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Green walls for greywater treatment and reuse in Mediterranean countries

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Abstract This paper describes four case studies in which two types of green walls are implemented for greywater treatment and reuse in Mediterranean countries, Living walls and Green façade. Green walls are vertical vegetated systems that can be integrated into urban environments, providing various benefits. The green walls described in this paper were implemented as part of the NAWAMED project in Mediterranean countries in public facilities with the aim of demonstrating the potential of Nature Based Solutions and reducing the use of potable water by reusing treated greywater. The pilot projects are located in Italy, Jordan, Lebanon and Tunisia, and the treated greywater is mainly reused for irrigation and toilet flushing. In addition, technical indications are provided to foster future implementations of green walls for this specific application and to disseminate sustainable water management schemes.

Keywords: Greywater; Sustainable Water Management; Green Walls; Nature-Based Solutions.

1. Introduction

Green Walls (GWs) are vertical vegetated systems, generally built along the walls of buildings, obtaining multiple benefits, such as thermal insulation, noise reduction or aesthetic improvement. Recently, these systems are starting to be investigated to also implement the additional purpose of treating greywater produced by the facility for reuse.

The NAWAMED project aims at demonstrating the technical and economic feasibility of nature-based and low-cost solutions, to treat non-conventional water resources in schools, universities, and public facilities. To this aim, it was planned to implement real scale pilot installations for greywater/rainwater treatment and reuse in each participating country (Italy, Tunisia, Jordan and Lebanon), recovered greywater will be reused for different purposes, including toilet flushing and irrigation, therefore, reducing the consumption of potable water for domestic uses.

There are different types of GWs: they can consist of climbing plants planted in trenches along the walls, structures anchored to the walls with planted pots, or planted on the roofs and pending along the façade.

Two types of GWs are implemented in the projects, Green façades (GFs) and Living walls (LWs), according to the classification given by Bustami et al (2018) for greenery systems: Green façades are planted with ornamental and climbing plants; Living walls are modular tray containers with pots filled with filling medium in which the vegetation grows.

This paper wants to share the part of the preliminary experience of the NAWAMED project in designing GWs for the particular application of greywater treatment and reuse. This use of GWs is still at an infant stage of the technology, and it was principally studied in a few pilot research studies (e.g. Masi et al. 2016), as also recently reviewed by Boano et al. (2020). Therefore, NAWAMED also aims to push the technological readiness level of this solution with real full-scale demonstration sites, helping to address significant engineering challenges at full scale that still needs to be answered.

2. Case studies

2.1. Ferla, Italy

Coordinates: 37°07'06.6"N 14°56'12.0"E

The Living Wall implemented in Ferla treats greywater (from sinks) produced by the middle school Istituto Comprensivo Statale "Valle dell'Anapo", in Sicily, Italy, with a total of about 190 students. The system was designed considering to treat a greywater flow rate of 1.3 m^3/d, about 260 m^3/year, corresponding to 23% of the school's water demand for toilet flushing.

The LW covers an area of about 30 square meters (**Figure 1**), and is divided into 3 façades (north-west, north-east, south-east). The treated greywater is accumulated in an underground deposit and reused for toilet flushing and irrigation.

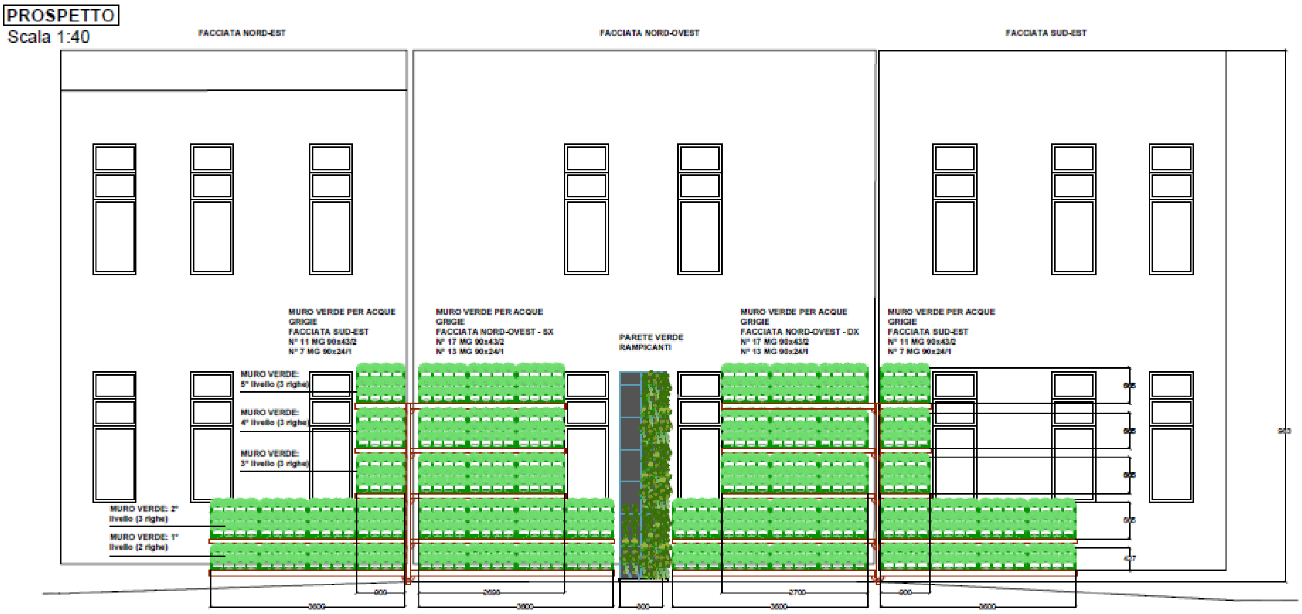

Figure 1. Front view of the Living wall designed in Ferla, Italy

Figure 2. Typological front view and section of the Green façade, designed in Beirut, Lebanon, and Amman, Jordan.

2.2. University of Jordan, Jordan (UJ)

Coordinates: 32°00'58.4"N 35°52'10.7"E
Both living walls and green façades were designed with the aim of treating and reusing greywater produced by one of the buildings of the University of Jordan, in Amman. The building is considered to host about 300 students for ten months per year, and the GWs are expected to treat and recover a greywater flow rate equal to about 4.45 m^3/d, about 1300 m^3/year.
The green walls are divided into four different areas (Area 1 – 4), providing a total green wall surface coverage of about 363 m^2 (11 m^2 for the LW and 352 m^2 for the GFs). The treated greywater is reused for parking and lawn irrigation, and for toilet flushing.

2.3. Jewett Hall, Lebanon (JHA)

Coordinates: 33°54'02.0"N 35°29'09.2"E
The project for the green walls for Jewett Hall, a dormitory in Beirut, regards the construction of living walls and green façades, designed with the aim of treating and reusing light greywater (from showers and washbasins) produced by the dormitory, and will be reused for toilet flushing.
The living walls are divided into the East Living Wall, and the West Living Wall, for a total surface area of approximately 80 m^2, while the green façade covers a surface area of approximately 105 m^2. Therefore, the NBS of Jewett Hall are expected to treat up to 2.9 m^3/d of greywater, about 1060 m^3/year.

2.4. CERTE, Tunisia

Coordinates: 36°42'31.0"N 10°25'34.4"E
In Tunisia, green walls are designed to treat and reuse greywater produced by CERTE, a research center in Tunis (**Figure 3**). The living walls are divided into six zones (Zone 1 – 6), the average daily flow is equal to 0.31 m^3/d for Zones 1-2 and 0.35 m^3/d for Zones 3-4-5-6, leading to a design flow rate of 2.0 m^3/d for the whole green wall system, 700 m^3/year.
The green walls are divided into 3 living walls, which cover a total surface area of approximately 70 m^2: Greenwall 1, narrow north-east front (about 11 m^2); Greenwall 2, large north-west front (about 34 m^2); Greenwall 3, n° 2 front-rear self-sustained systems (about 29 m^2). The treated greywater is reused for irrigation and for toilet flushing.

Figure 3. Rendering of the green walls of CERTE, Tunisia

3. Preliminary design indications and methods

The GWs were designed as vertical submerged subsurface flow treatment wetlands, i.e. unsaturated and batch-fed, for the following key reasons: limited weight, reduction of evapotranspiration (the project will be implemented in water-scarce arid environments), and a wide choice of plant species.
Green façades were designed as unsaturated vertical flow constructed wetlands, but planted with climbing ornamental plants (**Figure 2**), according to the experience of Kotsia et al. (2020). Therefore, design methods followed common books and guidelines on this type of systems (Dotro et al., 2017; Nivala et al., 2018).
On the other hand, for Living walls, being such an innovative solution, no standard design procedures are yet available, therefore LWs were designed based on a literature analysis, including results from R&D pilot systems (SUPERGREEN project). Modulogreen modules were chosen for the LWs among those available on the market as they were deemed the most appropriate for greywater treatment. The feeding in the LWs takes place through perforated pipes only in the first of the three rows of pots in the modules, the water then passes through the rows below to be then collected by drainage channels. The design of the feeding system was one the most challenging aspects in the design of LWs from the hydraulic perspective, since the use of greywater does not allow the use of conventional pressure valves used in common applications of green walls; therefore, the distribution system was sized with hydraulic modelling and the EPANET software was used, following the approach proposed by Paul et al. (2018). The porous media was selected according to literature evidence, with a mixture of coconut coir, leca, and sand (Boano et al., 2020b; Masi et al., 2016).
The sizing of the green walls was based on the dimensional parameters from literature, which are summarized in Table 1. Particularly, GWs are sized with the oxygen balance method, considering an average transfer rate (OTR) on the area dedicated to the treatment, i.e. the transversal treatment area of the pots and the green façades. The treatment performance was checked with the loading rate graphs of NBS treating greywater provided by Arden and Ma (2018) and Boano et al. (2020a). Plants are selected by local botanic experts, starting from a list of plant found suitable for use in green walls for greywater treatment and reuse (Boano et al., 2020b; Kotsia et al., 2020): e.g., *Lonicera*, *Carex*, and *Hedera*.
All systems described include a preliminary treatment (degreaser), a collection system and accumulation tank and a UV disinfection phase before reuse.

4. Conclusions

Thanks to green walls for greywater treatment two main benefits are obtained: (i) the saving of drinking water thanks to the reuse of greywater for toilet flushing, irrigation and other uses; (ii) the reduction in the volume of wastewater daily discharged in the public sewer thanks to the recovery of grey water.

Due to the many advantages they provide, green walls are considered among the most promising green architecture solutions capable of combining the need for wastewater treatment and recovery and the acceptance by residents of the inclusion of decentralized treatment solutions in urban environments (Liu 2017).

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Table 1. Green walls sizing parameters. LW: living walls. GF: green façade. OTR: oxygen transfer rate. HLR: hydraulic loading rate. OLR: organic loading rate.

Sizing parameters	Unit of measure	Ferla	University of Jordan		Jewett Hall		CERTE
Green Wall type		LW	LW	GF	LW	GF	LW
Average daily flow	m^3/day	1.3	0.25	4.2	2.1	0.8	2
Influent BOD concentration	mg/L	80	120	120	120	120	100
Influent COD concentration	mg/L	160	240	240	240	240	200
Green Wall coverage area	m^2	30	11	352	80	105	70
LW transversal treatment area - first row	m^2	4.4	1.2	-	10	-	2.8
LW transversal treatment area	m^2	11.9	3.5	-	29	-	19
GF transversal treatment area	m^2	-	-	53	-	21	-
OTR	gO2/(m^2 d)	17	17	30	17	30	17
HLR – LW first row	l/(m^2 d)	300	200	-	200	-	250
HLR – GF	l/(m^2 d)	-	-	90	-	80	-
OLR – LW first row	gCOD/(m^2 d)	47	50	-	50	-	50
OLR – GF	gCOD/(m^2 d)	-	-	20	-	20	-

References

Arden, S. and Ma, X., 2018. Constructed wetlands for greywater recycle and reuse: a review. Science of the Total Environment, 630, pp.587-599.

Bustami, R.A., Belusko, M., Ward, J. and Beecham, S., 2018. Vertical greenery systems: A systematic review of research trends. Building and Environment, 146, pp.226-237.

Boano, F., Caruso, A., Costamagna, E., Ridolfi, L., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A. and Masi, F., 2020 (a). A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. Science of the total environment, 711, p.134731.

Boano, F., Caruso, A., Costamagna, E., Fiore, S., Demichelis, F., Galvão, A., Pisoeiro, J., Rizzo, A. and Masi, F., 2020 (b). Assessment of the Treatment Performance of an Open-Air Green Wall Fed with Graywater under Winter Conditions. ACS ES&T Water.

Dotro, G., Langergraber, G., Molle, P., Nivala, J., Puigagut, J., Stein, O., & Von Sperling, M. (2017). *Treatment wetlands.* IWA publishing.

Kotsia, D., Deligianni, A., Fyllas, N. M., Stasinakis, A. S., & Fountoulakis, M. S. (2020). Converting treatment wetlands into “treatment gardens”: Use of ornamental plants for greywater treatment. *Science of The Total Environment*, **744**, 140889.

Liu, R., Wei, T., & Zhao, Y. (2018), Presentation and perspective of appealing green facilities for eco-cyclic water management. Chemical Engineering Journal, 337, 671-683.

Masi, F., Bresciani, R., Rizzo, A., Edathoot, A., Patwardhan, N., Panse, D. and Langergraber, G., 2016. Green walls for greywater treatment and recycling in dense urban areas: a case-study in Pune. Journal of Water, Sanitation and Hygiene for Development, 6(2), pp.342-347.

Nivala, J., van Afferden, M., Hasselbach, R., Langergraber, G., Molle, P., Rustige, H., & Nowak, J. (2018). The new German standard on constructed wetland systems for treatment of domestic and municipal wastewater. *Water Science and Technology*, **78**(11), 2414-2426.

Paul, U., Karpf, C. and Schalk, T., 2018. Hydraulic simulation of perforated pipe systems feeding vertical flow constructed wetlands. Water Science and Technology, 77(5), pp.1431-1440.