Green architecture and water reuse: examples from different countries

This paper shows different examples from different countries (Italy, India, Tanzania) of green architectural solutions (green wall, green roof, roof wetland) in which water (rain and treated greywater) are reused as a resource, in order to reduce the use of drinking water for activities not needing a high quality of water.

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Abstract

Water is a valuable resource which should be better managed to develop a sustainable future. Green architecture is starting to be largely applied, principally for aesthetic improvement of urban centres. However, green architectural solutions provide different additional benefits, among which the reuse of rain and treated grey water. Hence, green architecture can be also viewed as an option to limit the waste of drinking water for applications where the required quality can be lower. In this paper we report the application of three different green architectural solutions in which rain and treated grey water are reused (roof wetland, green roof, and green wall) in three different countries (Tanzania, Italy, and India).

Technical data:

Roof constructed wetland (Tanzania):
- Greywater reused for irrigation
- Greywater consumption of max 4 m^3 per day
- Sewer network for greywater and blackwater segregation
- Two-chamber tank (2 m^3) as pre-treatment
- Pumping station (1.1 kW power, 30 l/min) to feed CW on the roof
- Horizontal flow constructed wetland (23 m^2, HRT 0.8 d) for greywater treatment planted with *Phragmites Mauritianus*
- Lightweight clay aggregates used to reduce weight of the system for both building materials and filling media
- UV disinfection of treated greywater for safely reuse

Green wall (India):
- 2 pilot green walls installed to test the efficiency in treating greywater for irrigation reuse
- Degreaser (125l) as pre-treatment
- Each pilot green wall has 12 parallel frames; every frames constituted of 6 pots in series; total vertical area covered 1.8x0.9m (1.6 m^2)
- Lightweight clay aggregates used as filling media mixed with coconut fibres in a pilot unit and with sand layers in the other
- Expected treatment capacity of 125-250 l per day

Green roof (Italy):
- Green roof installed for aesthetic and thermal insulation reasons, in which the rainwater is harvested for irrigation reuse;
- Intensive green roof of 141 m^2 and 21 cm substrate thickness comprising of a 15 cm of substrate and 6 cm layer for drainage and water storage;
- Tank for collection of harvested rain water;
- Expected rain water harvested 47 m^3.

Introduction

Sustainable water management strategies are considered to be the key solutions to cope with the issues of available potable water shortage and water pollution (Regelsberger et al., 2007). The increasing water shortage reported over the past decade is caused primarily by a growing population combined with lifestyle changes, especially in urban areas, and changing rainfall patterns. Both result in an increased conflict between agricultural and other water uses. Sustainable management is currently becoming a dominating approach, focusing on long term research objective of closed loop recycling (Lens et al., 2001). Taking advantage of alternative water sources is one possible response to the challenges of fresh water demand, water shortages and environmental protection. Raw water sources available include rainwater, sea and brackish water, grey water, and domestic/municipal wastewater. Among these, grey water represents the most profitable source in terms of its reliability, availability and raw water quality (Dixon et al. 1999; Nolde, 1999). The domestic wastewater segregation of black and grey water produces highly concentrated black water (BW) from toilets and possibly the kitchen, with organic content ranging from 500 to 2,000 mg/L (COD) and the majority of the nitrogen content of the mixed wastewater. Grey water (GW) contains low nutrients concentrations, ranging from 5 to 22 mg/L of total nitrogen and 0.2 to 3.9 mg/L of total phosphorus, an easily biodegradable organic content and a relatively low pathogens content (Jefferson et al., 2001, Li et al., 2009). For these reasons, GW is much easier to treat and safer to recycle for water usages that do not need potable water quality, such as toilet flushing, urban landscaping or road washing, than mixed wastewater or BW. As long as there is potable water consumption, greywater, unlike rainwater, could provide a reliable and perennial water source. Typical greywater quality parameter reported in literature are shown in Table 1. Green treatment systems with low footprint can be applied to reach the multiple goals of improve building aesthetic, from an architectural point of view, and to treat greywater for reuse purposes (e.g. Masi et a., 2010). In this paper we illustrate two different green architectural solutions able to reach this goal:

- Roof constructed wetlands
- Green walls

Roof constructed wetlands (CWs) exploit the physical, physiological and biochemical processes occurring in CWs (Kadlec and Wallace, 2009) to treat greywater, with a proper design to limit the overall weight of the treatment plant. In this way, CWs can be placed on rooftop with additional benefits in terms of recovering unused portion of the building and improving the building aesthetic.

Green walls (or bio walls or green bio walls or vertical gardens) are already adopted by architects to reduce energy costs, increase biodiversity, reduce noise pollution, increase building longevity, and improve building aesthetics. However, green walls are living ecosystem in which practically occur the same processes of a constructed wetland, therefore their efficiency in wastewater treatment, and particularly greywater, is an interesting additional benefit which is currently under investigation by the scientific community.

Rainwater harvesting is a well-known practice in arid regions (e.g. Biazin et al., 2012), but it's starting to be considered a good opportunity to reduce the water supply of drinking water also in more developed urban area (e.g., Spinks et al., 2006). Although green roofs reduce the quantity of rainwater harvesting due to water retention aimed to sustain plants and evapo-transpirated by them during not rainy days, not negligible runoff occur anyway during rain events and can be collected and reused. Green roofs change the quality of runoff rainwater, increasing the concentration of nutrient and contaminants retained during dry period; for these reasons, rain water harvested from green roofs is suggested to be used for activities not directly involved with direct human utilisation, i.e. irrigation or toilet flushing (Hassell et al., 2007).

Table 1: Quality of untreated greywater (Regelsberger et al., 2005)

	BOD_5 [mg/l]	COD [mg/l]	TOC [mg/l]	Dry Solids [mg/l]	N_{tot} [mg/l]	P_{tot} [mg/l]	Faecal Coliforms [mg/l]	Coliforms [mg/l]
WOHNSTADT, 1998,	100–130	200–250	120–130	70–90				
Jefferson & Laine, 1997		257		78				
Bahlo, 1999	240	470			22.0	2.0		
Fitschen & Niemczynowicz, 1997	165	361			18.1	3.9		
Nolde, 1999	5–360 (BOD_7)	100–600			5-18	0.2–4.5	10^0–10^5	10^3–10^6

Examples of green architectural solutions with water reuse

Roof Constructed Wetland, Tanzania

The aim of the project is the realisation of a reed bed for the greywater treatment, aimed to produce an appropriate effluent for its reuse in irrigation, to be located on the rooftop of a resort building in the Grumeti Community of Serengeti, Tanzania. The roof CW is currently under construction and the end of the work is planned for the end of 2015. The settlement includes primary building with bedrooms, bathrooms, dressings, living rooms, kitchen, laundry, wine room, and gym; support/ancillary buildings with garage, tool shed, bedrooms, living and dining rooms; a pool and an outdoor dining/terrace/deck with fire pit terrace, rock garden, and viewing deck.

For the design, the influent greywater quality has been set according to literature (Table 1) as following:

- BOD_5 100 mg/l
- COD   200 mg/l
- N_{tot} 10 mg/l
- TSS   80 mg/l
- P_{tot} 2 mg/l

In order to reuse the treated greywater, the CW has been designed to produce the following effluent water quality:

- TSS   < 20 mg/l
- BOD_5 < 20 mg/l
- N_{tot} < 10 mg/lNO_3--N < 10 mg/l
- FC   <2000 cfu / 100ml
- FS   < 1000 cfu / 100ml
- Salmonella   Absent in 5000 ml
- Cholera (vibrion)   Absent in 5000 ml

The greywater quantity per day has been estimated in maximum 4 m^3 per day, considering all the activities developed in the buildings which generate greywater (e.g., bathroom, kitchen, laundry, pool).

Greywater and blackwater is segregated by a sewer system realized with U-PVC SN4 4" pipes.

To reduce the amount of solids in the inflow and to minimize the risk of clogging of the filter bed a pre-treatment is required. A two-chambers septic tank with an effective volume of 2 m^3 is designed for primary sedimentation and grease removal. The retention time, considering a maximum sludge volume equal to the 50% of the total net volume, is about 6 hours.

A pumping station has been installed to feed the CW system situated on the rooftop. The pumping system is constituted by one submerged pump with a nominal power of 1.1 kW, discharge of 30 l/min for a total head of 16 m. The pump start and stop is controlled by a timer and a time switch, in order to equalize the inlet flow. Considering the design flow, the proposed feeding scheme is designed to start the pump every 30 minute, for a corresponding pumped volume of 80 to100 liter.

A single bed horizontal flow (HF) constructed wetland has been designed to treat greywater, with an area of 23 m^2, planted with *Phragmites Mauritianus*, and guaranteeing a hydraulic retention time at maximum flow rate of 0.8 day. The HF CW technical specification are resumed in Table 2.

Table 2. Technical specification of the roof CW

Item	Unit	Value
Total bottom surface	[m²]	23
Bottom length	[m]	4,9
Bottom width	[m]	4,9
Gravel height	[m]	0,45
Medium porosity (Granular Leca Ø 10 mm)	[-]	0,4
Average water level	[m]	0,35

The inert material in the basins has to provide a filtering effect and growth support for microorganisms but also to ensure an adequate hydraulic conductivity; these inert materials (in this case granular Leca) represent the support for the growth of the roots of the emerging plants. The water remains always under the surface of the filtration basin and flows horizontally thanks to a slight difference between the inlet and the outlet levels, preventing odours and mosquito development and allowing public access to the wetland area.

During the passage of wastewater through the rhizosphere of the macrophytes, organic matter is decomposed by microbial activity, nitrogen is denitrified, if in presence of sufficient organic content, phosphorus and heavy metals are partly fixed by adsorption on the filling medium or by precipitation of their insoluble salts; the contribution of the vegetation to the treatment process can be represented both by the development of an efficient microbial aerobic population in the rhizosphere and by the action of pumping atmospheric oxygen from the emerging part of the plants to the roots and so to the underlying soil portion, with a consequently better oxidation of the wastewater and creation of an alternation of aerobic, anoxic and anaerobic zones. This succession of zones leads to the development of different specialized families of micro organisms and a good reduction of pathogens, highly sensitive to rapid changes in dissolved oxygen content; in a single reactor there are therefore multiple transformation pathways for the pollutants contained in the inlet wastewater.
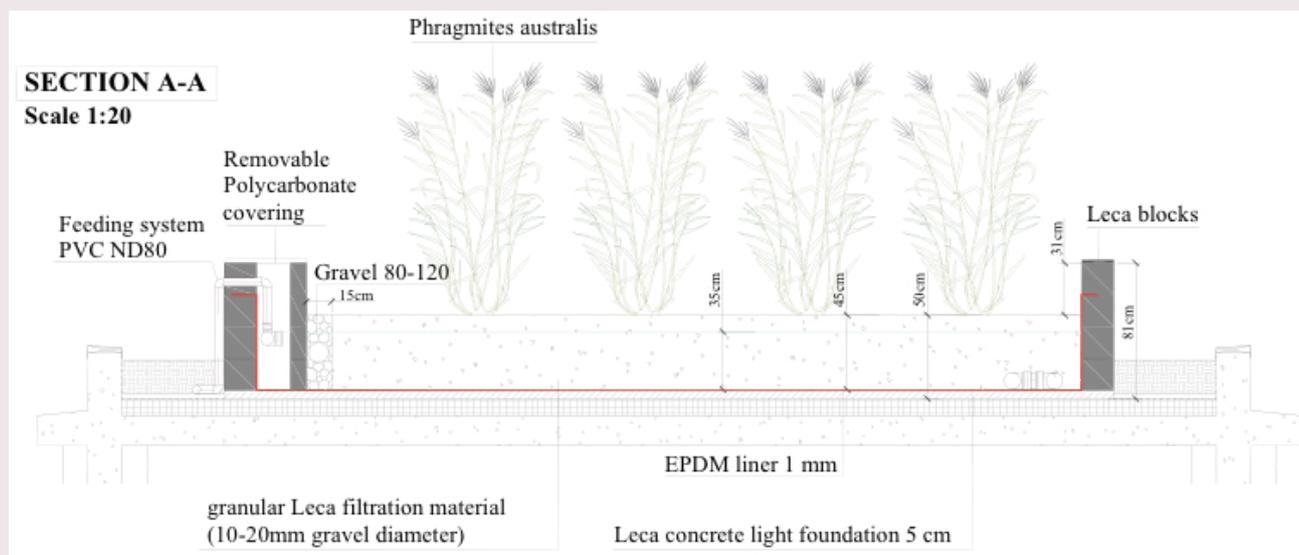
Figure 1. Section of the roof wetland designed for Grumeti Community of Serengeti, Tanzania

The peculiarity of this CW application is the use of light construction materials (LECA in this case) to reduce the weight of the treatment plant, allowing its placement on rooftop. LECA has been used as starting material for lean concrete used in foundation. Moreover, LECA blocks have been used for boundary walls of the bed. Finally, LECA has been adopted also as filling material of the bed.

A UV disinfection unit has been installed to guarantee a safely reuse for irrigation of treated greywater.

Green wall, India

Two pilot green wall units have been installed at the MJP head office (Maharashtra Jeevan Pradhikaran, Water Supply and Sanitation Department of Maharashtra) in Pune (India) to investigate the greywater treatment efficiency. This demonstrative plant is operated under the umbrella of the EU-India research project **"NaWaTech - Natural Water Systems and Treatment Technologies to cope with Water Shortages in urbanised Areas in India"** (http://nawatech.net/), funded by the Seventh Framework Programme of the European Commission and the Department of Science and Technology (Government of India) for cooperation in water technology and management.

The office houses 125 fixed staff and a daily visitor count of 65. Dual plumbing was installed in the first and second floors of the building, which connects approximately 60 staff and 25 visitors connected to a storage tank of 300 L capacity. The pilot green wall comprises of two parallel units on either sides of the entrance. The inflow from the collection tank is stored in two intermittent loading tanks of 100 L capacity each whose outflows are controlled by a timer based solenoid valve. The feeding of the treatment unit happens through a hourly flush of 10 L of greywater. The discharge is directly allowed to flow into the garden next to the walls. The system is designed to treat from 125 L up to 250 L per day.

Each individual treatment unit consist of a 12 x 6 matrix of pots (6 pots in a column and 12 pots in a row). Each pot has a top surface of 0.01 m^2.

The frames are fixed to the wall by stainless steel screws, drilling the coverage and reaching the concrete structure.

The frames and the pots for the realization of the green wall are produced by the Indian company Bajnath and their characteristics are shown in Figure 2. Each pots is filled by LECA (light expanded clay aggregates) and planted with different species. The drainage system is constituted, per each parallel line, by a gutter connected to a vertical pipe that discharges the treated water in a channel placed on the bottom in the soil, as per drawing. The performances of the pilot green wall in greywater treatment are currently under investigation.
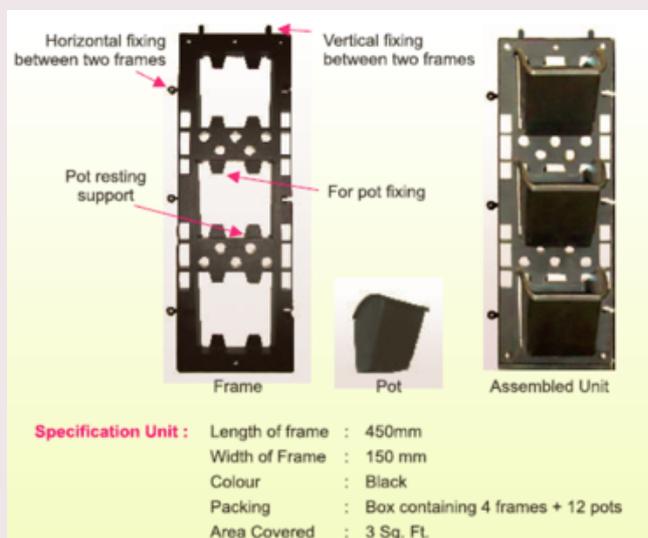

Figure 2: "BIOWALL" characteristics, produced by the company Bajnath

Figure 3: Demonstrative pilot green wall installed at MJP head office in Pune (India)

Green roof, Italy

An intensive green roof has been installed in a wooden house in Treviso, Italy. A green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, installed over a waterproofing membrane. The house has been designed with an eco-sustainable approach: green roof for thermal insulation; renewable energy harvesting by solar panels; wastewater treatment by constructed wetlands; harvesting of rain water and reusing treated wastewater for gardening. The house has been realized in the second half of 2012.

The green roof is extended for 141 m² and is thick 21 cm with the following layers (Figure 4):

- 15 cm of an industrial substrate layer to support a proper plant development (water retention capacity higher compared with traditional soil, proper balance between air and water and between organic and chemical fertilizer, balanced pH, thermal insulation, no plant diseases);
- a geosynthetic layer for fine particle filtration;
- 5 cm of water storage layer with pearlite pillows to guarantee optimal moisture storage for plant development and to reduce green roof weight;
- 1 cm an industrial drainage layer in HDPE;
- Waterproofing membrane.

The green roof has been equipped with a drip irrigation system.

The rain water is harvested and collected together with the effluents from a CW in a tank for irrigation reuse. The average annual precipitation in Treviso is about
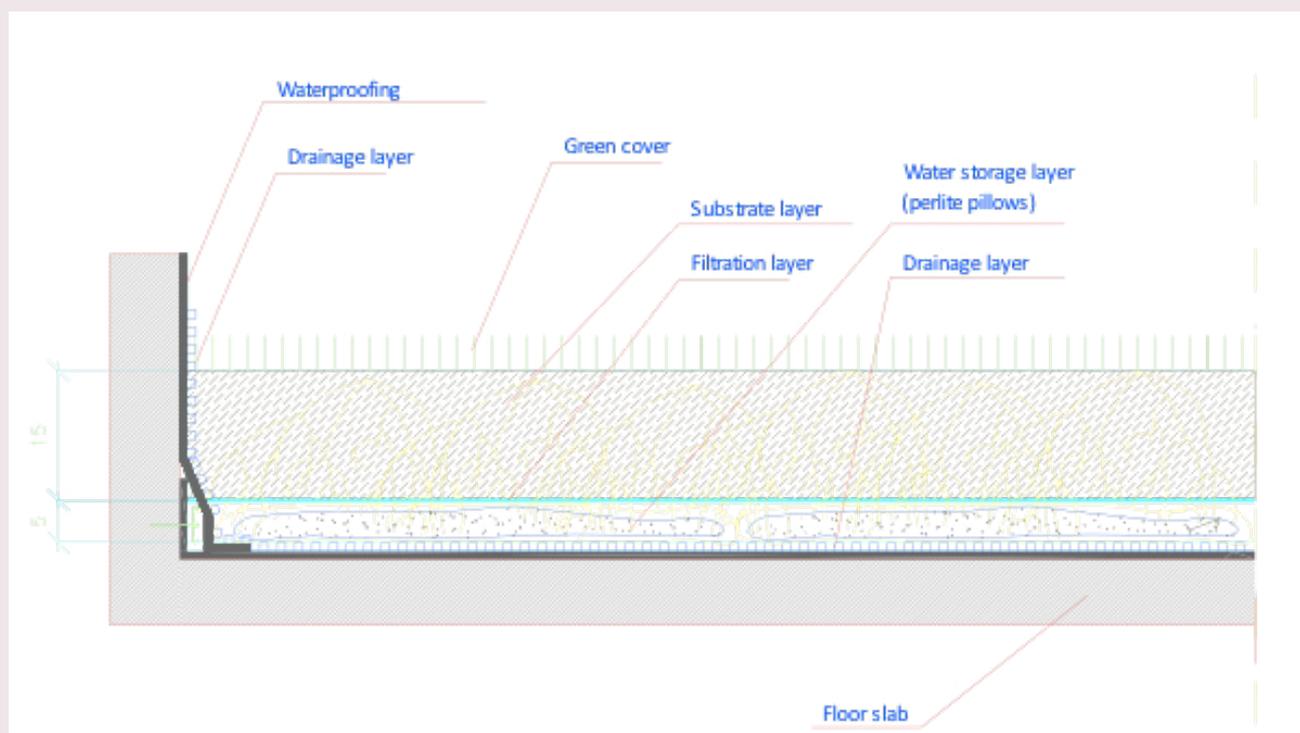

Figure 4: Green roof filling layers

Figure 5: Green roof at the wooden house in Treviso, Italy

1125 mm. Assuming a runoff coefficient of 0.3, the expected rain water harvested from the green roof is 47 m³, which represents a not negligible contribution in limiting the use of drinking water for activities that are requiring water with lower quality.

The capacities of green infrastructures, like green walls, rooftop CWs and the green roofs themselves, are being explored as viable greywater treatment systems that can extremely minimise the treatment footprint and usage of land, contributing therefore to a close-loop decentralised approach for the wastewater purification and the consequent creation of alternative water sources, providing at the same time a series of benefits in the urban landscape (greening, CO_2 trapping, O_2 production, microclimate effects, houses insulation, etc.). We believe therefore that this kind of application can have a tremendous potential in the market and be a relevant item for the green economy development.

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