The role and importance of plant purification systems in the ecological approach to landscape design

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Abstract. The continuous city expansion and use of various impermeable pavement materials greatly hinder the rainwater surface runoff by conventional drainage systems, especially during heavy and extreme precipitation, which is occurring more frequently. Also, mostly as a rule, natural watercourse discontinuity and/or their canalization results in more frequent floods in cities. An additional problem is rainwater pollution, which, with conventional drainage systems, ends up in natural watercourses, rivers, lakes and seas often without any or even minimal treatment. These are some of the main reasons why rainwater management is becoming increasingly more important and indispensable segment of contemporary sustainable city development. Among many other approaches, it also includes conventional rainwater drainage systems replacement and the application of biological rainwater treatment systems as much as possible. The positive impact of sustainable and environmentally friendly rainwater treatment systems has already been widely recognized. However, their application is still slightly limited compared to the problems that occur in modern cities. The aim of this paper is to present biological rainwater treatment systems (basic categories and characteristics) and to analyze their implementation possibilities in urban green areas. Their ecological and aesthetic values will be considered, and how users generally perceive structures of ‘natural’ characteristics within designed landscapes will be discussed. The analysis of fourteen recently constructed parks will be carried out to determine the ways of integrating biological purifier systems in the park, the possibilities of their use, and the degree of biological purification systems influence on the overall park design concept. Criteria or guidelines that should be taken into account when designing biological rainwater purification systems will be proposed in order to simultaneously meet their basic function and other roles of such structures within the city park.

Keywords: parks, sustainable water management, wetlands

1. Introduction

The continuous city expansion and use of various impermeable pavement materials greatly hinder the rainwater surface runoff by conventional drainage systems, especially during heavy and extreme precipitation, which is occurring more frequently. Also, mostly as a rule, natural watercourse discontinuity and/or their canalization results in more frequent floods in cities. An additional problem is rainwater pollution, which, with conventional drainage systems, ends up in natural watercourses, rivers, lakes and seas often without any or even minimal treatment.

These are some of the main reasons why rainwater management is becoming increasingly more important and indispensable segment of contemporary sustainable city development. Sustainable rainwater management involves different approaches and systems, and depending on the requirements can be applied in combination or independently. Today, sustainable stormwater drainage systems are increasingly being used, and they gradually supplement or replace conventional drainage systems, especially in urban areas.
Depending on the function they perform in the rainwater management process, the systems can be divided into six basic categories: infiltration systems, filtration systems, constructed wetland systems, retention systems and flow control structures and detention systems [1]. Infiltration systems enable the slow flow and filtration of rainwater and its drainage to another area (most often natural watercourses) and thus mitigate urbanization impact on the natural water balance in a particular area. They can also contribute to the protection against erosion due to the large amounts of rainwater influx and flood protection. Filtration systems also collect water, filter and remove the contaminants, but are primarily used to collect rainwater from roads and other non-impermeable areas [2]. Although there are several different filtration systems, only rain gardens in which plants play the most important role in the water treatment mechanism are mentioned. Rain gardens are usually designed as narrow linear elements that collect water, infiltrating it gradually into the soil, collecting at the bottom of the rain garden, or discharging it into a natural watercourse [1]. The successful functioning of these systems does not require the constant presence of water. That is a basic difference compared to wetland systems that must be underwater throughout the year. Constructed wetlands are designed shallow depressions with dense plantations of aquatic plants used to maximize pollution removal from rainwater, and include designed wetlands and wet ponds [1]. These systems are the most important plant purification systems and provide various applications in the design of open green areas that will be discussed in detail later in the paper. Retention systems are ponds, designed/created using natural depressions that are constantly underwater, with landscaped banks to mitigate surface impact and erosion due to heavy rainfall [3]. The last category is detention systems (includes dry ponds and dry swales) and their role is to retain rainwater during heavy rainfall in order to reduce the pressure on other rainwater collecting systems and reduce the possibility of flooding [1].

Even though the positive impact of all sustainable and environmentally friendly rainwater treatment systems has already been widely recognized, their application is still quite limited considering the advantages that they have over conventional systems. This statement is partially, in the context of a theoretical approach to modern sustainable/ecological approach to landscape design, confirmed by a research which identified sustainable rainwater management and biological (plant purification) water treatment as some of the basic principles associated with ecological system imitation [4]. Although, according to the analysed theoretical works, these two principles should be generally applicable as a gold standard in contemporary landscape design, the analysis of recent park projects shows that the principle of rainwater management is used in 60% and the principle of biological water treatment in 37% of parks [4]. Despite all the limitations and possible shortcomings of that research the results indicate that approaches to sustainable rainwater management and biological water treatment are not applied in the design of open green areas to the extent expected, given the global importance of the sustainability paradigm in contemporary society.

That is why the aim of this paper is to present biological rainwater treatment systems (basic categories and characteristics) and to analyze the possibilities of their application in urban green areas.

2. Materials and methods
A literature review and analysis of scientific and professional literature from several different fields (sustainable rainwater management, wetland/plant purification/systems, ecology, environmental psychology) was conducted to determine the main characteristics of plant purification systems from different aspects.

Also, an analysis and comparison of fourteen recent parks (Table 1) with a system of plant purifiers as a water element in the park was made. Parks selection was based on
these criteria: realization within the last 15 years, location within the urban structure, public park and plant purification system as an integral part of the park. The main source of data about the parks were the park authors’ descriptions published on the web.

Analysis and comparison of parks refers to the relationship of plant purification systems with other functions in the park, the design of plant purification system and the impact of the application of plant devices on the overall design concept of the park.

**Table 1** List of analyzed parks

| Park Name                        | Location            | Year | Previous Use                          | Area  | Authors                          |
|----------------------------------|---------------------|------|---------------------------------------|-------|----------------------------------|
| Shanghai Houtan park             | Shanghai, China     | 2010 | Industrial                            | 14 ha | Turenscape                       |
| Qunli park                       | Qunli New District, Haerbin, China | 2011 | Wetland area                          | 34.2 ha | Turenscape                      |
| Tianjin Qiaoyuan park            | Tianjin, China      | 2008 | (shooting range) used as a landfill   | 22 ha | Turenscape                       |
| Minghu wetland park              | Liupanshui, Guizhou, China | 2012 | A canalyzed river in the city         | 90 ha | Turenscape                       |
| Weiliu wetland park              | Xianyang, China     | 2017 | River area between two cities         | 152 ha | Yifang Ecoscape                 |
| Sydney park                      | Sydney, Australia   | 2015 | Industrial                            | 44 ha | Turf Design Studio i Environmental partnership |
| Le Pare du Chemin de l’Ile       | Nanterre, France    | 2006 | River bank                            | 14 ha | Mutabilis Paysage et Urbanisme   |
| Yichang Yunhe park               | China Yichang, Hubei, China | 2015 | Former fish pond                      | 12 ha | Turenscape                       |
| St Jacques ecological park       | Ille & Vilaine (35), France | 2013 | Outside of the city along the agricultural land | 40 ha | Atelier des Paysages Bruel-Delmar |
| Grorudparken                     | Oslo, Norway        | 2013 | One of 4 parks by the river           | 12 ha | LINK Arkitektur                 |
| Pirrama park                      | Sydney, Australia   | 2010 | Port                                  | 1.8 ha | ASPECT Studios                  |
| Magnuson park                    | Seattle, Washington, USA | 2009 | Airport takeoff                       | 142 ha | The Berger Partnership and Sheldon Associates |
| Northala Fields park             | London, Great Britain | 2008 |                                      | 27.5 ha | By FoRM Associates              |
| Barry Curtis park                | Auckland, Australia | 2009 |                                      | 94 ha  | Isthmus                         |

3. **Wetland (plant purification) systems**

Plant purification systems include designed systems that imitate natural wetland systems [5]. Their goal is to create conditions for enabling the treatment of wastewater flowing through the system thanks to various physical, biological and chemical processes [6]. In addition to purifying rainwater in cities, these systems can also successfully be used for treating gray household water and even wastewater generated as a product in various types of industrial activity.

3.1. **Types of plant purification systems**

Plant purification systems can have different design, construction and functional characteristics, and can be classified according to: plant type, water flow regime, types of plant purification systems configuration (hybrid, single-stage or multistage systems), type of treated wastewater, level of wastewater treatment, type of pre-treatment, type of
The water flow regime has become established as the basic criterion for the typology of plant purification systems, according to which surface and subsurface plant purification systems are distinguished. The main difference between them is that in the surface plant purification systems the surface of the water passing through the system is exposed to the atmosphere while in subsurface plant purification systems, wastewater passes through the substrate (gravel or soil) in which the plants are planted and the water face is not in contact with the atmosphere [8]. Hybrid systems that consist of a combination of one or more surface and subsurface plant purification systems are also mentioned in literature [7].

A plant purification system with a surface water flow consists of a shallow pool of water, soil, or another medium that serves to grow rooted wetland plants, looks and functions like a natural wetland, and is a habitat for many plant and animal species. Depending on the type of plants, they can be divided into systems with plants whose parts protrude above the water surface level, systems in which plant parts float on the water surface and systems in which plants are submerged below the water surface level [5]. A subsurface plant purification system consists of one, or more, interconnected, embedded pools filled with gravel, sand or some similar medium substrate of different granulation. The same authors state that the surface can be dry and wet, and is regularly planted with selected plants whose roots penetrate the substrate and serve as a medium for developing microorganisms.

Although the hydrological requirements of plant purification systems are similar to natural wetland systems, plant purification systems, due to their large water surface and shallow depth, are highly dependent on meteorological conditions (precipitation and high temperatures) that lead to excessive evaporation.

### 3.2. Criteria for preparation and construction of plant purification systems

Although in this paper plant purification systems are considered primarily from the aspect of landscape design, it is important to note that in order to achieve a functional system, it is crucial to involve an interdisciplinary team of experts for their design and implementation.

For successful planning and construction of a plant purification system, it is necessary to research and analyze the area climatic characteristics, terrain topography, soil composition, groundwater characteristics (if any) and socioeconomic factors of the local community [5]. It is also necessary to ensure watertightness and gravitational water flow towards the system by the natural terrain topography (reduces the construction energy consumption) or, if necessary, to remodel the terrain.

An important factor in designing a plant purification system is certainly the quantity (including seasonal, weekly and daily variations) and quality (concentration of pollution) of wastewater and the requirement for the quality of treated water, which all affects the determination of capacity or size of the plant purification system. It is necessary to stress the importance of ensuring an adequate volume of one, or more, rainwater reception and retention basins long enough for the purification process to be completed [9].

Also, it is significant to select appropriate plant species. Various authors emphasize the importance of using local and indigenous wetland and aquatic plant species precisely because indigenous species are best adapted to the local climate thus increasing the probability of successful wastewater treatment [6,10,11]. In this context five planting zones of certain plant species and communities (depending on the depth of water and flooding frequency) are distinguished.

### 3.3. Advantages and disadvantages of plant purification systems

Among the advantages of plant purification systems, firstly their ability to remove contaminants from water should be mentioned. Various authors list five basic groups of substances that need to be removed: suspended solids, organic matter, nitrogen and
nitrogen compounds, phosphorus and phosphorus compounds, and microorganisms [5,7,12]. Heavy metals and pathogenic substances are also mentioned by some authors [13].

The overall system cost-effectiveness, lower construction costs compared to conventional systems, low costs and energy consumption for system maintenance (carried out periodically), and recycling and reuse of water facilitation are also emphasized as their advantages [11]. According to the same author, the main disadvantages of plant purification systems are: significantly larger area required for construction compared to conventional systems (in the context of space as a resource and land economic value), the sensitivity of biological components to toxic compounds (e.g., ammonia and pesticides), but also clogging or poor functioning of a system that can disrupt the flow of water.

Regular monitoring, maintenance (a period of several months to several years depending on the part of the plant purification system) and remediation are the key factors for the successful long-term functioning of the plant purifier system. The most common problems due to poor management are: sediment accumulation (reduced storage volume), waste accumulation (blocks water supply and drainage), damage to pipes and pumps, the too rapid spread of invasive plant species that clog the rest of the wetland vegetation, vegetation loss on slopes and erosions and the collapse of the structure of embankments or basins [14].

3.4. Ecological and aesthetic values of plant purification systems

When it comes to ecological benefits, it should be said that natural wetland systems are considered to be one of the most biologically productive ecosystems on Earth and as such are characterized by exceptional biodiversity. The goal of plant purification systems is to imitate natural wetland systems [5]. Their design and construction create habitats suitable for the development of numerous plant and animal species, which ultimately has a positive effect on the biological diversity of the area. The approach of plant purification system design additionally, to a certain extent, contributes to this goal and should strive to form irregular edges of plant purification system with complex bottom topography, achieve changes in hydrological conditions (permanently and occasionally flooded zones) and alternating groups of plants and open water face [9]. Although, essentially the functioning of plant purification systems (wetlands) is not related to the way they are designed (geometrically or close to nature), it can still be concluded that from the aspect of biodiversity or landscape ecology, 'naturalistic' design might achieve better results.

This paper discusses the possibilities of application and the role of wetland systems in urban public open green areas, so it is important to mention their aesthetic role in the context of user perception. Water is unquestionably one of the elements that generally positively affects the attractiveness of the landscape, although, according to some research, wetlands are much less positively assessed than other aquatic phenomena (e.g., lakes and rivers) [15,16]. Also, people generally find scenes that look natural more attractive [17,18,19]. However, what is perceived as a natural landscape may differ from ecological naturalness, which is one of the basic wetland characteristics [20]. In this context, it should be mentioned that respondents rate landscapes of extreme biological (ecological) diversity as untidy and non-maintained, and ecologically restored landscapes were not necessarily attractive to them. This perception can be associated with a sense of security in a particular space (extremely important to its users), which is the lowest in more closed spaces with a dense lower vegetation, and the highest in open spaces [22].

Despite the different results of numerous analyzed studies naturalness, spaciousness and coherence are some of the landscape characteristics that contribute to a more positive assessment. The same author also points out that it is not possible to draw general conclusions about peoples' preferences for visual landscape features because they are diverse and depend on several different spatial, social, and even economic criteria and factors. It
can be concluded that people in their environment want diverse landscapes [23] that will satisfy the needs and preferences of, primarily, local users.

4. Analysis of wetland (plant purification) systems in park design
Fourteen public parks were considered in which wetlands, i.e., plant purification systems, are applied in different ways, located in several countries on four continents - six parks in China, four in Europe, three in Australia and one in the USA. They are mostly situated within the densely built-up urban tissue along the river or sea, in a wetland, and almost all examples are brownfield sites (former industry, port, fishing ponds, landfill, etc.).

Probably this is the reason why the basic goal of almost all parks was the regeneration or revitalization of the degraded area as well as the water purification and/or soil purification. Reconstruction of the bank or riverbed, flood protection, creating a protective green belt between cities, etc., are also mentioned. In addition to the importance of a positive environmental impact, particular emphasis is placed on the educational role of parks in the context of learning about polluted water treatment technology and wetland habitats.

Since these are all public parks, they are characterized by various facilities and structures, however, the focus is mainly on pedestrian and bicycle pathways, various pavilions, canopies, benches, etc., and in several parks, there are other facilities such as a children’s playground, a park for dogs, etc. In any case, the primary function of all parks is spending time in nature, leisure and recreation. The presence of a natural water element largely defines the character of all considered areas (except in three parks). Probably this is the reason why all parks have one feature in common, and that is providing access to water/wetlands to park users, which is most often achieved by placing a plateau above the water and a network of pedestrian pathways. This approach encourages spending time in an ecologically diverse area, which on the one hand, enriches the diversity of experiences in the park, and on the other hand, allows direct observation and education about natural processes.

The process of water purification by its nature presupposes gradualness, which most often results in a series of interconnected wetland elements, which are ultimately, at the end of the process, connected with some natural water element (river, lake, sea). In design, this often results in elongated, linear formations, and less frequently, and in examples of small-format wetlands, the elements are grouped into a field (e.g., Tianjin Qiaoyuan Park). As stated in the previous discussion, there is a tendency for a design that mimics nature, especially in the design of larger wetlands. Still, even in these cases, often some of the edges bordering the existing geometrically shaped structures (coast, road, etc.) are geometrically defined. Several characteristic examples showing these tendencies are considered in this paper.

Houtan Park (Figure 1) is a longitudinal spatial composition that stretches between the indented river bank and the city road. The main formal element of the park is a designed wetland that stretches along the entire length of the park and divides it into two parts with significantly different design characteristics. Part of the park towards the river is characterized by close to nature (curvilinear) design, which contrasts with the geometrically designed edge from previous industrial use.

Quinly Park (Figure 2) is located in the existing wetland area, which remains the main, central part of the park retaining its natural forms. All newly introduced facilities and elements are located at the edge of the park along the road. The peripheral belt forms a linear series of interconnected surface plant purification elements and mounds of irregularly broken geometric shapes connected by two pedestrian pathway systems designed in the same manner.
The spatial composition of Tianjin Qiaoyuan Park (Figure 3) consists of two contrastingly designed units, one of which is dominated by design close to nature, and the other of regular geometric shapes, separated from each other by a large L-shaped water surface of the same characteristics. The dominant part consists of egg-shaped swamps and modelled elevations of exact edges. Secondary elements - a pathway network in an irregular geometric grid is formed in their interspaces as a distinct contrast. The network and the wetlands system are framed by a curvilinearly shaped main promenade and separated from, on the one hand, by high vegetation-rich space leaning on the road, and on the other hand, from the contact surface to the water. The second part of the park is characterized by regular geometric shapes.

Unlike previous examples in Minghu Wetland Park (Figure 4), the central motif is a lake enriched with new architectural and park elements of a predominantly curvilinear character along its entire northern and southern shore. Existing streams and wetland ecosystem are integrated into the ecological rainwater wetland system, parallel to the lake shore that is formed by a series of elongated terraces connected by an intertwined dense network of pedestrian communications. The most pronounced element is the circular organic form bridge that connects the facilities on the northern shore of the lake with the wetland system.

Weiliu Park (Figure 5) also has a longitudinal form with edges of contrasting characteristics - curvilinear towards the river and a linear edge along the road. The central axis of the park is a linear promenade, both the main pedestrian and bicycle corridor stretch from the southwestern to the northeastern edge of the park, with many other facilities arranged next to it.. The promenade divides the park into two parts, both of design close to nature, but on the south side there is a system of plant purification elements, and on the north side are located all other facilities.

In Sydney Park (Figure 6), the central motif of the park is a wetland system composed of four bioretention water bodies of nature like character. Water flows through a series of...
cascades from the north to the south of the wetland system. Here, too, all the facilities are located on the periphery, and are connected by a network of curvilinear pedestrian pathways.

Northala fields park (Figure 7) is divided by the main promenade into two differently designed parts. The main design elements of one part are the geometric structures of four modelled regular cones, and the other part a series of interconnected and watercourse-connected lakes. The shape of the lakes varies, so those located along the main promenade, are almost regular geometric shapes. In contrast, the more distant ones have more and more curvilinear, close to nature design elements. The paths are of a geometric character (rectilinear, segments of a circle and a spiral).

The Pirrama park (Figure 8) design backbone is the main promenade (linear element), which also divides the park into two completely different parts. The part of the park towards the coast is a unique area of lawn plane on which smaller irregular groups of high vegetation have been introduced along the perimeter. The contact with the sea is formed by the existing sequence of wooden platforms, supplemented by a geometrically articulated bay coast that gradually descends towards the sea. The second part of the park is fragmented by a series of angled straight paths and retaining walls in the same geometry. High vegetation in numerous groups is freely superimposed on the geometric base. Biological water treatment pools are accompanying elements and occur as a narrow linear sequence along the promenade.

5. Guidelines and conclusion
The recent ecological design paradigm (water purification, etc.) is not experiencing its full potential in newer park designs and it is only expected to be more widely used outside the brownfield area. When introducing wetlands into urban areas, it is important to pay attention to the design that users will perceive as safe and desirable to use.

The design of these close to nature ecosystems implies creating complex spaces and forms, because the spaces designed in this way encourage the emergence of diverse habitats, which ultimately encourages biodiversity in a particular area. The experience of previously built parks shows that in intensive water treatment, wetlands usually form a separate spatial unit relatively separate from other facilities, and trails and plateaus for leisure and observation in these parts are the predominant facilities. The educational component of wetlands is vital for the overall understanding of ecological processes and raising awareness of their importance, and could be used as a demonstration site on a smaller scale and in smaller spatial units.
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