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Conference Paper · December 2019

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Embedding sustainable storm water management in urban blocks

Towards an Urban Water Model for architects

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The paper describes an urban storm water management model under development designed specifically for architects, allowing the visualization of storm water management scenarios in urban blocks, as well as the quantitative comparison of their impact to the microclimate. It seeks to answer the question of how computational technologies can help architects integrate storm water management into the design process and engage with water sensitive design principles through the development of an "architect-friendly" model. The model is expected to function as a simulation tool that will support design decisions on storm water management retrofitting measures in urban blocks, by allowing the evaluation of an urban water improvement project at its initial design stage, as well as the generation and comparison of alternate water integration design solutions. Selected urban blocks in Greece will be used as case studies to test and evaluate the urban water model during the model development stage.

Keywords: *Water Sensitive Urban Design, storm water management model, "architect-friendly" model, simulation tool*

INTRODUCTION

In contemporary cities the natural cycle of water has been replaced by the urban water cycle, characterized by rapid collection and drainage of rainwater, as well as minimal infiltration and evaporation, which, combined with the negative effects of climate change, has contributed to the deterioration of the urban environment microclimate and living conditions. Specifically, the conversion of the natural water cycle into the urban water cycle has the following

negative effects:

- Water infiltration into the ground, as well as groundwater replacement rates are reduced. In the long run, this reduction will also lead to a reduction in the available groundwater for drinking water supply.
- The local climate is negatively affected as, due to the reduction of infiltration and evaporation, a drier and warmer climate is created in

the city center than in suburban areas (phenomenon of urban heat island).

- The possibility of flooding is increased. This is due to the inability of conventional storm water management systems to readily accommodate larger storm water volumes. This is a result of the ever increasing urbanization, which leads to reduced infiltration, and climate change that is manifested by an increase in the frequency of extreme rainfall events. (Hoyer, J. et al., 2011)
- The public's inability to appreciate the role and importance of storm water. For example, conventional rainwater management systems rely on underground storm water pipe networks or covered waterways such as rivers or creeks, and thus residents are less likely to understand and appreciate the value of storm water - instead, they treat it as worthless dirty water.

In order to avoid an aggravation of the problem of the current hydrological urban cycle and to remedy the environmental imbalance caused by conventional water management models, a philosophical change is required in the way urban areas are planned and designed (Wong et al., 2000). This change is based on the principles of the Water Sensitive Urban Design (WSUD). In essence this effort refers to the or design or redesign of cities with increased retention and use of rainwater. This approach will let cities benefit from natural water treatment systems and will reshape the landscape towards these goals, while providing opportunities for environmental, recreational and cultural activities (Fragkou M. and Kallis C., 2010). The objective of WSUD is to combine the demands imposed by the sustainable storm water management with the demands of urban planning, and it will thus bring the urban water cycle closer to the natural water cycle (Hoyer, J. et al., 2011).

Integrating, however, sustainable storm water management into the design and planning process has not yet been accomplished, as it remains a complex issue for architects and urban planners that re-

quires specialized technical knowledge, relevant experience, and interdisciplinary collaboration.

STATE OF THE ART

The concept of WSUD appeared in 1994 in Australia when Whelans proposed design rules for the design of settlements that would respect the aquatic environment around them (Wong et al., 2000). Since then, the term has been gaining more and more ground in Australia while in the meantime it has also been gradually spreading to European countries such as the Netherlands, Germany, and England.

Alongside the dissemination of the WSUD term, urban water models have been developed for the design, implementation and assessment of WSUD measures. Urban water models can be used as decision support tools by allowing a quantitative comparison of conventional and non-conventional water management strategies for the supply and use of water in an urban environment. The use of urban water models provides a structure in the sustainability assessment process, allows for the examination of their components and interactions, and enhances communication among engineers (Jake-man et al. 2006). Models range from simple spreadsheets that predict a single process such as the runoff from a single storm, to complex simulations that predict multiple, inter-related processes including performance of multiple Best Management Practices (BMPs) (MPCA, 2017). During the last 20 years many storm water management models have been developed. Haris et al. give an overview of some of models (Haris et al., 2016): the Storm Water Drainage System design and analysis program (DRAINS), the Urban Drainage and Sewer Model (MOUSE), InfoWorks River Simulation (InfoWork RS), Hydrological Simulation Program-Fortran (HSPF), Distributed Routing Rainfall-Runoff Model (DR3M), Storm Water Management Model (SWMM), XP Storm Water Management Model (XPSWMM), MIKE-SWMM, Quality-Quantity Simulators (QQS), Storage, Treatment, Over-flow, Runoff Model (STORM), and Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-

HMS).

Despite this increase in storm water management models, there is still a gap in the literature regarding models integrating storm water management measures with urban planning processes, thus hindering their application in practice. Kuller et al. raise the question why the “planning side” of urban water management remains underexposed. As Kuller et al. states there is a variety of possible explanations for this ‘implementation gap’ that have been suggested by literature (Geertman and Stillwell, 2004; Klosterman, 1997; te Brommelstroet and Bertolini, 2008; Viavattene et al., 2008; Vonk et al., 2005 cited in Kuller, M. et al., 2017): they may be too generic, complex, inflexible, incompatible, technology-rather than problem oriented. Some other explanations can be provided by the fact that the models may lack the ability for scenario-building, storytelling and visioning. Their lack of transparency, user friendliness, an interactive nature and communicative value, might be additional reasons.

CONCEPTUAL MODEL DESCRIPTION

The model described in this paper takes into consideration the implementation gap that the existing storm water management models present. The main goal of the proposed model is to integrate purely environmental parameters into the design criteria and methodology that need to be adopted and applied by architects. This model is expected to link the urban built body and the storm water infrastructure planning and assessment into a spatial simulation environment. A key feature of the model will be its “architect-friendliness” following the criteria Attia et al. have provided for an “architect-friendly” tool: 1. Interoperability; 2. Usability; 3. Accuracy and ability to simulate complex forms; 4. Integration of intelligent design; 5. Integration into design environment (Attia et al., 2012, Attia et al., 2013).

Accordingly a computer-based model that will serve as an exploratory modelling tool for the simulation of storm water management scenarios is proposed. This means that the model is not expected to

deliver a detailed description of storm water runoff, but rather to provide a decision-support tool that enables architects to test possible strategies and measures.

In order to achieve a more “water sensitive state” for the urban block, the architect will be able to test different BMPs. A storm water Best Management Practice (BMP) is a practice that is suitable for treating pollutants in storm water runoff and/or reducing the volume of runoff (Pekarek K. et al., 2011). BMPs treat rain near the source (source control). The BMPs suggested in this model address two criteria that are critical to managing urban storm water runoff:

1. **Volume:** Reduction of storm water volumes directly collected by storm water pipes increase stormwater infiltration and evapotranspiration (ET) (sum of evaporation and plant transpiration) during ordinary rainfall events.
2. **Peak Discharge:** Reduction of the maximum flow rate into the combined system by decreasing the storm water volume and lengthening the duration of discharge.

The model will give the user the freedom to choose from a range of different BMPs, create his own surface water balance scenarios, assess them, and finally choose the most appropriate one with regard to its impact to the microclimate as well as its infrastructure requirements.

In terms of its simulation capabilities, the model will calculate and display in a graphic environment the urban block’s water balance in its current state, and after selected BMPs are applied (“water sensitive” state). It will also simulate microclimate conditions in terms of humidity and temperature within the urban block in its current as-built state and the improved, “water sensitive” state, after storm water management measures are applied.

Regarding its scope of implementation, the model is not designed to primarily address new urban blocks, as sustainable storm water drainage management is usually incorporated into their design process. The emphasis in the design of the

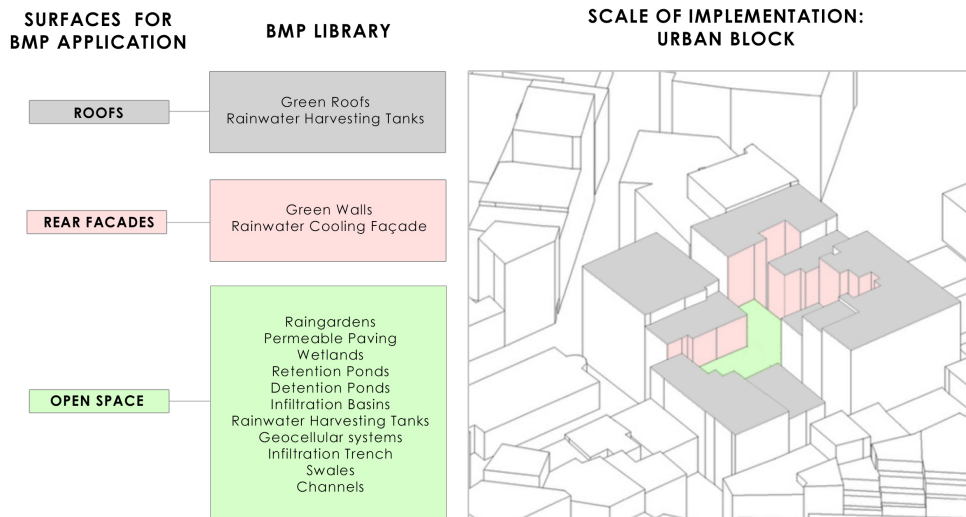


Figure 1
3D drawing of an urban block in Greece depicting the three categories of surfaces where BMPs will be applied in the proposed storm-water management model and the list of BMPs in the BMP Library for each surface.

model is placed on retrofitting storm water management BMPs to existing urban blocks by proposing realistic and low tech storm water management interventions on:

1. Roofs
2. Building Facades
3. Open spaces between buildings

BMPs (Figure 1) are divided according to the surface type (roof, rear façade, open space). Following are generic definitions of the proposed BMPs (Sus-drain,2019):

Roof: proposed BMPs for roofs are green roofs and rainwater harvesting tanks. **Green roofs** are designed to intercept and retain rainwater, reducing the volume of runoff and attenuating peak flows. **Rainwater harvesting tanks** are used to collect and store rain water runoff from the rooftop in order to reuse it when needed in the future.

Rear Facades: proposed BMPs for the rear façades are green walls and rainwater cooling façades. **Green walls** are vertical structures that consist of different types of plants or other greenery

attached to them contributing to the evapotranspiration of water. **Rainwater cooling façades** convey water but also sprinkle it to the atmosphere during conveyance, reducing in this way the temperature of the building surface.

Open space: a variety of BMPs can be applied in open spaces either individually or in combination. **Raingardens** are relatively small depressions in the ground that can act as infiltration and treatment points for roof water and other 'clean' surface water. **Permeable paving** are surfaces that allow rainwater to infiltrate through the surface and into underlying layers. The water can be temporarily stored before infiltration to the ground, reused, or discharged to a watercourse or other drainage system. **Wetlands** are densely vegetated water bodies that use sedimentation and filtration to provide treatment of surface water runoff. **Retention ponds** can provide both storm water attenuation and treatment and **detention ponds** are storage basins or facilities that provide flow control through attenuation of storm water runoff. **Infiltration basins** are dry except in periods of heavy rainfall and are vegetated depressions designed to store runoff on the surface and infiltrate

it gradually into the ground. **Rainwater harvesting tanks** are water tanks used to collect and store rain water runoff and **geocellular systems** are used to control and manage rainwater surface water runoff either as a soak away or as a storage tank. **Infiltration trenches** are hollow excavations with rubble or stone that create temporary subsurface storage of storm water runoff, thereby enhancing the natural capacity of the ground to store and drain water. **Swales** are shallow, broad and vegetated channels designed to store and/or convey runoff and remove pollutants. Finally, **channels** are open surface water channels with hard edges. (susdrain, 2019)

It should be noted that urban blocks in Greece are used as case studies to test and evaluate this tool. These urban blocks usually contain a number of multifamily apartments, but their layout varies widely (Figure 1). This is due to the intense urbanization that occurred in Greece after the second half of the 20th century, which resulted to the rapid expansion of urban areas, particularly in Athens and its suburbs, based on large infrastructure projects (mainly roads) as well as the construction of thousands of multifamily apartment buildings without oftentimes serious city planning interventions. The expansion of the underground storm water drainage system, as well as the covering of several urban streams in conjunction with the wide use of water-impermeable materials, such as cement on pavements, adversely affected many Greek cities' microclimate.

Model structure (Figure 2):

1. The architect (user) enters the geometric data of an urban block. A detailed 3D model of the urban block will be developed/built in a graphical environment. Subsequently, the 3D model that will include information about all the buildings in the urban block, will be linked to the urban storm water model. Additional information regarding each one of the buildings will be provided by the architect through a user friendly input application.
2. Taking into consideration the geometric data, as well as additional information provided by

the architect (static adequacy, temperature absorption, reflectance and water permeability of each roof and façade surface), the model will simulate infiltration volumes, evaporation volumes, runoff volumes (to sewers) and peak runoff rate for the “as built” state. The results of the simulation will be visualized through colour coding.

3. The architect will be able to start testing different storm water management measures, by selecting one measure at a time from the BMP Library and applying it on a selected surface of the 3D model. The model will guide the user during the selection on his options of storm water management intervention scenarios for each surface. This will depend on whether the surface is a roof, a façade or part of the open space between the buildings, and on the selected surface's permeability. It will also provide information on the optimal features and values of each BMP selected, according to the static adequacy and the geometric characteristics of the surface.
4. The model will then simulate infiltration volumes, evaporation volumes, runoff volumes to sewers and peak runoff rate, and will visualize them through colour coding. The most critical geometric and other features of all BMPs will be shown on the 3D model during the design process.
5. The model will then simulate (calculate and visualise) microclimate conditions in terms of humidity and temperature within the urban block in the improved, “water sensitive” state, when certain storm water management measures are applied. The architect will be able to compare the outcomes of the “as built” state simulation and the proposed scenario simulation with the assistance of the following sustainability indicators: 1. Infiltration volumes; 2. Evaporation volumes; 3. Runoff volumes to sewers; 4. Peak Runoff rate; 5. Temperature.
6. The architect will be able to alter certain pa-

rameters of the proposed storm water management scenario, in order to simulate and compare multiple variations of the original scenario. Based on the received input, he will decide on the most appropriate scenario, based on its impact to the microclimate as well as its infrastructure requirements.

EXPECTED OUTCOMES

The “architect-friendly” storm water management model under development is expected to integrate entirely environmental parameters into the design criteria and methodology to be adopted and applied by architects and city planners. Thus the project intends to address the climatic problems that have risen in contemporary cities due to conventional water management and waterways concealment.

In the long run, the model will contribute to the promotion of the concept of Water Sensitive Urban Design (WSUD) to the architectural design practices by introducing a user friendly ancillary tool that will help the architect design and apply interventions for better runoff water management in existing building blocks.

At the moment, the model addresses two main fields impacted by such interventions:

1. **Flood Management.** Management of the rate and volume of surface water runoff and reduction of flood risk. Besides providing for urban drainage under normal weather situations, WSUD also mitigates and limits the impacts of extreme rainfall events. Flood control is one of the main design purposes of such technologies (Mitchell et al., 2007).
2. **Climate change consequences.** Storm water management measures can affect the microclimate, and lead to temperature decreases, air quality improvements etc. They can also help in reducing the negative effects of the climate change on the urban climate, the urban heat island effect in particular.

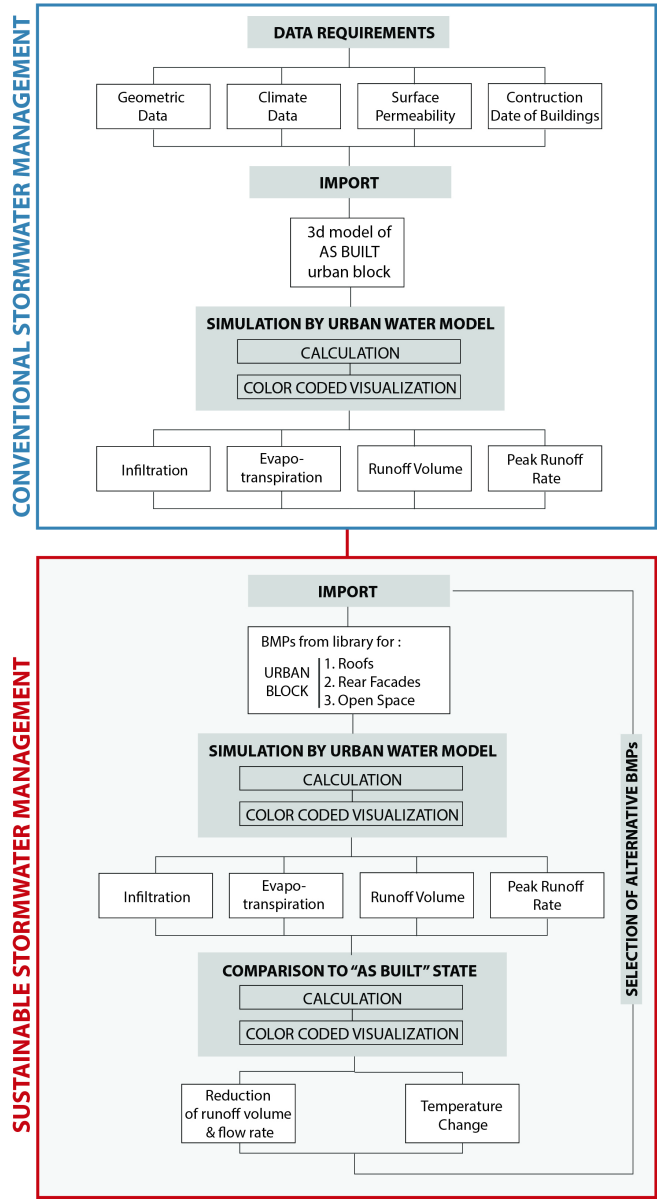
Furthermore, implementing BMPs in urban blocks

can also have a great impact on:

- **Amenity and aesthetics.** Retrofitting can enhance and improve the urban space, contributing to place making.
- **Biodiversity and ecology.** Soft and green storm water management measures can increase biodiversity and ecology and enhance the area creating new habitats. (Digman, C. and Glerum, J., 2012).
- **Urban vegetation** (particularly trees) which is sustained by reused stormwater is known for its ability to purify air from toxic gases such as ozone (O₃), sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and particles such as fine dust (PM-10) (Escobedo et al., 2008; Nowak, 1994, cited in Kuller M. et al., 2017).
- **Cost effectiveness:** Water Sensitive Design is usually based on low tech interventions whose costs are much lower than the cost of future damages (e.g. flood damages) or the higher energy consumption costs due to the temperature rise in urban areas. If the natural hydrological cycle is restored, the economic benefits in the long run are expected to be substantial. Many examples from around the world also suggest that reducing surface water from entering an existing drainage system through retrofitting, can be more cost effective than increasing drainage capacity.
- **Social impact:** water sensitive interventions in cities make the public aware of the value of water and its benefits in everyday life, as opposed to conventional water management models, in which stormwater is distributed underground, thus encouraging the false concept of “out of site, out of mind.”

Simulation results of the multiple effects of different BMP scenarios in urban blocks will be added to the model in the future.

Figure 2
Conceptual
diagram of the
proposed storm
water management
model



ACKNOWLEDGEMENT

This work constitutes part of the first author's doctoral dissertation. The author wishes to thank and acknowledge the Onassis foundation for providing a competitive scholarship which partially funds her doctoral research.

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