MARSH

An innovative model for integrating water sensitive urban design in architectural practice

Kyratsoula-Tereza Papanikolaou [1], Ioannis Sibetheros [2], Katherine Liapi [3], Evangelia Vlachaki[4]
[1,3,4] Department of Architecture, University of Patras [3] Department of Civil Engineering, University of West Attica
[1] arc888@upnet.gr [2]sibetheros@uniwa.gr [3]kliapi@upatras.gr [4] arc935@yahoo.gr

This paper introduces MARSH (Model for Assessment of Runoff and Stormwater Harvesting), an architect-friendly urban water model designed for 3D stormwater scenario assessments, integrating Water Sensitive Urban Design (WSUD) principles into architectural practice. Developed in the context of a funded research project UBWARMM (Urban Best Management Practices Model for Rainwater Management) and implemented in Grasshopper, MARSH serves as a comprehensive 3D toolkit for architects to evaluate stormwater scenarios effectively. The purpose of the model is to facilitate sustainable stormwater management and therefore runoff mitigation, and rainwater harvesting enhancement. Key components, including the Time Period Precipitation Calculator, Incident Radiation Analyses, BMP Library, Rainwater Harvesting Cistern Component, Roof/Inner Block Void Runoff Calculator, and Runoff Visualization, contribute to MARSH's robust structure. The conceptualization outlines precise data requirements, incorporating historical climate data and geometry datasets. Assessing Best Management Practices (BMPs) performance, MARSH delivers both numerical outputs (irrigation percentages, runoff reduction) and visual representations. MARSH's objectives encompass simplified processes, light data entry, accurate simulation, flexibility, a user-friendly interface, and result visualization. The research explores estimation methods, utilizing the Penman-Monteith equation for BMPs irrigation demands and the Soil Conservation Service Curve Number (SCS-CN) method for runoff estimation, addressing challenges related to runoff control and irrigation considerations. The model's adaptability, user-friendly interface, and visualization tools facilitate informed decision-making, in regions where WSUD integration is of critical importance. Validation through a case study in Athens provides insights for future studies, showcasing adaptability to different timeframes and scalability for city-scale applications. The potential of MARSH for both micro and macro-level stormwater management applications is also discussed in the paper.

Keywords: *Urban Water Management, Water Sensitive Urban Design (WSUD), Stormwater Management, Grasshopper, Sustainable Practices, 3D Visualization, Best Management Practices (BMPs), Rainwater Harvesting*

INTRODUCTION

Rapid urbanization in cities worldwide has disrupted the natural water cycle, mainly due to increased urban density, impermeable surfaces, and insufficient green spaces. Meanwhile, traditional stormwater management methods prioritize rapid collection and drainage, leading to decreased infiltration and evaporation. These changes, coupled with the projected increase in extreme rainfall events due to climate change (extremes (Myhre et al., 2019; Liu et al., 2019b; IPCC 2022 cited in Cristiano et al., 2022), have significant implications for urban environments. This research focuses on Athens, Greece, which has undergone rapid urbanization since the latter half of the 20th century, resulting in a transformation of the natural water cycle to an urban water cycle. This shift has resulted in challenges such as reduced water supply, adverse local climate effects like the urban heat island effect, heightened pollution in water bodies, and increased flood risks. To address these challenges, there has been a global shift towards Water Sensitive Urban Design (WSUD), which aims to mimic natural water cycles and integrate natural water treatment systems into urban planning. Implementation of WSUD involves utilizing Best Management Practices (BMPs) at various scales, including green roofs, permeable paving, and rainwater harvesting. According to Papanikolaou K. *et al.* (2022) , regarding Greece, urban blocks are an ideal scale for stormwater BMP retrofitting due to their characteristics. Implementing BMPs in urban blocks could yield significant benefits, including runoff mitigation and evaporative cooling during summer periods.

In the context of the UBWARMM research project (Urban Best Management Practices Model for Rainwater Management), a computational model has been developed named "MARSH", which stands for "Model for Assessment of Runoff and Stormwater Harvesting." The model serves as a decision-support tool for architects, facilitating the simulation of different BMP implementation scenarios for stormwater management in existing urban blocks. It incorporates components for estimating runoff, evapotranspiration, and visualizing scenarios. By bridging the gap between WSUD principles and architectural practice, MARSH aims to contribute to more sustainable urban development practices, particularly in countries like Greece where WSUD is not widely implemented in architecture programs and professional offices.

The key features, as described by Papanikolaou K. *et al.* (2023) of the architect-friendly urban water model are as follows:

- **Simplified Processes:** The model simplifies complex natural processes using widely accepted concepts, making it accessible to architects and urban planners with limited hydrological knowledge.
- **Light Data Entry:** Minimizes data entry requirements by utilizing existing data sources and automating input where possible, saving time and reducing the need for specialized data collection.
- **Accurate Simulation:** Balances simplicity with precision to provide architects with reliable information for making informed decisions on stormwater management strategies.
- **Flexibility:** Adaptable to different urban blocks in Athens, Greece, and other cities worldwide, by adjusting climate data and BMP libraries to specific geographic and climatic conditions.
- **User-Friendly Interface:** Features an intuitive layout with clear instructions and interactive elements, enabling easy navigation for architects and urban planners without technical barriers.
- **Visualization of Results:** Presents outcomes on a 3D drawing of the urban block using Rhino and Grasshopper software, facilitating comprehensive evaluations and efficient comparisons ~~between~~ of stormwater

management strategies. Helps architects effectively communicate design proposals to clients, stakeholders, and communities.

The model bridges the gap between WSUD and mainstream architectural practice, offering practical solutions for incorporating sustainable water management principles into architectural design. As the model evolves and more meteorological and other data is incorporated into it, it has the potential to become an essential tool for architects and urban planners undertaking retrofitting projects ~~in~~ not only in Athens but in other cities around the world with similar climatic and urban conditions.

MODEL CONCEPTUALIZATION

MARSH provides an innovative solution for tackling stormwater runoff management challenges. Currently, it evaluates the effectiveness of Best Management Practices (BMPs) in reducing stormwater runoff within the Athens urban area, with the flexibility to adapt to other cities or countries by adjusting climate data. By utilizing advanced data analysis, climate simulation, and 3D visualization, the model offers valuable insights into effective stormwater management strategies. Figure 1 illustrates the model's structure, categorized into four main sections: 1. Analysis Period; 2. Data Requirements; 3. Model Components; 4. Outputs.

1. Analysis Period

The model's assessment timeframe, set by its start and end dates, determines the time period for which stormwater management strategies are evaluated.

2. Data Requirements

- *Climate Data:* Historical climate records from the EnergyPlus file and site-specific precipitation data in Athens serve as the basis for climate simulations and runoff calculations.
- *Geometry Data:* To accurately represent the study area, the model relies on four essential geometry datasets:

- *As-Built Geometry of Buildings:* Detailed data on existing buildings to evaluate their impact on stormwater runoff.
- *As-Built Geometry of Inner Block Void:* Geometry data for internal open spaces affecting local runoff patterns.
- *Context Building Geometry:* Surrounding building geometries provide context for runoff analysis and urban drainage behavior.
- *BMP Surfaces:* Precise surface area data for BMPs selected from the BMP Library.

3. Model Components

MARSH consists of several interconnected components essential for the analysis:

- *Time Period Precipitation Calculator:* Computes precipitation data for the specified assessment period, influencing BMP performance evaluations.
- *Incident Radiation Analysis:* Evaluates solar radiation exposure, crucial for assessing BMP placement.
- *BMP Library:* Individual components for green roof, living wall, raingarden, tree, and pervious pavement simulate the behavior of each BMP.
- *Rainwater Harvesting Cistern:* Models rainwater collection and storage to reduce reliance on network water supply for BMP irrigation.
- *Roof/Inner Block Void Runoff Calculation:* Determines runoff from rooftops and internal open spaces based on their properties and BMP coverage.
- *Runoff Visualization:* Presents a visual representation of runoff reduction achieved by integrated BMPs, aiding decision-making.

4. Outputs

The model provides valuable numerical and visual results for assessing stormwater management strategies:

- *Numerical Outputs:*

- *Irrigation from Network Water Supply System (%):* Percentage of water from the network used for irrigation.
- *Irrigation from Cistern(s) (%):* Percentage of water from rainwater harvesting cisterns used for irrigation.

- *Irrigation from Precipitation (%):* Percentage of water directly used from precipitation for irrigation.

- *Runoff Reduction (%):* Overall reduction in stormwater runoff achieved through BMP implementation.

- *Visual Outputs:*

Visualization of Runoff Reduction: Representation of runoff reduction across the study area in a 3D environment, aiding in BMP selection.

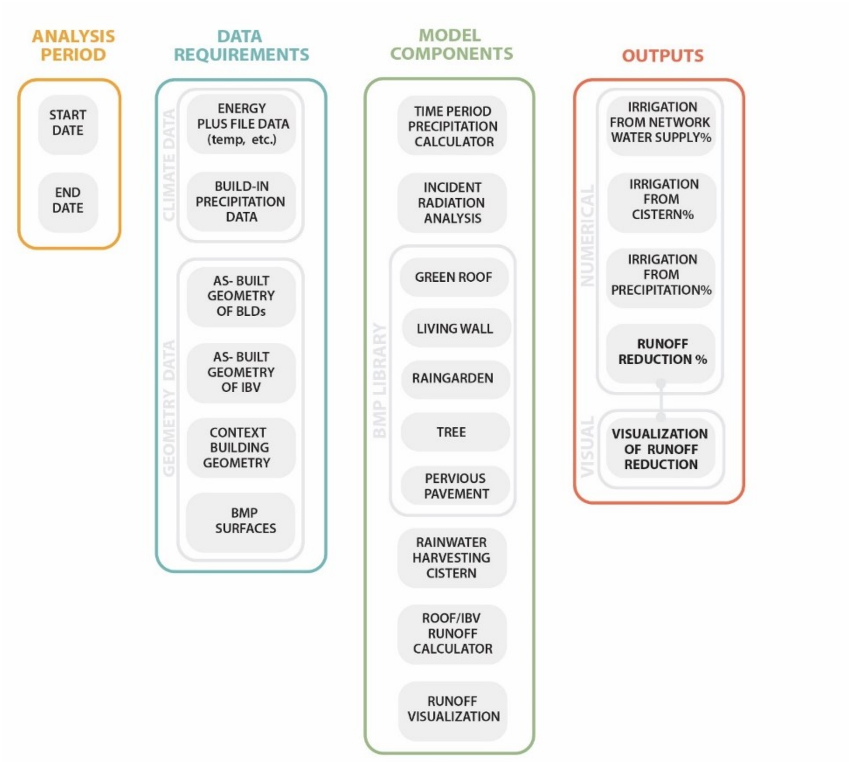

Figure 1
Model structure diagram in 4 categories: Analysis period, Data requirements, Model Components, outputs

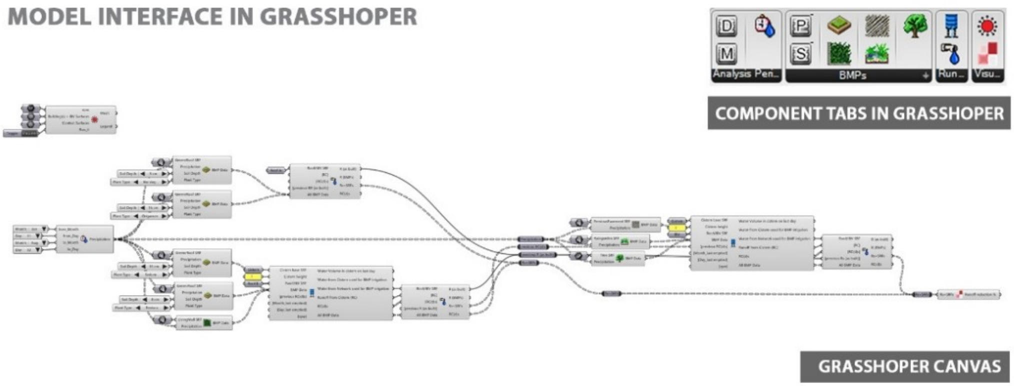

Figure 2
Component tabs of model and example of the model components linked to each other on the Grasshopper canvas

MODEL DEVELOPMENT

MARSH was developed using Grasshopper, leveraging its visual programming capabilities (see Figure 2). Python programming was also integrated to manage algorithms related to water management within the cistern. As a plugin for Grasshopper, the model's interface consists of a series of tabs in the Grasshopper Ribbon and a canvas where components are interconnected. These tabs provide access to various categories of model components, allowing users to add required functionalities to their designs. Components on the Grasshopper canvas are represented as icons, each performing a specific task, and connected by lines indicating data flow (see Figure 2).

WATER CYCLE IN THE MODEL

The urban water cycle involves both inputs and outputs, each playing a role in the dynamic movement of water within urban environments. In the context of the model, inputs to the urban block water cycle consist primarily of precipitation, including rainfall and other natural water sources, as well as water from the supply pipeline network. Conversely, outputs encompass evapotranspiration and runoff (see Figure 3).

Evapotranspiration represents water loss due to both surface evaporation and plant transpiration. The Penman-Monteith method for reference crop evapotranspiration estimation (ETo) is employed in the model, recognized for its accuracy and widespread acceptance across various climates. According to Mecham (1996), cited in Tegos (2013) it has demonstrated excellent performance in both arid and humid climates and has been found to be the most accurate method for estimating the water needs of turfgrass.

Runoff refers to excess water that does not infiltrate into the ground but instead flows over surfaces, ending up into the drainage system or a water body. The Soil Conservation Service Curve Number (SCS-CN) method was chosen for the runoff estimation due to its simplicity, well-documented nature, and global acceptance among engineers and water practitioners. This method, relying on a single parameter known as the curve number (CN), is appreciated for its ease of implementation and consideration of various factors influencing runoff generation, as highlighted by Ponce and Hawkins as cited in Soulis, K. X. (2021).

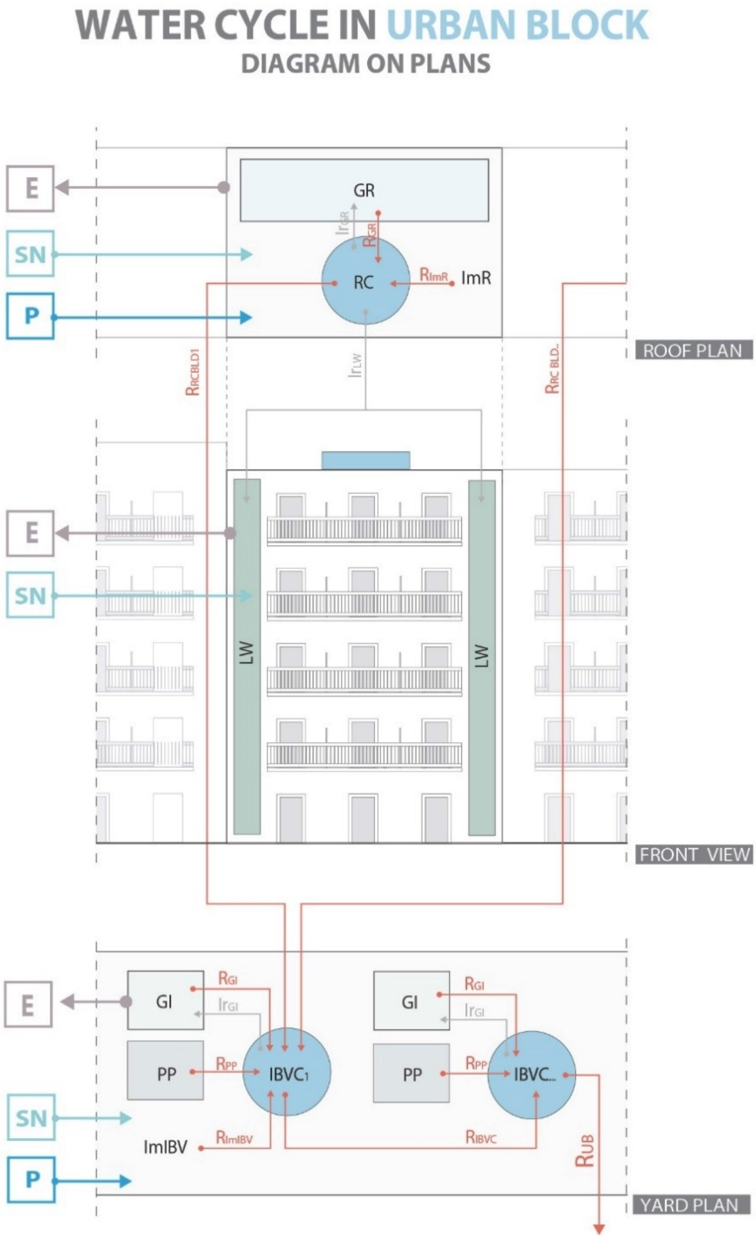

Figure 3
Generic diagram of water circulation from building rooftop to inner block void
SN=Supply Network
P=Precipitation
GR=Green Roof
RC=Rainwater harvesting Cistern
LW= Living Wall
GI= Green Infrastructure
PP= Pervious Paving
ImIBV= Impervious Inner Block Void surfaces
IBVC=Inner Block Void Cistern
R=Runoff
ImR= Impervious Roof surfaces
Ir= Irrigation
UB= Urban Block

CASE STUDY: URBAN BLOCK

According to Gerolymbou et al., (1986) the urban blocks in Greek cities are considered as the basic organizing cells of the urban space. The selected urban block for the case study is situated in the heart of Athens, bounded by Vassilisis Sofias, Mihalakopoulou, Lourou, and Semitelou streets. Its strategic location places it near notable landmarks such as the American Embassy and the Athens Music Hall. Typically, buildings within this block consist of 5 to 6 floors, accommodating a mix of apartments, offices, and ground-floor spaces for retail outlets or entrance halls. Some buildings also feature under-basement levels. Architecturally, the block exhibits consistent traits such as stepped setbacks on upper floors, narrow balconies along facades, and underutilized or unused rooftop areas.

The objective of the model testing involved creating two distinct scenarios. In the first scenario, a comprehensive set of Best Management Practices (BMPs) from the model's BMP Library was applied to the study area, excluding rainwater harvesting systems. The second scenario mirrored the first but included the integration of rainwater harvesting systems into the BMPs. The focus was on analyzing the impact of these scenarios on runoff mitigation without considering structural parameters, as structural adequacy was not a concern in the model's current developmental phase.

MARSH BMP Library Components and Rainwater Cistern Components were introduced to the Grasshopper canvas to incorporate BMP geometries and additional data. This facilitated the visualization of BMPs, represented by varying colors on the 3D model of the urban block in Rhino.

SIMULATION RESULTS

In the first scenario, buildings within the urban block operate without rainwater harvesting cisterns. Runoff mitigation and irrigation rely primarily on conventional drainage systems and the network water supply. Simulation data reveals varying degrees of runoff reduction, ranging from approximately 15.3% to 29.9% across different rooftops during the annual an analysis period of one year.Likewise, the portion of irrigation sourced from precipitation varies between 5.6% and 8.8% for green roofs and living walls, with the remaining percentage supplied by the network water.

In contrast, in the second scenario integrates rainwater harvesting cisterns are included, resulting in a notable shift in runoff mitigation and irrigation strategies. By capturing and storing rainwater, these cisterns significantly decrease dependence on the network water supply. Data indicates an increased reliance on cisterns for irrigation, ranging from 13.2% to 35.6% across rooftops during the annual analysis period. Moreover, runoff reduction from rooftops sees a substantial decrease, ranging from 62.1% to 86.3%. In this scenario, irrigation from the network water supply is minimized due to the utilization of rainwater harvesting cisterns.

Similarly, runoff decrease percentages as high as 84.8% are observed in the inner block void on remaining surfaces, showcasing the potential of such spaces for effective runoff management.

The "Runoff Visualization" component of MARSH was employed to visually depict the runoff reduction outcomes for both scenarios. Using Rhino as a visualization platform, the winter analysis period was selected. In this representation, a color scheme was utilized where red indicates a higher degree of runoff reduction, gradually transitioning towards white to indicate lesser reduction (see Figure 5).

CONCLUSIONS

The model's adaptability, user-friendly interface, and visualization tools represent significant advancements in integrating Water Sensitive Urban Design (WSUD) principles into architectural practices, particularly within Greece's context where such integration is crucial. By bridging the gap between complex hydrological concepts and architectural practice, the model aids architects in making informed decisions regarding stormwater management strategies.

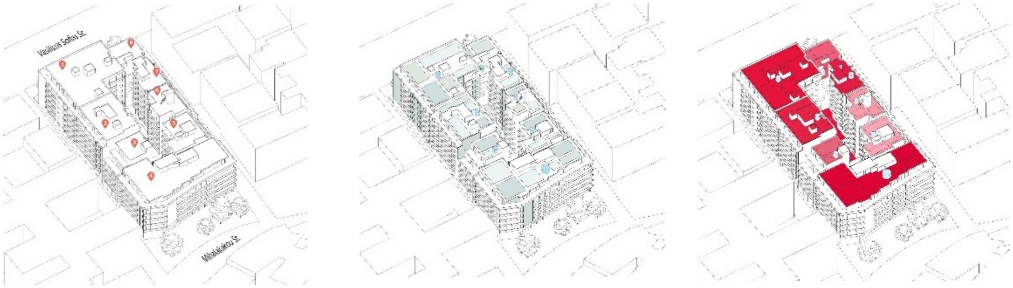

Figure 5
Left: Axonometric view of as-built urban block
Middle: Scenario 2 axonometric
Right: Visualization of runoff reduction of Scenario 2

In conclusion, the architect-friendly urban water model represents a significant advancement in addressing current challenges while also paving the way for future research and applications. Developed to inform urban planning strategies and shape policies for sustainable water management, the model aims to serve as an invaluable tool for architects, urban planners, and students alike. Its scalability allows for city-scale applications, contributing to the design of water-sensitive urban areas essential for building resilient and sustainable cities. As the model continues to evolve through ongoing refinement and practical applications, its accuracy and applicability across diverse contexts will only further enhance, reaffirming its pivotal role in advancing the integration of stormwater management into architectural design processes.

ACKNOWLEDGEMENT

The research project was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I) under the "2nd Call for H.R.R.I. Research Projects to support Faculty Members & Researchers" (Project Number: 4603)

REFERENCES

Cristiano, E., et al. (2022) 'How much green roofs and rainwater harvesting systems can contribute to urban flood mitigation?', *Urban Water Journal*, 00(00), pp. 1–19.

Gerolympou, A., Kalogirou, N., Kafkoula, K., Papamichos, N., and Hastaooglou, V. (1986) 'On Urban Architecture: The Old and the New in Urban Planning', in Gerolympou, A., Kalogirou, N., Kafkoula, K., Papamichos, N., Tsouloubis, L., Hatzimichalis, K., and Hastaooglou, V. (eds.) *Epi Poleos [On the City]*, Thessaloniki: Ekdotikoi Synchrona Themata, pp: 1-10.

Papanikolaou K., Liapi K. Sibetheros, I.Vlachaki E. (2023), 'A Simulation Model for Stormwater Runoff Management in Urban Blocks', *Proceedings of the 41st International Conference on Education and Research in Computer Aided Architectural Design in Europe,* [Volume 2]

Papanikolaou K., T.Liapi K., Sibetheros I. (2022), 'Environmental Impact Assessment and Visualization of Rain-water Best Management Practices for Urban Blocks: An "architect friendly" simulation model', *Proceedings of the International Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe)*

Ponce, V.M. and Hawkins, R.H. (1996) 'Runoff Curve Number: Has It Reached Maturity?', *Journal of Hydrologic Engineering*, 1, pp: 11-19.

Soulis, K. X. (2021) 'Soil conservation service curve number (SCS-CN) method: Current applications, remaining challenges, and future perspectives', *Water (Switzerland)*, 13(2). pp. 1–4.