Rain Drops © 2013 Seniju

DRAINING COMPLEXITY: WORKFLOW FOR DRAIN SIZING OVER DOUBLE-CURVED SURFACES

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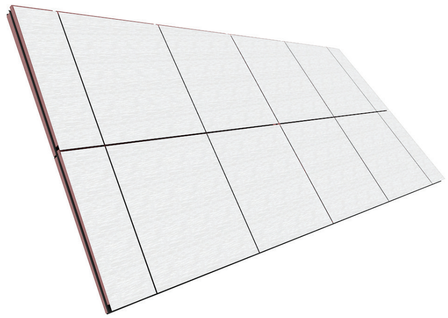
This paper presents the Studios' analysis process, design models and findings from a custom tool and process to determine the drainage paths and quantities across double-curved curtainwall systems. The case study project includes a facade with geometry that requires a custom process to determine where the water will flow on top of and within the curtainwall system. The case study is a double-curved surface facade with orientation rotating from vertical to horizontal. The hybrid nature of this surface creates a set of performance challenges that have not been dealt with before, from the constructability and waterproofing to the stormwater drainage paths and buildup — the focus of this report.

CASE STUDY DRAINAGE STRATEGY

The double-curved facade surface is clad with a metal rainscreen anchored and weather sealed to aluminum gutters that run continuously from the storefront level towards the peak of the tower. The metal rainscreen overlaps the gutter, which has an open joint to the exterior but is weather sealed on the interior side of the joint. This allows the stormwater to flow to the gutter and drain down towards the storefront but keeps it from leaking to the interior of the system. At the top and bottom horizontal joint of the rainscreen, there is a rainscreen gasket which will deflect the majority of stormwater, although some will penetrate and fall into the horizontal gutter that will lead the water back to the vertical gutters. Once the stormwater is in the vertical gutters, it will drain towards the storefront until it hits either one of the balcony openings in the rainscreen, where it will drain to the balcony's drainage system, or to a larger gutter either along the top of the storefront or along the edges of the large inner courtyard.

The challenging aspect of the drainage strategy is sizing the gutters and drains to appropriately handle the stormwater that would accumulate along the drainage paths in a 100-year storm. When dealing with a typical roof, it is fairly simple to calculate the accumulation of water using a 100-year storm map and a roof plan. In New York City, the 100-year storm rate is 3.0 inches of rainwater per hour as defined in the New York City Plumbing Code Section 11061.1. Thus, each square foot of a roof receives 0.25 cubic feet of water per hour. With the total area of the roof and the quantity and layout of roof drains, the quantity of water each drain will receive in a 100-year storm can be calculated, and the drain can then be sized to accommodate that maximum volume. For this case study, however, with each rainscreen panel angled at a different angle, the drainage slope was not easily determined to define how much of the stormwater falling on each panel would flow to the vertical or horizontal



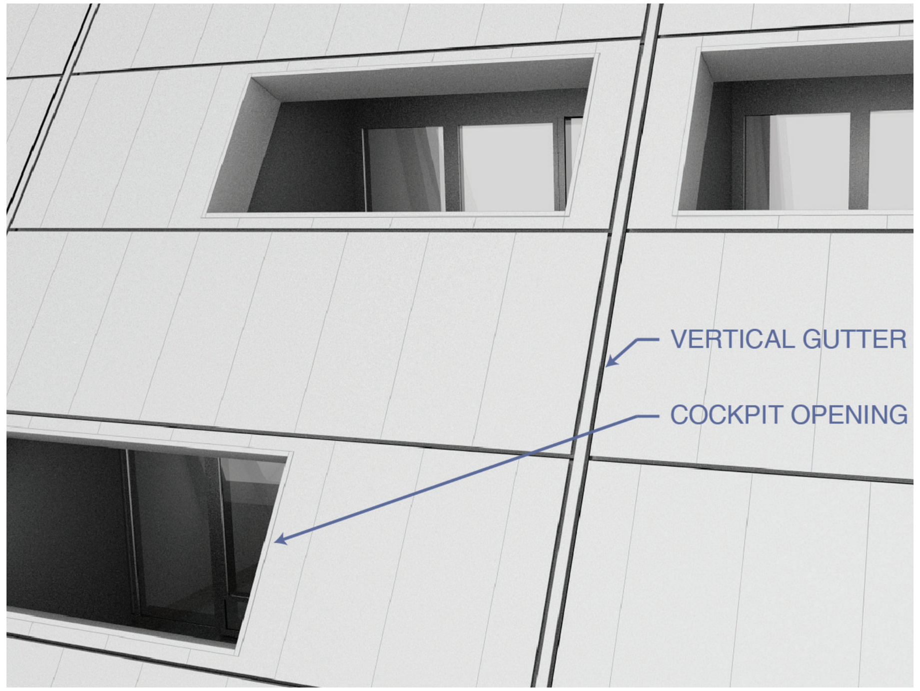


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FIGURE 1
The case study is a double-curved hybrid curtainwall rainscreen system that necessitates custom tools for drainage analysis.

FIGURE 2
Water drains either to the vertical gutters on each side of the panel or to a drain on the balcony within the balcony opening.

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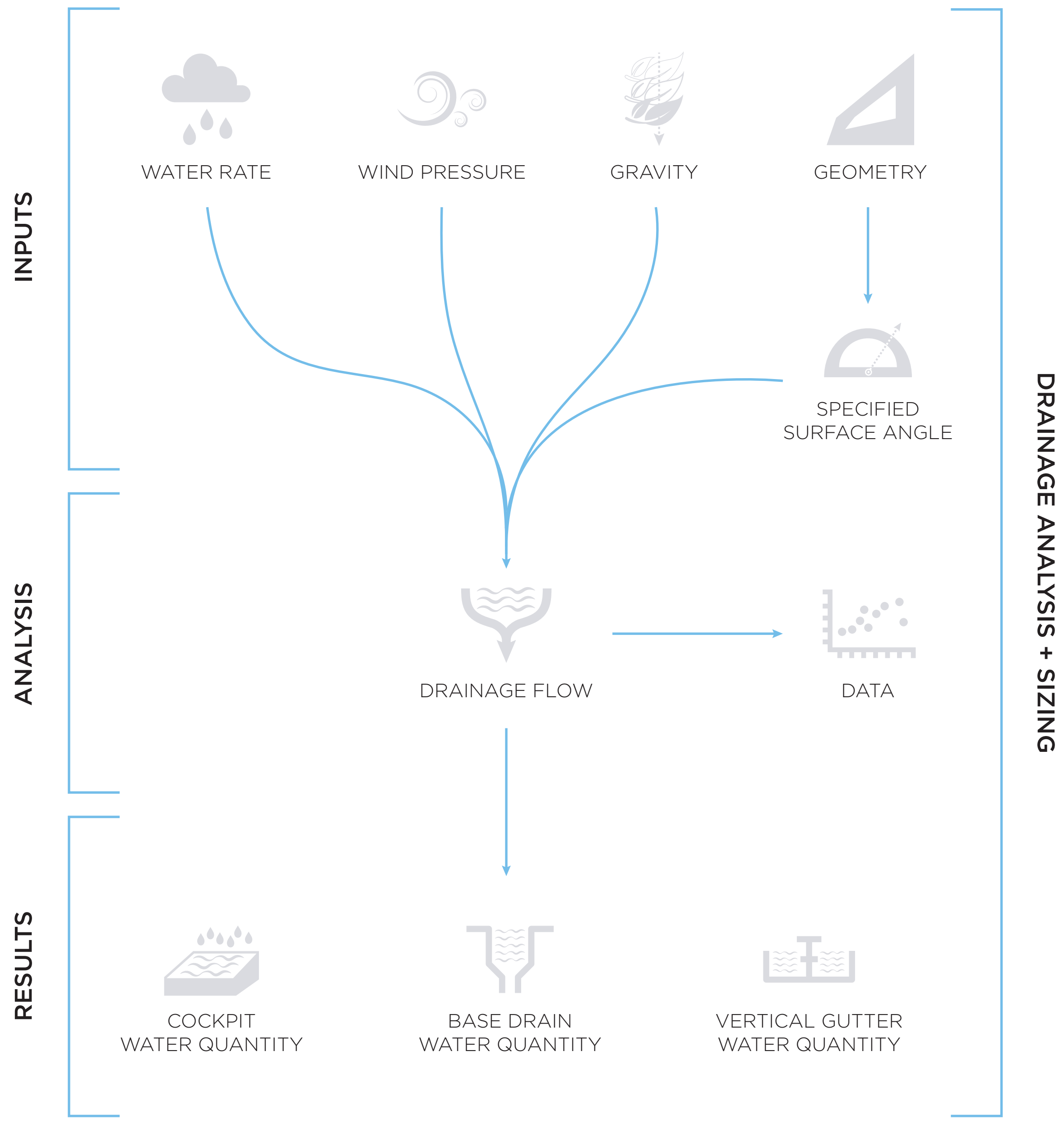
FIGURE 3
Input-output diagram for drainage analysis and sizing across the double-curved surface.

gutters and how much would flow directly to the rainscreen panel below it. The analysis is complicated further by the irregular pattern of balcony openings, one of the final destinations for stormwater.

METHOD

Today, computational fluid dynamics (CFD) can be used to solve a variety of building physics problems. These range from designing the mechanical systems for human comfort to assessing the energy consumption of a specific building design. CFD methods solve the mathematical equations that describe the motion of fluids. Grid-based fluid implementations have been favored in computer simulations in building technology for the last decade. However, when it comes to detailed fluid simulations of large models, these techniques are not optimal. Recently, particle-based solutions have been introduced into CFD techniques. It is our understanding that particles have proven to be a good choice for large-scale fluid simulations that allow for the study of large models where the relative accuracy is of the primary importance.

The smoothed-particle hydrodynamics (SPH) formulation has been widely used to simulate astrophysical phenomena, where complex problems can be expressed and understood more intuitively. SPH is an interpolation method to approximate values and derivatives of continuous field quantities by using discrete sample points. The sample points are identified as smoothed particles that carry concrete entities (e.g., mass, position, velocity, etc.), but particles can also carry estimated physical field quantities dependent on the problem (e.g., mass-density, temperature, pressure, etc.). The SPH quantities are macroscopic and obtained



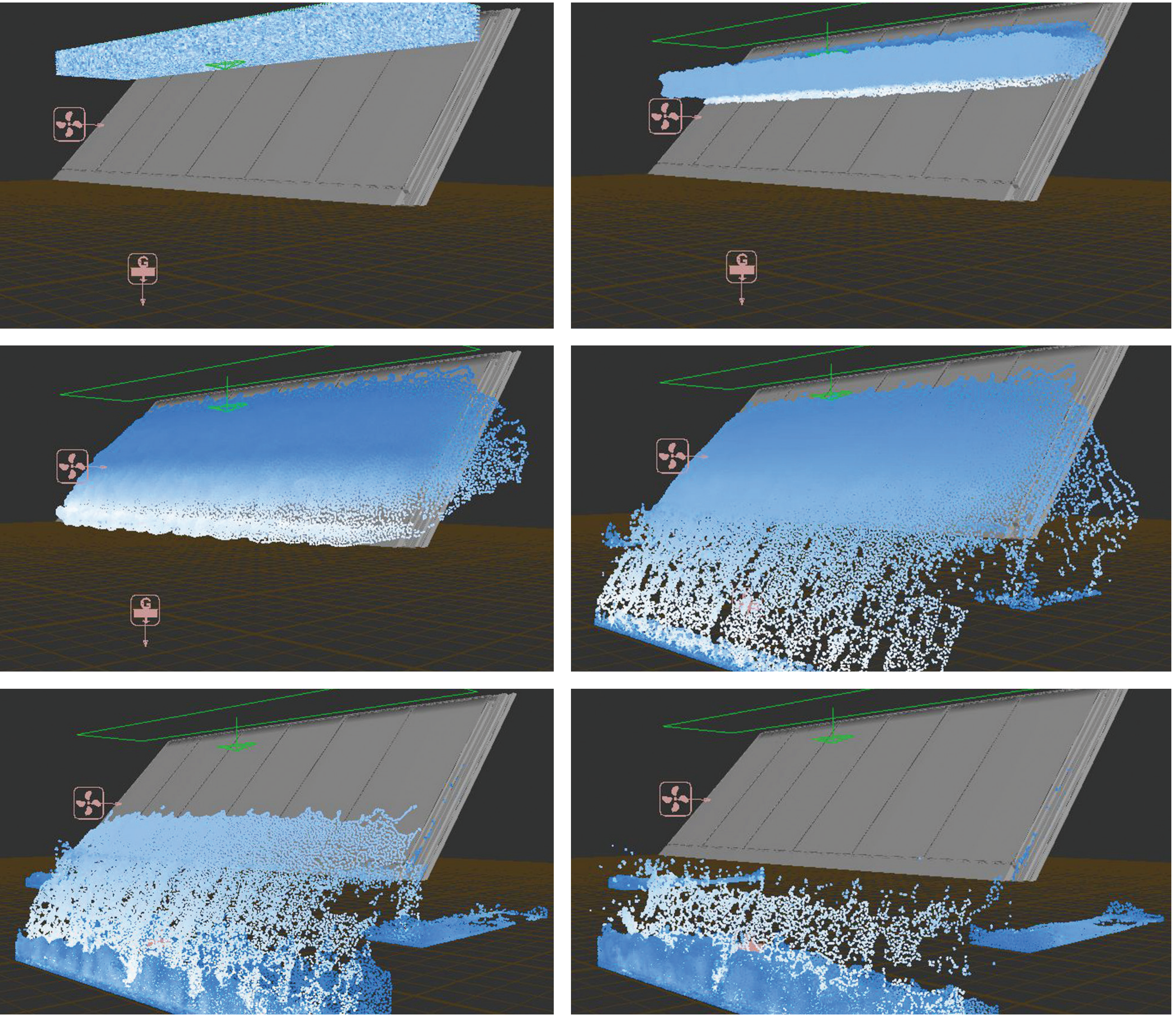


FIGURE 4
RealFlow particle analysis of typical panel angled at 55° slope from horizontal.

as weighted averages from the adjacent particles. Compared to other methods for numerical approximation of derivatives (e.g., the finite difference method, which requires the particles to be aligned on a regular grid), SPH can approximate the derivatives of continuous fields using analytical differentiation on particles located completely arbitrarily. Each particle is thought of as occupying a fraction of the problem space, and to get more accurate weighted quantity averages, the sample particles must be dense.

In the analysis to follow, the Studio utilized the RealFlow software developed by Next Limit Technologies. This software is a complete stand-alone fluid application that utilizes the SPH method and supports different types of fluids (e.g., gases and liquids). RealFlow calculates the particle motions to simulate fluid flows that are designed by an end user. The computed particle motions, together with other particle attributes, are then exported from the program to compute the distribution of the flow in the various regions of the model.

In this study, RealFlow is utilized to determine the percentage of stormwater, approximated as RealFlow particles, that flows to either the vertical gutters or the rainscreen panel below at the following angles: 5°, 15°, 25°, 35°, 45°, 55°, and 65°. The environmental conditions that affect the flow are gravity, wind pressure and surface tension of the panels. The results are used as input for an iterative algorithm defined in Grasshopper to sum the accumulated stormwater at each panel, vertical gutter and balcony on the sloped facade.

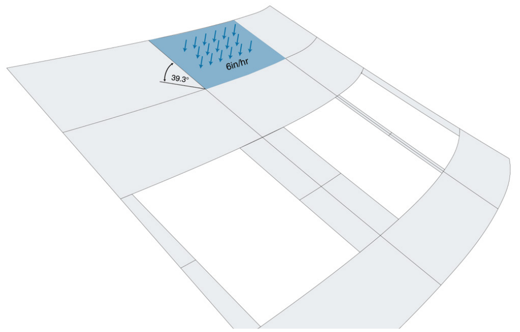
In Grasshopper, a visual object-oriented programming plug-in for Rhinoceros3D, a custom algorithm was defined in VB.NET to determine the angle of each panel and apply the appropriate RealFlow results to that panel. The 6.0 inch/hour storm rate (a safety factor of 2.0) is applied to each panel to determine the volume of stormwater that flows to either the vertical gutter or rainscreen panel below. This algorithm is iterated for each bay of panels using a custom Grasshopper component, Hoopsnake, developed by Yannis Chatzikonstantinou, to sum the stormwater that falls directly onto the rainscreen panel with the percentage of accumulated stormwater that will flow from the rainscreen panel above. Where there is a balcony opening, the algorithm determines the volume of water that it receives as well as the quantity that continues to flow past it to the panels below.

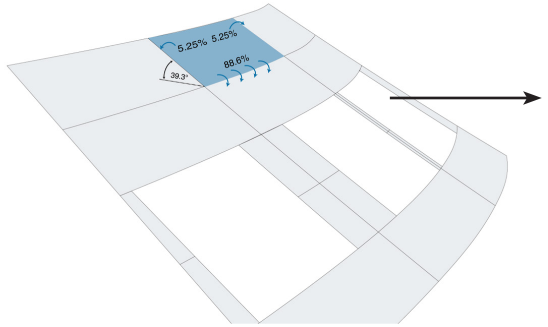
RESULTS

For a 100-year storm, the Studios used a safety factor of 2.0, doubling the rainfall to 6.0 inches of rain per hour. Per our assumptions, the majority of vertical gutters will accumulate less than 100 ft^3 of water if there are no intermittent downspouts draining the vertical gutters to the balconies. The worst case scenario is at the vertical gutters between panel bay F and G, where the water accumulation is 168.52 ft^3 due to low-angle panels which direct more water to the vertical gutters.

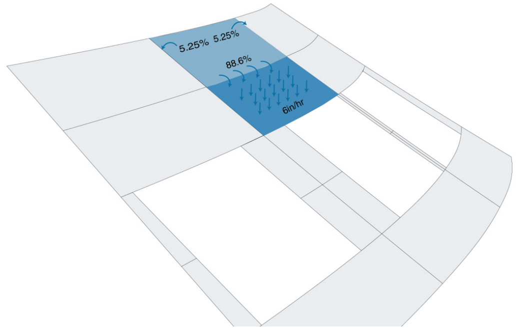
Per our assumptions the majority of balconies will receive less than 100 ft^3 of water and less than 1.5 ft^3 per projected square foot of the balcony. The worst case scenario for total volume is at balcony D9 at 1407.92 ft^3. However, it only receives 0.96 ft^3/sq-ft. The worst case scenario for total volume per projected square foot is at balcony V6 at 3.79 ft^3/lf.

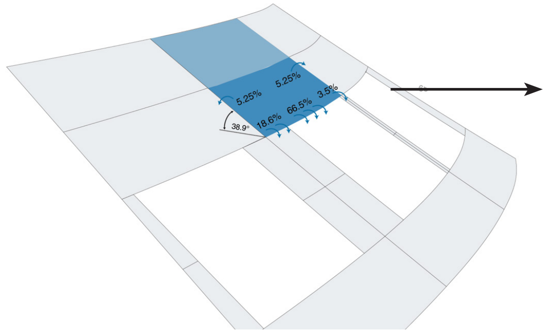
Per our assumptions the majority of base drains will receive less than 100 ft^3 of water and less than 4 ft^3 per linear foot. The worst case scenario is at panel bays C and F, where the water accumulation is 17.30 and 15.67 ft^3, respectively, per linear foot of the base drain, due to the absence of a balcony near the bottom of these panel bays.





PANEL	PANEL BELOW	VERTICAL GUTTER	ON PANEL
5°	62.2%	32.2%	0.6%
15°	81.2%	16.6%	0.2%
25°	87.8%	10.9%	0.1%
35°	88.6%	10.5%	0.9%
45°	89.2%	10.3%	0.5%
55°	89.6%	10.1%	0.3%
65°	89.9%	10.0%	0.1%





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55°	89.6%	10.1%	0.3%
65°	89.9%	10.0%	0.1%

FIGURE 5
The first step of our Grasshopper algorithm is to calculate water accumulation for the square footage of a panel during a 6.0 in/hr rainstorm.

FIGURE 6
Based on the angle of the panel, the accumulated stormwater flows either to the panel below or to the vertical gutters.

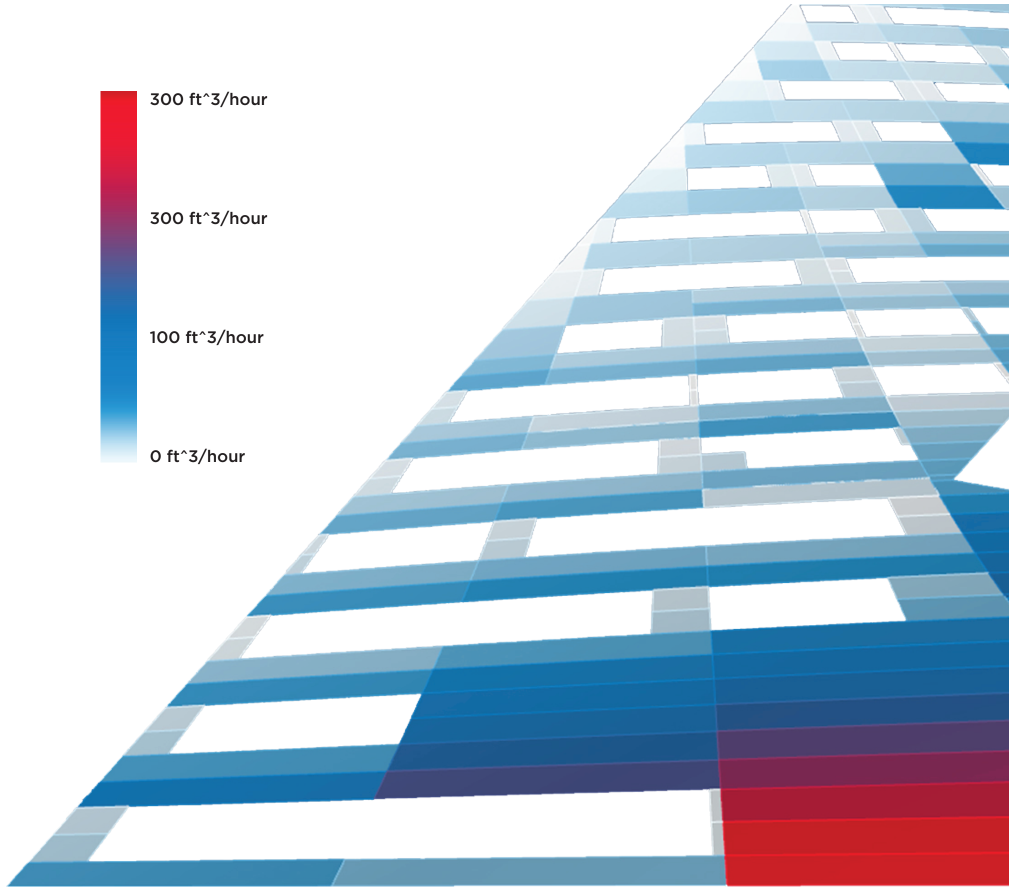
FIGURE 7
The percentage of accumulated stormwater from the panel above is added to the 6.0 in/hr rainwater of the next panel.

FIGURE 8
Based on the angle of the panel, the accumulated stormwater from the panel above and the rainwater falling directly on the specified panel, water flows either to the panel below or to the vertical gutters. If there is a balcony opening below the panel, a proportion of the water to the balcony drain.

FIGURE 9
Stormwater accumulations on rainscreen panels during a 6.0 in/hr rainstorm.

CONCLUSION

The first step in the process, the RealFlow smoothed-particle hydrodynamics analysis, revealed that aside from the extremely horizontal panels with a normal vector at the centroid of their surface around 5° and 15° from vertical, the vast majority of the particle flow was to the panel below, rather than to the vertical gutters. At 5° and 15°, respectively, 62.2% and 81.2% of the particles flowed to the panel below and 32.2% and 16.6% flowed to either the left or right vertical gutter of the panel. However, the particles dropped onto the panels angled at 25°, 35°, 45°, 55°, and 65° away from vertical acted very similarly. For these panels, the percentage of particles that flowed to the panel below gradually increased from 87.8% to 89.8%, and the percentage of particles that flowed to the vertical gutters gradually decreased from 10.9% to 10.0% as the panels tilted up towards 65°. A small portion of the particles, less than 1%, remained on the surface for all of the panel angles due to the surface tension of the panel. The double-curved panels quickly transition from behaving like a roof-type surface when angled at 5° and 15° from vertical, with water flowing off the crown of the curved surface to the sides, to behaving more like a traditional facade when angled over 25°, with water flowing predominantly down as the angle of the panel minimized the effect of the double-curved geometry of the panel.



In the second phase of the study, the iterative algorithm developed in Grasshopper, it became apparent that the location of balcony openings is as much or more of a factor than the tilt of the panel in regards to the volume of stormwater accumulation on each panel. Water quickly accumulates on panels that are tilted 25° from the vertical or greater, as only about 10% of the water sheds to the vertical gutters and the rest flows to the panel below. In the locations on the facade that have a continuous run of panels without a balcony, water accumulates at an even greater rate. Even as few as three panels in a row without a balcony opening can lead to large stormwater accumulation. If a continuous run of panels is located where the tilt is greater than 25°, where the panels square footage is greater, or where the run of panels is several more than three in a row, the accumulation multiplies at a much quicker pace.

This study applied the custom tool and process developed by the authors to a case study double-curved surface to identify the areas of large stormwater accumulation and the places where the water would flow. This information could be used to size gutters integrated into curtainwall system as well as the gutters and drains of the building water management system.