Green Roof Technology as a Sustainable Strategy to Improve Water Urban Availability

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Abstract. The scale of the potential impacts of climate change is uncertain but, concurrently with other demographic, land-use, socioeconomic changes, it is affecting water availability and demand and increasing competition for water. As temperature increases, evaporation increases, resulting in droughts and devastating effects on fresh water supplies. Water will be one of the key resources for a sustainable urban development. Making clean water available in the next forty or so years will require the extending of the service to 3.7 billion more residents in urban areas. Therefore, it is necessary to promote an engineered redistribution of fresh water in space and time. This problem must be solved in a sustainable way using an innovative Green Infrastructure (GI) able to increase the water provision in urban systems realizing the recovery of rainwater and domestic water and reusing the same for irrigation and non-potable uses. Therefore, the aim of this research is to develop a project idea of GI focused on the reuse of water resource in a condominium of 40 housing units located in Lecce, south Italy. In particular, the project will exploit the free areas on the roof of the building, accounting a total surface of about 900 sqm. The project involves the construction of a green roof to develop the ecological functions linked to the purification of wastewater like in a Constructed Treatment Wetland (CTW) that represents a low-cost alternative to conventional secondary or tertiary wastewater treatment. This green roof allows the reuse of wastewater on site for sanitary, garden activities and other uses in the building, reducing the exploitation of the already scarce regional freshwater resources. The project idea also includes the possibility of using aromatic and medicinal plant species for phytoremediation, with potential applications in phytotherapy and cosmetics. CTWs produce ecosystem services like ones provided by wetlands and, therefore, act as sinks of CO2. Moreover, it is widely recognized that the green roof reduces the heating of the buildings caused by the solar irradiation, thus reducing the consumption of energy necessary to cool the apartments. So, the green roof turns from an unused cemented roof into a source of ecosystem services related to both the reuse of water resources and the development of potential economic activities. The cost of the work can be reduced by government incentives for the development of gardens in condominiums or for energy efficiency of the building. At the municipal level, the replication of this project on many buildings could reduce the water demand for residential areas as well as can mitigate the island heat effect that afflicts urban area during the summer and improve the quality of life in the city. This approach offers many opportunities for integration of water resource conservation, economic development and public health promotion.
1. Introduction
The scale of the potential impacts of Climate Change is uncertain but, concurrently with other demographic, land-use and socioeconomic changes, it is affecting water availability and demand and is also increasing competition for water. Climate change directly affects water supply and water quality [1; 2] by:

- Increasing water shortages due to changes in precipitation pattern and intensity;
- Decreasing natural water storage capacity from glacier/snow cap melting;
- Increasing the vulnerability of ecosystems due to temperature increase, changes in precipitation pattern, frequent severe weather events, and prolonged droughts;
- Affecting the capacity and reliability of water supply infrastructure due to flooding, extreme weather, and sea level rise;
- Increasing extreme precipitation and flooding, that will increase erosion rates and wash soil based pollutants and toxins into streams;
- Contaminating coastal, surface and groundwater resources due to sea level rise, resulting in saltwater intrusion into rivers, deltas, and aquifers;
- Increasing water temperatures, leading to more algal and bacterial blooms that further contaminate water supplies.

Climate Change indirectly affects water demand and the ways water is used within and across regions and economic sectors [2], e.g. [1]:

- Increases water demand for agriculture, primarily for irrigation, due to prolonged dry periods and severe drought;
- Increases water demand for farm animals due to the higher atmospheric temperatures;
- Increases quantities of water needed for industrial cooling due to increased atmospheric and water temperatures.

Changes in precipitation and runoff, combined with changes in consumption and withdrawal and aquifer recharge, reduce surface and groundwater availability in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses [3].

Water will be one of the key resources for sustainable urban development. It is needed for virtually every human use – household, agriculture, industry, leisure – and water also has an important ecosystem function. Making clean water available in the next forty or so years will require extending service to additional 3.7 billion urban residents [4]. It is necessary to increase resilience and enhancing adaptive capacity to provide opportunities to strengthen the management of the water resources stressed by Climate Change impacts. Therefore, it is necessary to promote different solutions, including engineering, for the redistribution of freshwater in space and time. Many institutional, scientific, economic, and political barriers present challenges to implement adaptive strategies [2]. Some experts consider both technical issues, such as wastewater reuse, and management issues, including financial mechanisms for improved water sector management, as strategies for sustainable management of water resources for burgeoning mega-cities [4].

Empty spaces in cities can be appointed with a relevant role in the overall organization of the city and its functions [5; 6]. Empty urban spaces can be planned as green areas where small ecosystems can take place in order to introduce or enhance ecological functions supporting the city’s activities [6]. The ecological, social and economic values linked with such areas have to become a central issue in the urban planning and governance [7].

Today, we have to face new challenges about improving urban water availability in response to climate change, using available urban spaces. This problem must be solved in a sustainable way using innovative Green Infrastructure (GI) that combine technology with landscape design by enhancing ecosystem services provision of goods, of fundamental functions or ecological process supporting life on earth, like pollination, water purification, climate regulation. Those conditions improving the
psychophysical well-being (serenity, beauty, cultural inspiration), as well as the conservation of the biodiversity [6] [8]. The concept of Green Infrastructure (GI) emphasises the quality as well as quantity of urban, peri-urban greens spaces and natural areas, their multifunctional role, and the importance of interconnections between habitats [9; 10; 11; 12]. If a Green Infrastructure is proactively planned, developed, and maintained it has the potential to guide urban development by providing a framework for economic growth and nature conservation [13; 14; 15]. GIs include parks and reserves, sporting fields, riparian areas like stream and river banks, greenways and trails, community gardens, street trees, and nature conservation areas, as well as less conventional spaces such as green walls, green alleyways, and cemeteries [6; 16].

In terms of sustainable management of the water resource, these GIs must be able to increase the water provision ecosystem service in urban systems realizing the recovering of rainwater and domestic water and reusing the same for irrigation and non-potable uses.

Therefore, the aim of this research is to develop a project idea of GI in terms of ecosystem services focused on the reuse of water resource exploiting the areas not utilized on the roof of the buildings in the Apulia region, South Italy. The project involves the construction of a green roof to develop the ecological functions linked to the purification of wastewater like in a Constructed Treatment Wetland (CTW) that represents a low-cost alternative to conventional secondary or tertiary wastewater treatment [17]. In a modern urbanized society, the role of nature is extremely important. Inventions that include technologies, which help people to save environment, are becoming more and more successful. Nowadays smart solutions of green roofs are popular for their ecological, technical, economic benefits and aesthetic qualities. Green roofs are an important tool used in residential, commercial, government and public buildings to increase sustainability and biodiversity and decrease energy consumption, urban heat island impacts and greenhouse gas generation in the city [18].

In this project, the green roof was designed to integrate the reuse of wastewater on site for sanitary, garden activities and other uses in the building, reducing the exploitation of the already scarce regional freshwater resources.

2. Project idea
The project idea was developed following the scheme reported in Figure 1: it adopts a multidisciplinary approach in order to develop a management system for the areas that allows economic, ecological and social aspects to coexist without causing trade-off among them.

![Figure 1. Scheme of the proposal idea](image-url)
2.1. **Step 1**

Surface and groundwater supplies in Apulia region, South Italy, are stressed by increasing demand as well as declining runoff and groundwater recharge. The problem of the exploitation of water resources gets heavier in the summer when the high presence of tourists increases water needs. Therefore, the local water management agency (AQP) sometime decreases the water pressure in the pipes in order to reduce the amount of water delivered to the homes [19, 20].

This greater consumption of water is linked with some sewage treatment issues. Indeed, the wastewater treatment plants, designed and sized for the local populations, are not always capable to treat a greater flow of sewage during the summer. If the treatment plant has its waste water discharges at sea, the low efficiency of sewage treatment in the summer can compromise the quality of the bathing water with negative effects on the tourism sector.

2.2. **Step 2**

The project will exploit the empty space on the roof of a residential building with 40 housing units located in Lecce, south Italy (Figure 2), accounting a total surface of about 880 sqm.

The project includes the development of “intensive green roofs” installing a great variety and size of plants such as shrubs and small trees able to work as CTW. This kind of green roof is designed to treat the grey water (kitchen and soapy waters) to obtain a purified water with bacteriological parameters compatible with the reuse for domestic activities and on-site irrigation. Figure 3 represents a generic scheme of an intensive green roof.

The structure of the proposed green roof in this case study reflects a generic intensive green roof and therefore provides the use of impermeable materials of separation between the “medium” (where plant roots grow) and the floor. Compared to a generic intensive green roof, the difference with the proposed roof lies in the structure of the medium and in the selection of the plant species to be introduced that must be able to support the phytodepuration of wastewater.
Figure 3. Model of an intensive green roof extracted from Report of the United States General Services Administration: The Benefits and Challenges of Green Roofs on Public and Commercial Buildings [21].

The proposed green roof will treat sewage for 160 habitants. The available surface amounts to about 880mq; in order to guarantee high quality of water treatment, the proposed system will adopt a SFS-H (Subsurface Flow System - horizontal) or SFS-V (Subsurface Flow System - vertical) green roof scheme because both these typologies need only 4mq for habitant [17] for a total minimum surface not exceeding 650mq (Figure 4). In the SFS-h system the water flows horizontally while in the SHS-v system the water percolates vertically.

Figure 4. Operating scheme of the main types of CTW

Due to the availability of free space, in this project, the green roof extends for 700 sqm. With the aim of re-using the purified water on site, we designed the green roof as SFS-V because it is more effective than the SFS-H in wastewater treatment, even if it requires a medium thickness slightly higher [17] and therefore exerts more weight on the roof. In this case, the minimum thickness required for the medium
is 80 cm and we considered the use of “Expanded perlite” as a draining material to reduce the weight of green roof. The irrigation pipe is located at a depth of 15 cm under the surface of the medium, in order to avoid any contact between the water column and the atmosphere and, therefore, the diffusion of bad odours. Before flowing into the green roof, the wastewater must be conveyed into a grease-trap (16 mc in this case) located at the basement to treat kitchen and soapy waters and separate grease part from liquid part. The purified water must be collected in a tank before being used. The system requires two pumps, one for transporting wastewater from the grease-trap to the green roof and a second one to transfer the purified water from the collection tank to the homes for the use as sanitary water for toilets, irrigation and other uses. The system does not require a significant additional energy consumption for the building; however, a photovoltaic system can be installed on part of the roof.

The proposed system is planned to receive only greasy waters in order to assure a high-quality purified water, with values of bacterial contamination compatible with domestic use. The system could also be extended to black waters (wastewater from toilets) replacing the grease-trap with Imhoff tank. In this case, we consider the use of the output water limited to toilet use and irrigation. The conceptual model developed is shown in Figure 5.

**Figure 5.** Design scheme of the CTW associated with the green roof.

### 2.3. Step 3

The phytodepuration works by combining actions between medium, plants and microorganisms. The flow of the wastewater through the medium promote the presence of microorganisms involved in biochemical reactions degrading the polluting substances. The plants have the role to participate directly in the removal of pollutants and the reduction of the volume of wastewater through root absorption and leaf transpiration, enhancing the proliferation of microorganisms and providing the necessary chemical substances for the reactions. Moreover, microecosystems are formed around the rhizomes, that are very efficient and capable of eliminating foreign elements, such as pathogenic microorganisms [22; 23]. For these reasons, only specific plant species can be used in CTW and the most common species are: *Scirpus* sp., *Eleocharis* sp., *Cyperus* sp., *Juncus* sp., *Phragmites australis*, *Phalaris arundinacea*, *Glyceria maxima* e *Typha* sp, *Zantedeschia*, *Canna indica*, *Hosta*, *Iris levigata*, *Miscanthus sinensis*, *Cotoneaster horizontalis*, *Gunnera manicata*, *Salix rosmarinifolia*, *Salix purpurea* and *Hydrangea Quercifolia* [17].

In the developed project the *Juncus* sp. can be used in association with *Scirpus* sp and *Carex*, constituting a Community habitat similar to Mediterranean salt meadows (code 1410), present in Apulia region (Habitat Directive 92/43/CEE) and, thus, strengthen the European Natura 2000 ecological network with benefits at multiple scales.

Alternatively, the plant community can include *Canna indica* and *Salix purpurea* because they have applications in the medical field and therefore have a commercial value, or *Iris levigata* which has a value in the floriculture field.

### 2.4. Step 4 and Step 5

A Green roof structured as a CTW, produces ecosystem services like ones provided by wetlands and, therefore, act as a sink of CO₂ improving air quality. Intensive green roofs typically increase the biodiversity in the city because introduce vegetation that support a greater diversity of bird species.
Moreover, it is widely recognized that the green roof reduces the heating of the buildings caused by the solar irradiation, thus reducing the consumption of energy necessary to cool the apartments. So, the green roof turns from an unused cemented roof into a source of ecosystem services related to both the reuse of water resources and the development of potential economic activities.

Therefore, the economic benefits of installing green roofs include [21]:

- Lower energy costs due to the cooling effect of plant respiration and the insulation, shading and thermal mass of the plant and soil layers;
- A less frequent roof replacement schedule due to greater durability than conventional roofs;
- Reduced storm-water management costs;
- The creation of job opportunities in roof installation and maintenance and in the emerging field of urban agriculture.

Green roofs increase the quality of the buildings by reducing their impact on the urban landscape. Moreover, they can replace some functions of natural areas and therefore assume an important role in mental health. There is evidence for a positive relationship between access to natural environments and people's perceived overall general health, mental health, physical health and social health [24; 25]. The contact with natural environments promotes psychological restoration, improved mood and attention and reduces stress and anxiety. It can improve cognitive restoration and self-discipline, and can reduce aggression and crime rates [24; 16; 26] (Figure 6).

**Figure 6.** Example of aggressive cementification that would benefit from strategies of landscape design.

This approach offers many opportunities for integration of water resource conservation, economic development and public health promotion. Indeed, a project of green roof for water reuse could be developed at urban scale using different vegetation for each green roof with the idea to create widespread urban gardens. In this perspective, these green roofs could be also suitable areas for the development of projects for the fruition and environmental communication, education and touristic activities. At the municipal level, the replication of this project on many buildings could reduce the water demand for residential areas as well as can mitigate the island heat effect that afflicts urban areas during the summer and improve the quality of life in the city [21] (Figure 7). In the following figure, we selected the buildings characterized by a roof surface allowing at least 5 sqm per each of the building resident.
3. Conclusions
A proper design of a CTW should require a multidisciplinary approach: the design skills of engineering must be integrated with sustainable and environmental sciences related to landscape and urban planning. It becomes essential to develop projects that are able to integrate climate change studies, human needs with the persistence of biodiversity and the provision of ecosystem services. This is also important from the economic viewpoint, because it would allow the optimization of the already scarce economic resources in multifunctional projects in the context of socio-ecological systems, where the ecological and socio-economic aspects should not be faced separately [6].

Therefore, this typology of green roof can also directly and indirectly support human well-being by providing several valuable ecosystem services [27] such as water supply, habitats, aesthetic beauty, educational and recreational benefits.

Presently, in Italy the cost of this project can be reduced thanks to tax reduction for the development of gardens in condominiums or for improving the energy efficiency of the building. However, other incentives would be needed to encourage designers and entrepreneurs to use these solutions. A planning at the regional level would be necessary to further promote such GI; for example, guidelines could be included into the regional Water Protection Plan which aims to protect and manage the water resources. Moreover, municipal development plan can integrate ESS approach in order to consider them also in the authorization of new projects.

Therefore, the GI as green roofs can be considered as strategies able to promote sustainability of an urban system, because they can enhance the ecological functions sustaining a population in an area (ESS such as water, soil and atmosphere purification, biomass production etc.). These typology of projects, which represent green infrastructures to implement ecosystem services related to human activities, should be an integral part of the Strategic Environmental Assessment (SEA: Directive 2001/42/CE) and Environmental Impact Assessment (EIA: Directive 37/85/CEE), which are tools aimed to evaluate environmental impacts on plan and projects, in order to promote the sustainable development of human activities. An important part in any SEA and EIA is represented by the mitigation measures, actions to be implemented in order to mitigate the expected adverse environmental impacts. With regard to the water resource, the application of “green roof” does not represent a simple mitigation measure, but a development strategy that administrators (local, regional and national) should request in order to create added ecological and socio-economic value in the urban contest.

Figure 7. Example of the application of the project idea at a municipal level.
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