Szent István University

DEVELOPMENT OF SUSTAINABLE RAINWATER MANAGEMENT IN BUDAPEST

Theses of the Ph.D. dissertation

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The candidate fulfilled all the conditions prescribed in the Doctoral Regulations of Szent István University, the remarks and suggestions made in the preliminary disputation were taken into account during the revision of the dissertation, therefore the dissertation can be submitted for defense.

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Approval of the School Leader

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Approval of the supervisor Approval of the supervisor

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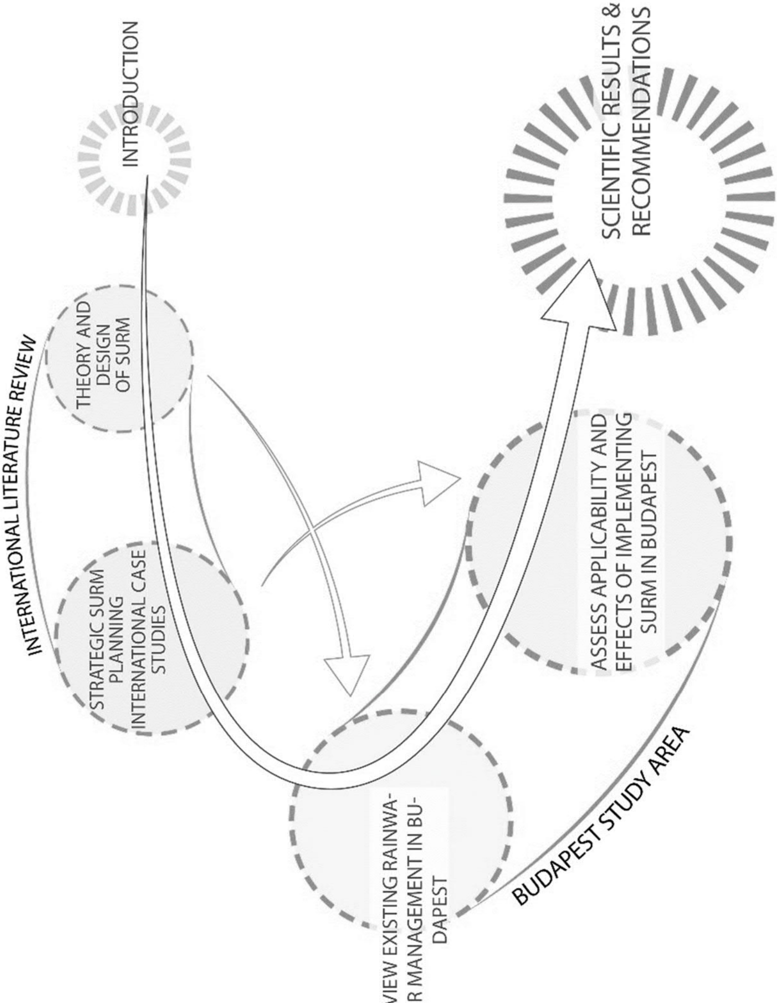
Aims and structure of the thesis

Climate change and global environmental degradation are our current urban development catalysts compelling the urgent and radical rethinking of our urban design approach. Water management lies in the focus of most climate-change related challenges. Therefore, the implementation of a more sustainable, integrated approach for water management by minimizing mankind's harmful impacts and maximising usage efficiency will be one of the most important challenges in the coming decades. The dissertation encompasses the field of sustainable urban rainwater management (SURM). While the application of SURM in new development areas has already been well established in some countries, its integration into an existent urban structure is a much less investigated and a rather challenging task. In the European urban context, Budapest was chosen as the study area to demonstrate the challenges and benefits of sustainable rainwater management in an existent urban environment.

The main goals of the research were the following:

- review the theory, principles and tools for strategic planning of sustainable urban rainwater management based on the international literature and case studies
- evaluate the applicability of the methods and design tools regarding sustainable rainwater management in Budapest
- establish a research base for blue-green infrastructure (BGI) development in Budapest by proposing research methods and suggesting recommendations for their implementation.

Structure of the thesis



The dissertation has the following four main pillars:

International literature review: A comprehensive literature review was performed to introduce the main goals, principles and leading scientific concepts of sustainable rainwater management. The aspects of SURM design that were investigated included methods, design tools, and the required dataset. A case study analysis of three cities with developed SURM approaches was introduced to gain a deeper understanding in strategic planning of SURM. The information collected from the international review served as a base for Budapest´s analysis and SURM applicability assessment.

Review of Budapest's current rainwater management: The city's geophysical and urban environmental factors, and the current institutional and legislative framework regarding rainwater management were investigated.

Large-scale assessment of SURM applicability: a unique methodology was established in order to assess the applicability of the three SURM methods (infiltration, retention, evaporation) within the urban texture. The assessment yielded an applicability map for each method and identified zones and land use categories that would benefit most from BGI implementation.

Small-scale assessment of the effects of BGI on the urban runoff and water balance: a socialist housing estate was chosen to assess the short-term and long-term impacts of BGI tools. The short-term assessment involved the estimation of the BGI´s potential runoff reduction in two different scenarios. Urban water balance modelling was carried out to estimate the effects of BGI on the urban climate.

Methodology

Large-scale assessment of SURM applicability

The applicability of SURM methods (infiltration, retention, evaporation) was investigated for Budapest´s geophysical (climate, terrain and soil, groundwater level) and urban environmental factors (drainage system, land use). A value of “not applicable”, “applicable”, or “insisted” was associated to each analysed factor, and for each method. The spatial data of the factors were overlaid and filtered according to the values, as shown in Figure 1.

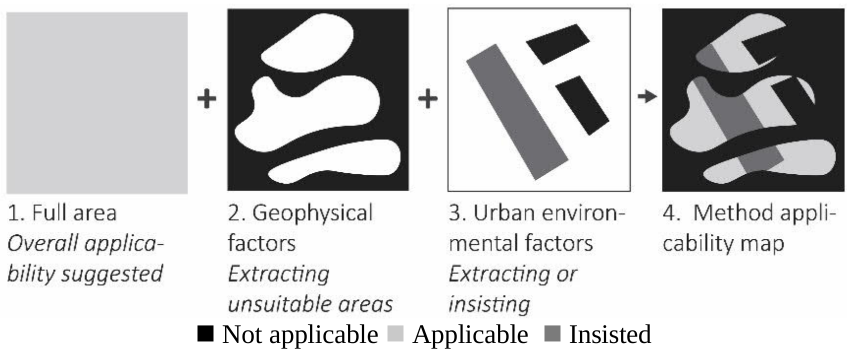


FIGURE 1: GENERATION PROCESS OF THE METHOD APPLICABILITY MAPS

Typical land use categories of the applicable and insisted method areas and the characteristics of the urban zones were investigated based on this overlaid dataset. The applicability maps of the three SURM methods were also overlaid to identify synergic areas with multiple suitable methods.

Small-scale assessment of SURM effects

The runoff analysis of Őrmező housing estate applied the calculation methods of the German norms DWA-A 138, and DWA-A 117[1]. Two different rain intensity scenarios: a small (4-year) rain event and a large (33-year) rain event were considered for the calculations. The design aimed to

[1] DWA A-138: “Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water”; DWA A-117: “Dimensioning of Retention Areas”.

keep the 4-year and 33-year runoff onsite using infiltration and retention tools, respectively. The study area was divided into catchment areas. A surface coverage map was established and combined with required planning data (soil permeability, groundwater level, precipitation data) in AutoCAD. A unique methodology was established to select the applicable BGI tools based on the collected tool properties from the international literature review and the local conditions. After the calculation of the required infiltration and retention volumes, a schematic design was processed in AutoCAD in order to place the BGI tools into the study area. The resultant runoff reduction was calculated from the summed capacity of all tools.

The annual water balance modelling based on German norm DWA-A 102 [2] was used to simulate the design's impact on the annual balance of evaporation, runoff and groundwater recharge. Based on the local climatic and geographic data, and the areas of different surface types and BGI tools, two scenarios were established in the program: Scenario 1, the existing development; and Scenario 2, the planned development with BGI tools. These two scenarios were compared to the original, undeveloped stage with natural vegetation (meadow).

[2] DWA-A 102: "Principles for the management and treatment of rainwater runoff to discharge into surface water bodies"

Scientific results

T1: Modifications of the current legal, institutional and technical environment are necessary to allow and facilitate the use of on-site rainwater management in Budapest. The most vital areas of improvement were identified as:

a. A legal definition and clear responsibilities encompassing rainwater management, and a legal obligation to prioritise the implementation of on-site rainwater management
b. Clarification of ownership and developer rights for blue- and green-infrastructure elements
c. Political commitment to provide sufficient and calculable resources
d. Access to good quality planning data
e. Expansion of expert knowledge

The analysis of Budapest´s current legal, institutional and technical environment confirmed findings similar to various international studies, in which the most significant obstacles to implement SURM are not due to financial or technical problems, but rather the institutional system. The main shortcomings that were identified have an impact on both the sustainable and conventional rainwater management.

T2: The land use classification system of Budapest offers a suitable framework in order to assess the applicability of sustainable rainwater management in the urban structure. Based on this, a unique methodology was established to identify the urban areas where infiltration, retention and evaporation tools either could be applied, or are insisted. The five urban development zones of Budapest have different characteristics:

a. The transition zone can host tools from all three SURM methods.
b. The suburban zone is typified by an insisted application of infiltration and retention tools
c. The core zone is typified by an insisted application of retention and evaporation tools
d. The hill zone and the Danube zone are characterised by an applicability for retention tools.

90% of Budapest's area consists of land use categories that are coherently homogenous and are based on factors, which are relevant for rainwater management (e.g. density, green area ratio, allowed usage). These categories are therefore suitable for the analysis of SURM applicability. The analysis proved that each urban zone of Budapest has a specific character regarding its applicable SURM methods. Multiple methods can be applied in most urban zones, which facilitates the use of multifunctional BGI tools.

T3: In areas with an overlap of at least two insisted SURM methods, high synergic benefits can be achieved by the implementation of complex BGI projects, thus their development would be most profitable for the city. Overlapping areas of insisted methods exist typically in the low-density suburbs of the suburban zone, brownfields and housing estates of the transition zone, and dense historic development of the core zone.

In areas where multiple SURM methods can be used, a well-designed blue-green infrastructure project can meet multiple needs simultaneously. Additionally, if the methods are insisted in the area, the development can be particularly beneficial for the environment and/or the spatial conditions are highly suitable. For this reason, urban areas with overlapping insisted SURM methods could host the most cost-effective BGI projects. Of the four identified area types, brownfields and housing estates have suitable spatial conditions to implement infiltration and retention tools, thus they were regarded as insisted. In suburban areas, an insisted application of infiltration and retention was determined due to the deficiencies in stormwater drainage infrastructure. In the historic core, congestion of the sewer network and the heat island effect justified the insisted use of retention and evaporation.

T4: The transition zone is the most suitable area to apply large-scale blue-green infrastructure projects due to the vast amount of large areas where sustainable rainwater management tools could be easily implemented. The establishment of a “blue-green belt” with a large retention capacity in the transition zone can assist to unload the core zone’s water infrastructure.

The transition zone’s two most important land use types – brownfields and housing estates – have very advantageous properties for BGI development: large open spaces (green areas in the housing estates in mostly municipal ownership and maintenance; large undeveloped areas in the brownfields with a potentially adjustable land use). Due to the radial design of Budapest's canal system, the sewage pipelines transporting rain to the inner zone pass through this zone. Therefore, large-scale retention tools in the transition zone could relieve the load in the inner zone and reduce the likelihood of flooding.

T5: The most effective measures to facilitate the implementation of sustainable urban rainwater management in Budapest are:

a. Preventional land use regulation of brownfield areas to secure the required space of future blue-green infrastructure

b. Inclusion of sustainable urban rainwater management into public open space development projects
c. Involvement of private owners (detached house owners and housing communities within the historic core) and the provision of incentives.

The stakeholder analysis of the most significant areas for SURM development identified the target groups that should be involved to develop these areas. The analysis showed that the active engagement of the local government is crucial in initiating changes, because the listed measures above primarily require institutional changes.

T6: A unique methodology was established in order to select the locally applicable blue-green infrastructure tools for different urban environments. In a typical socialist housing estate, a large variety of BGI tools can be applied which can effectively reduce the urban runoff and peak flow.

The developed methodology considers local conditions and evaluates the adequacy of BGI tools in the given environment based on its properties. Using the methodology, I have shown that the analysed housing estate is suitable to use all of the described BGI tools.
The study area's runoff calculation showed that despite the low soil permeability ($k_f=1\times10^{-6}$), blue-green infrastructure would be capable of reducing 77% of the existing runoff from a 4-year rain event and 78% from a 33-year rain event. The runoff calculation showed that a long duration, low-intensity rain event can produce a higher overall runoff than a short duration, high-intensity event. Therefore, dimensioning of on-site rainwater management tools require longer rain durations than the ones widely used for dimensioning the conventional drainage system.

T7: The development of blue-green infrastructure does not necessarily increase the evaporation rate. Therefore, annual water balance modelling must be included in the design of blue-green infrastructure in order to ensure that a positive effect on the urban climate can be achieved.

The annual water balance modelling showed that the short-term and long-term impacts of rainwater management tools can vary widely. To dimension the rainwater infrastructure, typically short-term goals (the retention of a required runoff volume) are considered. However, fulfilling the short-term retention goal can cause undesirable long-term effects. Increased infiltration removes water from the surface and can therefore lead to a low evaporation rate, similar to runoff being discharged into the sewage system. For this reason, the long-term effects of the implemented BGI tools on the evaporation rate must be simulated using annual water balance modelling to approach the natural water balance.

Conclusion and recommendations

The review of the most recent international researches and best practices of sustainable rainwater management defines methods and tools for the adaptation in Budapest. The research is the first study in Hungary, which analyses the potentials of on-site rainwater management by considering the natural conditions, land use, the existing green infrastructure and the drainage system. The dissertation collected the available data sources for rainwater management in Budapest and pointed out their shortcomings, which can serve as a basis for further research.

The runoff calculation not only demonstrates the effectiveness of BGI in typical socialist housing estates but also provides a viable example of the BGI design process. The annual water balance modelling presents an important new aspect and methodology for the research and planning, which is not yet considered and used in the current rainwater management of Hungary.

In addition to the scientific results, the research laid out recommendations to reshape the legislative system and integrate SURM planning and control into the existing planning hierarchy.

The insertion of a three-level plan system was recommended to extend the existing planning hierarchy:

- **Integrated Water Management Strategy:** provides targets for the integrated management of water resources and its infrastructure, including rainwater and the blue-green infrastructure
- **Rainwater Management Program:** outlines the mid-term goals (such as runoff targets) in the city’s water catchment areas

- **Rainwater Management Action Plans:** short-term action plans to coordinate the BGI implementation and maintenance in specific areas (e.g. housing estates, school gardens)

The thesis suggests three measures to facilitate the use of SURM through land use planning:

1. **Revision of the minimum green area ratio**: the ratio can be revised in specific areas by considering the space demand of on-site rainwater management tools.
2. **Definition of "maximum runoff ratio"**: defines the maximum allowed runoff departing from a plot. The local runoff targets of the Rainwater Management Program could be customized for each urban block, by the same principle in which building height is regulated.
3. **"Water management buffer zone" land use category**: a new category for water management, which could overlap rainwater management requirements (e.g. required retention targets in a specific area) with other categories and facilitate the implementation of multifunctional blue-green infrastructure. The category could oblige brownfield developers to include SURM from the onset of planning.

The establishment of a **Rainwater Management Authorisation Plan** was advised in order to inspect whether the rainwater management criteria of the land use plan are fulfilled by a development project.

The results of this thesis are a foundation for further researches and provide a contribution to establish a future Sustainable Rainwater Management Plan for Budapest.

Publications connected to the research topic

Books and book chapters

CSIZMADIA, D. (2016): *Vízérzékeny tervezés a szabadtereken*. ISBN: 978-963-9669-12-3 Tervezöi segédlet. Budapest: Fővárosi Főpolgármesteri Hivatal.

CSIZMADIA, D. (2016): Die Rolle der Donau in der Entwicklung des ökologischen Netzwerks der Stadt Budapest. In: *Donau-Stadt-Landschaften*. Berlin

Full papers

CSIZMADIA, D. SÄUMEL, I. PILLE, L. SZILÁGYI, K. BALOGH, P. I. (2017): Water sensitive design potentials in Paris, Berlin, and Budapest revisited. *Czasopismo Techniczne (Technical transactions), 114* 113-123 pp.

Conference papers

CSIZMADIA, D. SZILÁGYI, K. BALOGH P. I. (2017): A budapesti kék-zöld infrastruktúra fejlesztése a fenntartható városi vízgazdálkodás eszközeivel. *Ifjú tehetségek találkozója*. 139-149 pp.

CSIZMADIA, D. SZILÁGYI, K. BALOGH, P. I. SÄUMEL, I. (2017): More than green: implementation of multifunctional blue-green infrastructure in residential areas of European cities. *Acta Horticulturae, 1189* 553-556 pp.

Conference presentations

CSIZMADIA, D. (2016): Kék-zöld infrastruktúra fejlesztés a biztonságosabb és élhetőbb városokért. Nemzetközi példák és hazai adaptációs lehetőségek**.** Presented at the Települési Csapadékvízgazdálkodási Konferencia. Baja.

CSIZMADIA, D. (2017): A zöldinfrastruktúra szerepe a fenntartható városi csapadékvíz gazdálkodásban Green-city Konferencia. Budapest.

CSIZMADIA, D. (2016): Strategies for sustainable urban water management in European metropolises. Abstract, oral and poster presentation. Presented at the Annual Meeting of the Gesellschaft für Ökologie. Marburg.