) calculates that the total rainwater collection on a vertical facade can be used in conjunction with this fog harvesting tool to generate a total annual water collection for the mesh. On the 75’ x 100’ control geometry, the estimated rainwater collection was an additional 5,993,162 gallons, the combined fog and rainwater harvesting effort reducing the need for potable water by 73.69%.

In addition to potential water collection, the mesh screens can act as solar shading devices for glazing to decrease solar heat gain and increase daylighting comfort within the interior. With this in mind the script could be expanded upon, utilizing the location metrics by aligning the location of each panel with the programmatic daylight requirements of the spaces located inside.

This tool demonstrates the focus of computational design in architecture, understanding and evaluating the real-world scenarios to tackle an unwavering crisis, while educating the designer to find more meaningful and integrated solutions.

ENDNOTES

1. Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katherine Kao Cushing, and Amardip Mann. “Waste Not, Want Not: The Potential for Urban Water Conservation in California.” *Rep. Oakland: Pacific Institute for Studies in Development, Environment, and Security*, 2003. Print.
2. Damiano, Ashley, Beorkrem, C., Ellinger, J.. Kaktos: Facade Based Rainwater collection, Design Modeling Symposium, Paris, 2017.
3. Park, K.; Chhatre S.; Srinivasan S.; Cohen R.; Mckinley G.; 2013: “Optimal Design of Permeable Fiber Network Structures for Fog Harvesting.” Langmuir 29.43: 13269-3277. Web.
4. Roberts, A., 2014: “Predicting the future of global water stress.” MIT News. Web.
5. Schemenauer, R.; Cereceda p; Osses P., 2015: FogQuest - Fog Water Collection Manual. Kamloops, BC: Fogquest, Print.
6. United States. NASA. Langley Research Center, 1994: *Drop Size Distributions and Related Properties of Fog for Five Locations Measured from Aircraft.* By J. Allen Zak. Hampton, VA: NASA. Print.