Investigating the Impact of Urban Layout Geometry on Urban Flooding

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Abstract— **In this paper, we use a procedural generation system to design urban layouts that passively reduce water depth during urban floods. The tool enables designing cities that passively lower flood depth everywhere or in chosen key areas. Our approach integrates a porosity-based hydraulic model and a parameterized urban generation system with an optimization engine so as to find the least cost modification to an initial urban layout. In order to investigate the relationship between urban layout design parameters and flood inundation depth, correlation coefficient method is used. This paper concludes that the most influential urban layout parameters are average road length and the mean parcel area.**

Keywords- inverse procedural modeling; urban layout design; porosity-based hydraulic model; Pearson correlation; urban flooding.

I. INTRODUCTION

Structural flood controls such as levees, dams, and dikes have been widely used to reduce flood impacts. However, these structural measures have been criticized because they interrupt flooding processes by reducing natural water storage capacity and disrupting water flow paths [1] [2]. Currently, there is a shift from hard flood controls towards a more strategic approach characterized by mitigating flood risk and increasing resilience during the urban design process [1] [3]. This study uses a procedural generation system, proposed by [4], that automatically generates 3D urban layouts that consider the influence of geometric urban characteristics (e.g., road width, orientation, curvature, etc.) on water flow properties during urban flooding. Using this system, we explored urban geometric grammars that help reduce flooding, i.e., what urban design rules produce a passive barrier against natural floods?

The procedural generation system [4] consists of three components. First, it represents an urban area by dividing it into cells of 1×1 kilometers. For each cell, the system defines a parameterized procedural model that can generate a wide range of possible urban layout configurations. Second, a porosity-based hydraulic model computes the water flow characteristics of a proposed urban layout cell. Third, the system approximates the relationship between urban layout and flood flow characteristics with a trained neural network. The main contribution of this paper is the measurement of a statistical relationship between urban layout design parameters and water depth during a flood, which, to our knowledge, has not been done before.

The rest of this paper is organized as follows: Section II presents our methodology. Section III presents and discusses our findings. Section IV gives conclusions and as well as suggestions for future study.

II. METHODOLOGY

Altogether, our procedural model is controlled by a 10-dimensional parameter vector. These parameters are selected according to a literature survey of common parameters involved in previous studies [5] [6] [7]. In the following, we describe each parameter:

- average road length (P1) -- the distance between two adjacent intersections,
- road orientation (P2) -- orientation of the initial radially-outward road relative to lower-left corner,
- road curvature (P3) -- rotation of a road segment when it passes through an intersection,
- major road width (P4), and
- minor roads width (P5).

Parcels are defined based on a recursive subdivision of oriented bounding boxes (OBB) fit around each city block as in [6]. Parcels are controlled by the following parameters:

- percentage of parcels selected as parks (P6), and
- average parcel area (P7).

Buildings are generated with the following parameters:

- front (P8),
- rear (P9), and
- side (P10) building setbacks.

Our flooding depth simulations are performed by WOLF 2D model [8] [9]. Our hydraulic model focuses on river-based flooding scenarios.

By means of Pearson correlation, we explore the relationship between urban layout design parameters (P1-P10) and inundation depth. The system randomly generated 2000 urban layouts with built-up coverage of 20%, 30%, 40%, and 50% (500 layouts for each built-up coverage).

III. RESULTS AND DISCUSSION

Although some urban layouts might not be represented accurately, the proposed urban generation system supports a

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wide variety of typical urban layouts, which enables us to effectively find the desired layouts from an otherwise huge search space (Figure 1).

Based on several case studies, our findings highlighted that the impact of geometric characteristics of urban patterns (e.g., street width, park ratio, etc.) on flow properties during urban floods is significant. This is especially important for accurate flood/water simulations and for city planners concerned with flooding. Our approach can reduce water depth by proposing layout changes during the design phase of an urban space. Figure 2 (top) demonstrates that our system reduced flood inundation depth by about 6% keeping the same build-up coverage. Moreover, we can increase built-up coverage and keep the same inundation depth (Figure 2-bottom). This is done by only reconfiguring urban layout design without any additional flood controls. The computed water depths are minimum at the downstream faces and maximum at the upstream faces, because of the overall flow resistance induced by the buildings.

Figure 3 shows the Pearson correlation analysis for the relationship between urban layout parameters and flood inundation depth. The Pearson correlation value ranges from -1 for a perfect negative linear relationship to +1 for a perfect positive linear relationship. The value 0 indicates no linear relationship. The results reveal that P1 (average road length) shows the strongest relationship with inundation depth.

Figure 1. Real-world layouts versus procedural urban generator layouts.

This relation is positive implying that the inundation depth increases by increasing the average road length.

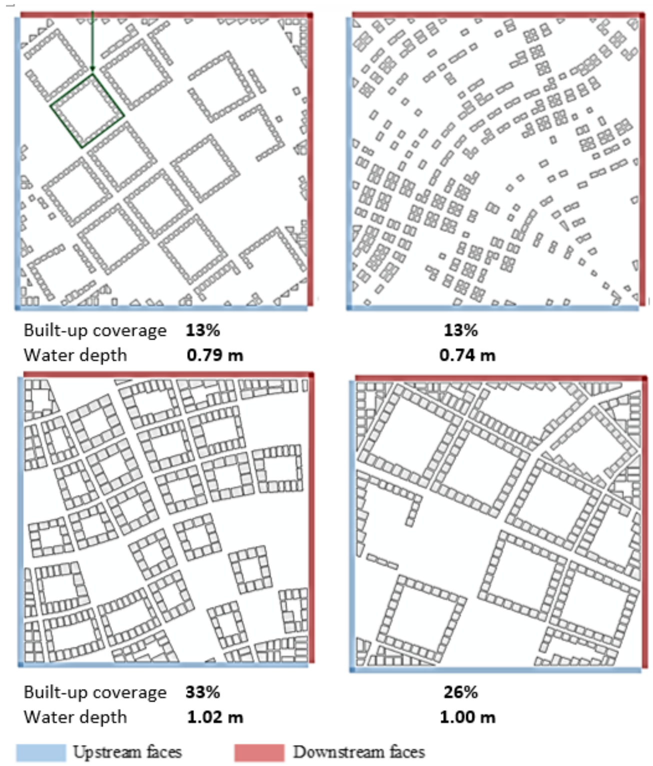

Figure 2. Built-up coverage and flood inundation depth (under the same inundation conditions) in 4 layouts generated by procedural modeling.

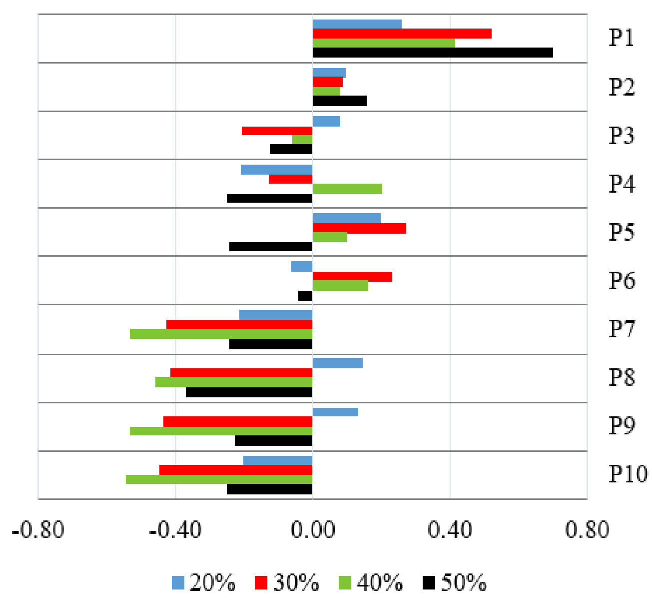

Figure 3. Pearson correlation coefficients that measure the strength and direction of a linear relationship between urban layout design parameter and flood inundation depth considering three built-up coverages (20%, 30%, 40%, and 50%).

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P7, P8, P9, and P10 (average parcel area, front, rear, and side building setbacks respectively) have a strong negative relation with inundation depth. The rest of the variables (P2, P3, P4, P5, and P6) show a weak relation with inundation depth. More importantly, the relation between each variable and inundation depth varies based on the built-up coverage.

IV. CONCLUSIONS

This paper used an automatic design approach for urban procedural modeling coupled with a hydraulic model to investigate the relation between urban layout design and flood inundation depth. We systematically explored the inundation flow in quasi-realistic urbanized areas, which links hydraulic modeling results with parameters of direct significance for urban planning. Based on porosity-based hydraulic computations of inundation flow for a set of 2000 different urban layouts, the relative influence of ten urban layout parameters (average street length, street orientation and curvature, major and minor street widths, mean parcel area, rear and side building setbacks and building coverage) on flood inundation depths were assessed. We found that the most influential urban layout parameters were average road length, the mean parcel area, and the building side-setbacks. This work helps with providing guidelines for urban planners to design flood-resilient cities.

An important next step in the research is the analysis of real-world case studies, which would showcase the operationality of our system and therefore increase the impact of this assessment tool for urban planning practice.

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