Sustainable Sanitation

Practice

EcoSan Club

Issue 23, 7/2015

- Green architecture and water reuse: examples from different countries
- Building-Integrated Indoor Vertical Ecosystem for Treatment and Recycling of Greywater
- Natural humidification by functional Green Walls and PrimaKlima® plants as resource-efficient and hygienic alternative or complement to technical devices
- Green roofs and living walls meet sustainable energy and building technologies

Green walls/roofs

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Cover Photo / ***Titelbild***

Detail of a vertical wall for treating greywater at a office building in Pune, India © Günter Langergraber

Editorial

„Green walls/roofs“ is the topic of issue 23 of the Sustainable Sanitation Practice (SSP) journal. Using green walls and green/ living walls has become a trend in sustainable building. Various aspects are covered in the four papers presented in this issue:

- Fabio Masi and co-workers present case studies from Italy, India and Tanzania,
- Andrea Zraunig et al. present VertECO, a vertical ecosystem for greywater treatment,
- Manfred Radke and Andrea Zraunig report on green walls for humidification of rooms, and
- Ulrike Pintha and Bernhard Scharf summarize the requirements and challenges in the interdisciplinary planning process needed to implement such technologies.

The thematic topic of the next issue (Issue 25, October 2015) is „Financing of sanitation“. If you are interested to submit a contribution please inform the SSP editorial office (ssp@ecosan.at). Contributions are due to 15 September 2015, the guide for authors is available from the journal homepage (www.ecosan.at/SSP). Please feel free to suggest further topics for issues of the journal to the SSP editorial office (ssp@ecosan.at). Also, we would like to invite you to contact the editorial office if you volunteer to act as a reviewer.

SSP is available online from the journal homepage at the EcoSan Club website (www.ecosan.at/SSP) for free. We also invite you to visit SSP and EcoSan Club on facebook (www.facebook.com/SustainableSanitationPractice and www.facebook.com/EcoSanClubAustria, respectively).

With best regards,
Günter Langergraber, Markus Lechner, Elke Müllegger
EcoSan Club Austria (www.ecosan.at/SSP)

Content

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.

Authors: Fabio Masi, Anacleto Rizzo, Riccardo Bresciani

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 m³ 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.

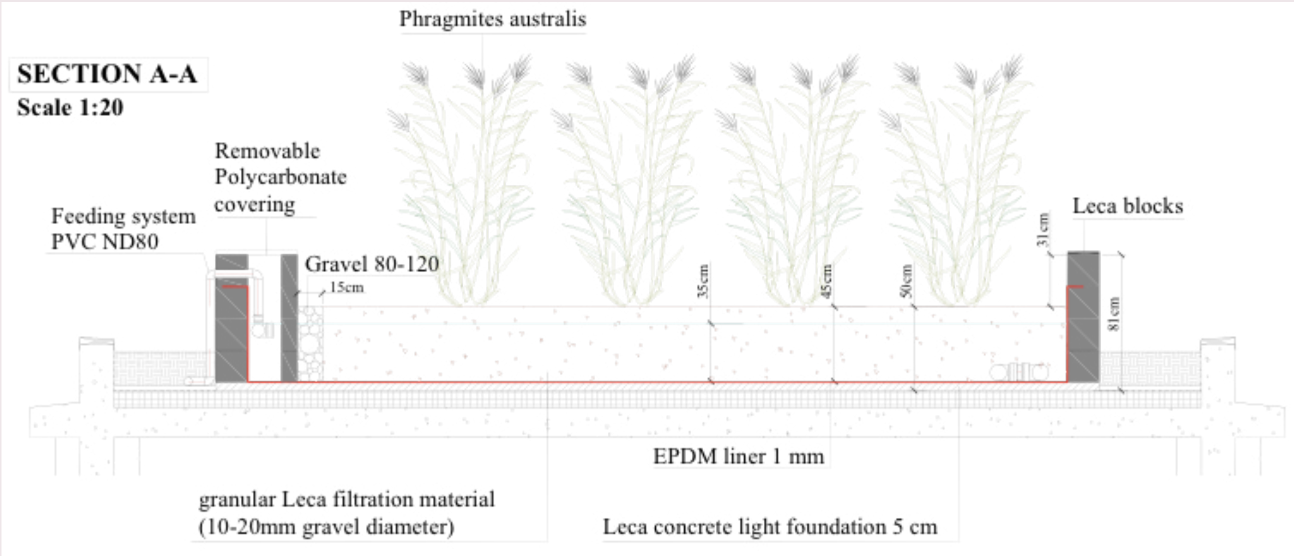

Figure 1. Section of the roof wetland designed for Grumeti Community of Serengeti, Tanzania

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.

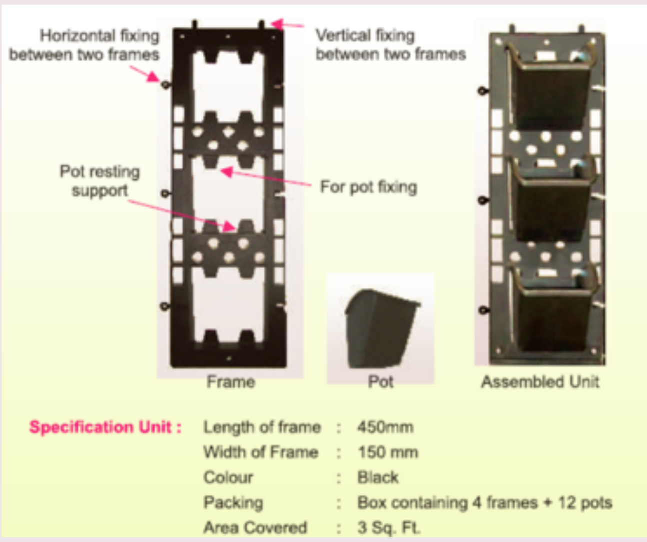

Figure 2: "BIOWALL" characteristics, produced by the company Bajnath

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 m^2 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

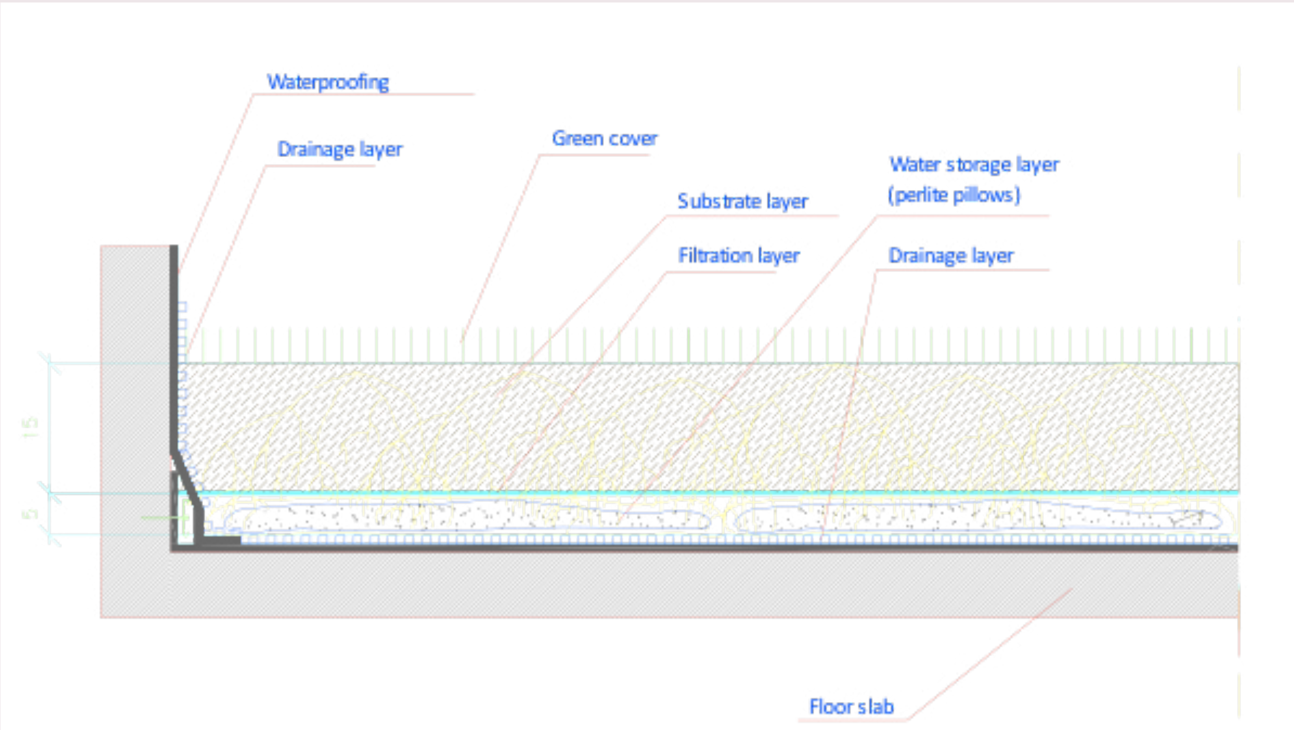

Figure 4: Green roof filling layers

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 m^3, 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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Building-Integrated Indoor Vertical Ecosystem for Treatment and Recycling of Greywater

This article describes the reduction of fresh water consumption with an integrated greywater treatment system in buildings based on the functionality of a natural ecosystem.

Authors: Andrea Zraunig, Heinz Gattringer, Johannes Kisser, Manfred Radtke

Abstract

The Vertical Ecosystem is a greywater purification system based on indoor constructed wetlands with cascading set-up that combines sub-surface horizontal water flow with stage wise vertical flow. A test unit with three levels of plant containers installed at the laboratory of alchemia-nova has been tested under conditions that simulate greywater pollution levels of tourist facilities. This Vertical Ecosystem supports the reduction of drinking water by providing an aesthetically appealing indoors solution utilising plants and their rhizosphere. The investigated plant species function in symbiosis with rhizosphere microorganisms providing water-cleaning abilities. Special focus lies on practical considerations regarding bottlenecks for market uptake of this concept. In relation to EU-legislations and recommendations the effluent of the Vertical Ecosystem can be used for toilet flushing, irrigation of private gardens, golf grounds, groundwater recharge and laundry, at the studied level of greywater pollution load and flow throughput.

Introduction

Constructed wetlands are well known to filter pollutants from water since the early 1950's (Seidel, 1961). These treatment systems use natural processes involving wetland vegetation, soils and their associated microorganism to improve water quality. Wetland plants offer proper conditions for microorganisms to live in the rhizosphere (Brix, 1987). Through a series of complex processes, these microorganisms transform and remove pollutants from the water (Vymazal, 1998; US EPA, 1999). The approach of reuse of treated greywater for applications with lower water quality requirements like toilet flushing, irrigation or groundwater recharge is not new. Due to the low contamination with pathogens compared to blackwater, the reuse of treated greywater becomes increasingly attractive (Li et al., 2009). With regard to innovative buildings, there are many integrated water management approaches (Nolde, 1999). In fact most plant-based wastewater treatment units are usually located outdoors. Often they are centralised and operated by companies or community services and infrastructure providers. Some efforts aim to treat greywater decentralised and on building sites, but these are all designed as outdoor solutions. Only a few horizontal indoor-constructed wetlands are known (Starkl et al., 2005; Weissenbacher et al., 2009).

Due to space limitations vertical Greenwalls (vertical greening elements) are already known as an architectural

Technical data:

Laboratory scale plant-based greywater treatment

- size 1 m (w) x 3 m (l) x 2,8 m (h)
- indoor, semi-indoor, in 3 cascading stages
- 0,5 m^3 volume rhizosphere
- forced air oxygenation of the rhizosphere
- flow rate 0,3-0,5 m^3/d, semi-continuous
- storage puffer tank
- pollution abatement: COD from > 300 mg O_2/L to < 10 mg O_2/L,
- BOD from > 200 mg O_2/L to < 5 mg O_2/L
- Energy requirement: 2,7 kWh/m^3 of treated greywater without artificial lighting

gardening structure (Carpenter, 2008; Timur and Karaca, 2008). These living walls or greenroofs are often used to reduce overall temperature of the building, improve air quality, buffer noise or are used for urban gardening, but mostly for aesthetic purposes. The combination of both, a vertical constructed wetland integrated in an indoor approach of a building, is new. This Vertical Ecosystem (VertECO) will solve the problem of reducing the consumption of drinking water by providing a technological solution based on plants. It will be tied into the greywater treatment cycles of the building and will support significant potable water savings by reusing water flows on site, e.g. for flushing toilets. This ecosystem technology is based on subsurface water flow through the root zone of plants (Seidel, 1965; Vymazal, 2011). The investigated plant species function in symbiosis with rhizosphere specific microorganisms providing intrinsic water cleaning abilities and will demonstrate that there are no negative odours or microbial impacts on the air or water treated by the system (Nolde, 1999). In fact, it will help to remove VOC`s (volatile organic compounds) from the ambient air (Wolverton et al., 1989), and also will demonstrate that this plant based water treatment technology is applicable to buildings in regions of all climate conditions. Particularly in Mediterranean countries or regions with an arid climate, water resources are limited and unequally distributed in space and time. As an educational side benefit, it will demonstrate tangibly the importance of wetland ecosystem services in relation to clean water for the planet and humanity.

The main demonstration site of the Vertical Ecosystem is Samba Hotel, a representative hotel chain located in Lloret de Mar, Girona, Spain. It is a large resort with 441 air-conditioned rooms, green areas and exterior pools, conference rooms, bar and restaurant. It is certified by EMAS and ISO 14001.

For this technology, a wide range of applications might be possible like public or private households, office buildings, commercial buildings, train stations, hotels, restaurants, airports, as well as for industrial end users like food processing industries or other industries (Vymazal, 2008).

Material and methods

The laboratory scale plant-based greywater treatment unit imitates real life conditions of a demonstration site located in a hotel at the Costa Brava in Spain. This unit is monitored for cleaning performance, microbiological factors, chemical pollutants, reliability, maintenance and energy demands. For the constructed plant based wetland a vertical stage wise set-up has been used combined with a sub-surface horizontal water flow. The laboratory small-scale wetland consists of three floors (Figure 1), connected by water tubes. A pump, with time controlled operation, feeds (grey)water from a buffer tank into the top floor. Water flows in a sub-surface horizontal manner, meandering through the rhizosphere and pushed down to the next floors by gravity. In order to improve the aerobic symbiosis (Stottmeister et al., 2003) of roots and microorganisms, air is continuously injected through perforated hoses at the bottom of the plant containers into the water. As an additional side-benefit, air-pollutants are also removed from the air through this ventilation system. Many harmful air-pollutants are known to be metabolised by microorganisms in the root zone (Wolverton et al., 1989). To ensure the largest possible area for the colonization of microorganisms, inorganic substrates with a large surface area (e.g. expanded clay) are most suitable (Kickuth, 1969; Geller et al., 1990). The substrate must also be stable, not biodegradable over time, so that it does not break up and clog any pipes. The investigated plant species are specifically suitable for this indoor constructed wetland system and have some decorative qualities (figure 1). With sensors from S::can (UV-VIS spectrometry, ion selective electrodes) and Thermo Scientific (electrochemical and ion selective electrodes) following chemical parameters are tested either online (continuously) or in situ (directly):

- organics: chemical oxygen demand (COD), biological oxygen demand (BOD), total organic carbon (TOC) dissolved organic carbon (DOC)

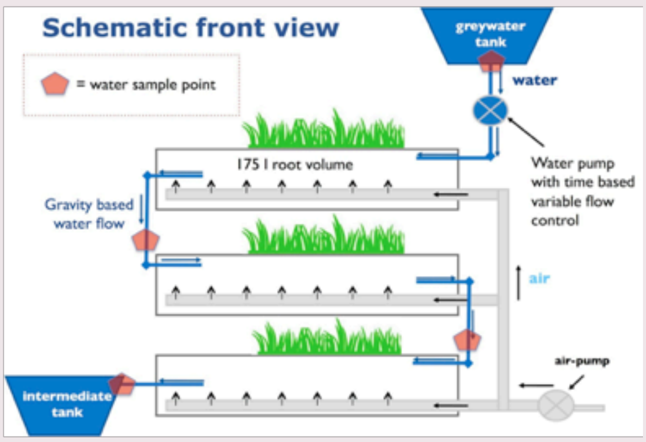

Figure 1: Vertical Ecosystem - laboratory test unit (left) schematic front view of the Vertical Ecosystem (right)

- nutrients: total nitrogen bound (TN_b), nitrate (NO_{3-}), nitrite (NO_{2-}), ammonium (NH_{4+}), total phosphorus (PO_4^{3-}), sulphate (SO_4^{2-}), sulphite (SO_3^{2-}), sulphide (H_2S), chlorine total (Cl_2)
- suspended matter: total suspended solids (TSS), turbidity
- on-site: pH, temperature, dissolved oxygen (DO) and conductivity
- surfactants: anionic, cationic and nonionic

For analysis of microbiological and pharmaceutical parameters, external laboratories were commissioned.

A water sampling campaign was done in June 2014 by a project consortium partner in the SAMBA hotel to get preliminary water quantity and quality data. Composite samples from the different streams were analysed for standard chemical parameters and some micro pollutants (pharmaceutical compounds). The sampling points at the hotel, relevant to the indoor constructed wetland technology are shower water, greywater tank and laundry effluent. Synthetic greywater that imitates the quality of the expected flows at the demonstration site was used for the laboratory experiments, Synthetic greywater is mixed using hygiene products (like soaps, shower gel, shampoo, conditioner, tooth gel, deodorant, cosmetics, body lotion), lavatory cleaning products, dust from a vacuum cleaner, citric acid to adjust pH, curing salts. Washing machine effluent was also prepared at the laboratory of alchemia-nova in Vienna. The salts are added to increase the electrical conductivity parameter and simulate a higher salt content as seems to be the case at the hotel in Spain, as well as to provide some nitrates to the mixture. The hotel located on the Mediterranean shore uses tap water that comes partially from desalination plants or groundwater, which seem to have a higher base salt content than the drinking water in Vienna, which comes mostly from natural springs in the close alps. The water flow is regulated so that a volume of 250 to 300 L/day is pumped through the laboratory small-scale test wetland. To obtain a higher cleaning performance, a longer retention time of the water in the treatment unit is desirable (Vymazal, 2011). For this reason, the water is pumped intermittently through the treatment plant. More than 90 plants (marsh plants, graminoids, tropical and subtropical plants) in different combinations were tested. These plants must satisfy following requirements: grow in inorganic, hydroponic-like substrates, tolerate the pollution load of greywater, thrive under limited amounts of light, show positive water cleaning interactions and have decorative value. The effluent from the Vertical Ecosystem was analysed for water quality defining parameters and compared to the initial values from the synthetic greywater to allow a performance appraisal.

Results and discussion

Table 1 compares values of key water quality parameters (reference values for pollution loads) for the synthetic greywater mixed at the laboratory in Vienna for test purposes and the values for the final outflow from the Vertical Ecosystem unit after the water has been treated. These values are averaged and condensed from a period of 9 months of tests with the unit at different greywater loads. Pollution abatement and water cleaning performance is considerable.

Table 1: Synthetic greywater (inflow), effluent water after treatment

Parameter	Unit	simulated greywater GW Tank	effluent after treatment cleared water
COD	mg O_2/L	336	8.9
BOD_5	mg O_2/L	238	3
TOC	mg C/L	122	3.9
DOC	mg C/L	109	2.8
TNb	mg N/L	2	0.3
NO_3-N	mg N/L	0.8	0.1
NO_2-N	mg N/L	0.089	<0.003
NO_4-N	mg N/L	0.04	<0.03
TSS	mg/L	46.9	4.61
Turbidity	NTU	43.9	0.3
pH		5.83	7.22
DO	% Sat	81.83	90.8
Conductivity	µS/cm	431.4	423.1
Surfactant anionic	mg/L	57	0.3
Surfactant cationic	mg/L	<0.2	<0.2
Surfactant nonionic	mg/L	1	<0.2

For a better insight, the average values at each sampling point for selected parameters are presented next. COD and BOD are very important in order to assess the cleaning performance of the system. Our sampling points are the greywater tanks with the synthetic mixture, after 175 L rhizosphere (1st floor), after 350 L rhizosphere (2nd floor) and after 525 L rhizosphere (3rd floor) (Figure 2). Drastic reductions in the COD and BOD parameters are obtained after the first cleaning stage, then this decrease levels off in an approximately logarithmic manner and at values of about 8,9 mg O_2/L for COD and 3 mg O_2/L for BOD. Further decreases do not seem practical anymore for a reasonable size (=root area) of the unit. Similar conclusions can be drawn for TOC and DOC (Figure 2). Odour levels throughout these tests remained within acceptable limits, though this may be a bit subjective. The emanated smell could be characterised as half way between fresh air and wet earth smell.

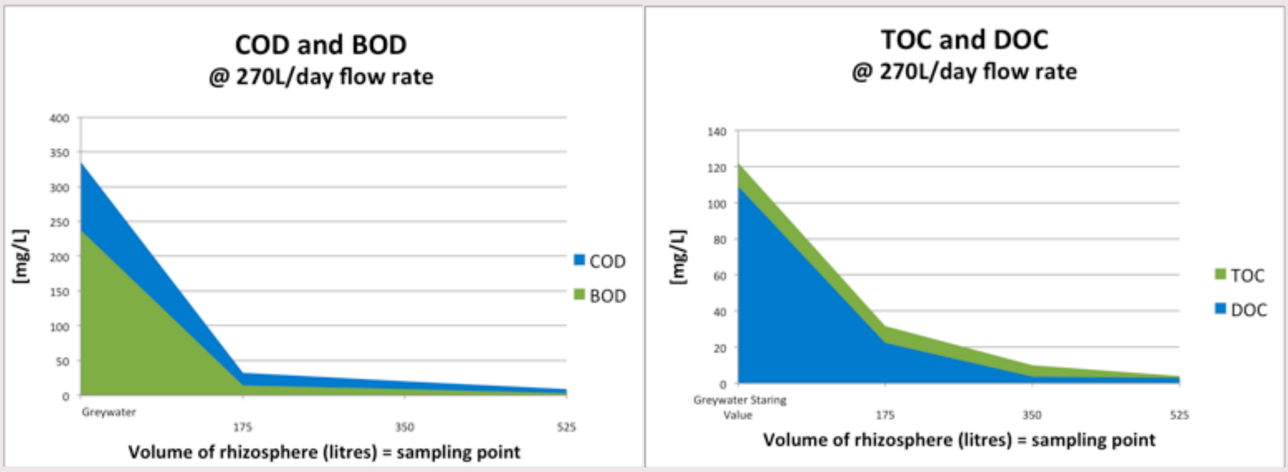

Figure 2: Cleaning performance of the Vertical Ecosystem for COD and BOD (left) and TOC and DOC (right).

Influent concentrations of nitrogen compounds have been very low (Table 1). Effluent concentrations of nitrogen compounds are close to or below the limit of detection. No accumulation of organic nitrogen during degradation of organic matter can be observed.

The turbidity decreases continuously from stage to stage, whereas for the TSS parameter the highest cleaning performance takes place in the first stage (Figure 3). Turbidity is an important parameter for water reuse. For most water reuses there are guidelines for groundwater recharge or irrigation of maximum 2 NTU established by law. After treatment with the Vertical Ecosystem the turbidity decreases with a value of 0,3 NTU, obviously below these guidelines.

The parameter of conductivity is one that does not evidence a satisfactory behaviour in the Vertical Ecosystem. The conductivity of the effluent water is as high or even slightly higher than the conductivity of the influent greywater (Table 1). Some conductivity increases can be attributed to the breaking up of pollutants into smaller polar components like acids. The higher unwanted salt insertion though seems to derive from the substrate itself. This indicates that some of the substrate components used have a high anorganic salt content, which is not washed out in a short time. This motivated the substitution of the initial substrate and also a search for plant species that would be adequate to grow in the unit and also extract and accumulate salts in their tissue.

Surfactants were also analysed in several experiments. There are high amounts of anionic surfactants in the greywater tank, while cationic and non-ionic surfactants where extremely low in the common greywater test mixture. Anionic surfactants have a negative charged head. Common types include e.g. sodium lauryl sulphate that is present in almost any common off the shelf soap, shampoo, shower gel etc. A satisfactory cleaning performance is achieved. According to our results, with an initial value of 57 mg/L in the influent only 0.3 mg/L are detectable at the effluent of the test unit.

For microbiological analysis (Escherichia coli and intestinal Enterococci) the test greywater was spiked at rather high levels of the studied microorganisms (E. coli at 6.77 x 10^5, c.f.u., Enterococci at 3.33 x 10^3). Although there is a remarkable reduction in the count of these potentially harmful microorganisms (down to 7,5 x 10^3 and <10 respectively), *E. coli* count could not

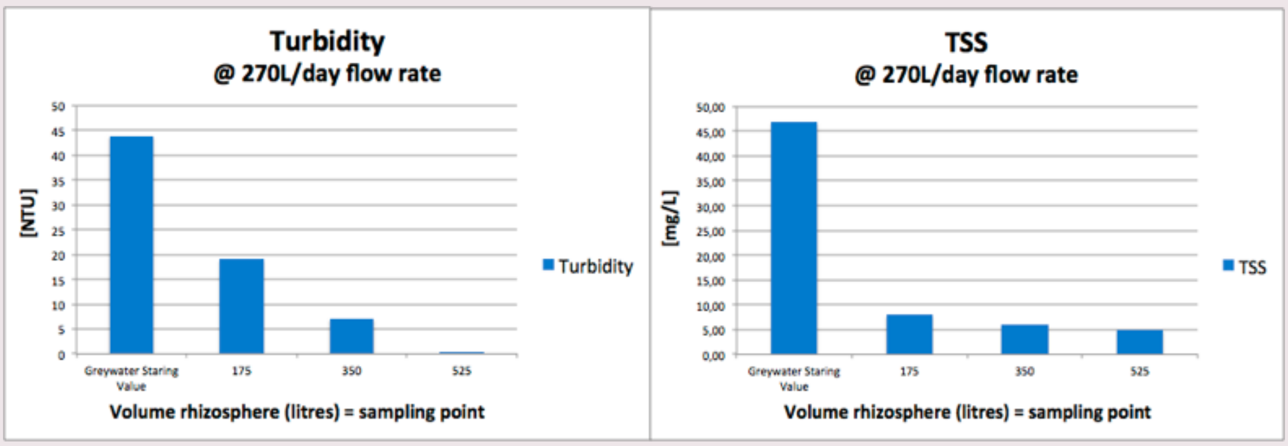

Figure 3: Cleaning performance of the Vertical Ecosystem for Turbidity (left) and TSS (right).

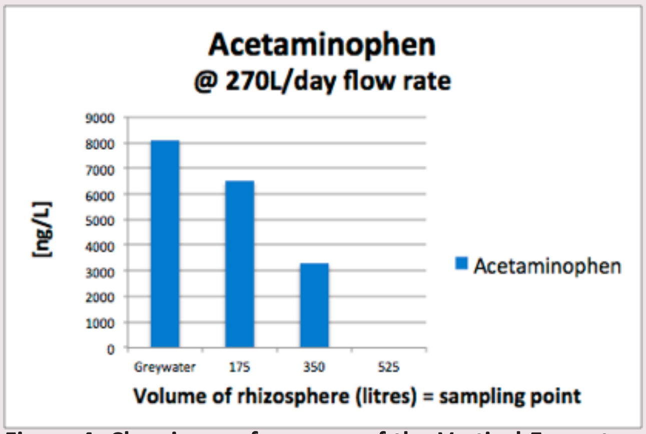

Figure 4: Cleaning performance of the Vertical Ecosystem (Acetaminophen)

be reduced to a desirable level of 0 given the water throughput of the test set-up. Since the reference data of microbiological pollution load from the water at the hotel demonstration site in Spain showed hardly any noticeable germ count, no further microbiological tests were performed.

For pharmaceutical tests a common painkiller (acetaminophen) was selected as test parameter. Initial mixture was 16 mg pill powder from the drug store preparation "Mexalen rapid, 500 mg" in 500 L greywater tank (Figure 4). With an initial concentration of about 8000 ng/L in the greywater, acetaminophen was not detectable (with a detection limit of 50 ng/L) in the effluent of the unit. However, these tests have just begun, repetitions, confirmation and metabolite analyses are needed. Initial results are definitely very encouraging.

Tests with higher chlorinated greywater were performed. To the mentioned recipe, 2 g of commercial swimming-pool chlorine were added to an approx. 450 L greywater tank. Results in the measurements did not show any great deviations in the cleaning performance of the unit and most parameters evidenced similar results as in non-chlorinated test tanks. Tests with laundry water from washing machines were also carried out, using two different kinds of detergents (one that claims to be more environmentally friendly and one that is just a standard detergent with colour enhancers). These experiments are still ongoing and data is still being collected, so no definitive conclusions can be offered. Preliminary results indicate that the cleaning performance of the unit is still very satisfactory. Nevertheless, the detergent perfumes in the laundry cleaning formulations are so strong, that the whole Vertical Ecosystems emanates these perfumes quite strongly, so that an indoor cleaning of laundry effluents seems not feasible, at least not in living quarters.

In the meantime more than 90 plants were tested in different combinations in a combined effort between Radtke Biotechnik and alchemia-nova. 15 species like marsh plants (Typha, Iris,…), graminoids (Carex, Cyperus,…), tropical and subtropical plants (Ficus, Spathiphyllum,…) were selected for use at the demonstration site, as they provided the best results.

Conclusions and outlook

Based on Table 1, a considerable cleaning performance of water was achieved by the Vertical Ecosystem. In relation to Spanish/EU legislations, preliminary results seem to indicate that the effluent of the Vertical Ecosystem can be used for applications with lower water quality requirements like toilet flushing, irrigation of private garden, golf irrigation, groundwater recharge and laundry, at the given load of greywater pollution and flow rate input of approximately 1 litre of greywater per litre of root volume per day (Table 2). Microbiological tests for key indicator species are still pending, but the target water streams at the demonstrations site at the hotel did not show any problems with microbiological load, probably because those water streams get chlorinated quite intensely.

Regarding physicochemical parameters the indoor Vertical Ecosystem performed remarkably well. It needs

Table 2: Pertinent regulatory guidelines for water quality for on-site recycled water compared to the results from the Vertical Ecosystem unit

			Potential Re-uses of VertECO effluent					
	Simulated greywater effluent	Water effluent after VertECO	Laundry	Groundwater recharge		Irrigation		Toilet flushing
				Direct injection	Localized ground percolation	Private garden irrigation	Golf irrigation	
European Directive			91/271/EC	91/271/EC	91/271/EC	91/271/EC	91/271/EC	91/271/EC
Spanish Legislations				RD 1620/2007	RD 1620/2007	RD 1620/2007	RD 1620/2007	RD 1620/2007
COD (mg/L)	336	8,9	125			125	125	
BOD_5 (mg/L)	238	3	25			25	25	
TSS (mg/L)	46,9	5	< 60	10	35	10	20	10
Conductivity (µS/cm)	287,83	423				6000	6000	
Nitrate (mg/L)	0,8	0,1		25	25			
Turbidity NTU	43,9	0,3		2		2	10	2

to be pointed out, that quite often the smell emanated from the unit would quite often be the limiting factor for acceptance of use, even if the chemical and physical parameters of the effluent water are well within range of acceptable limits. So the matter of smell will often define how much polluted water can be discharged into the unit in a given time frame, not the effluent water quality.

Further steps will be the optimisation and modification of the laboratory unit to better resemble the demo version and to increase the flow rate. Several tests at different pollution loads and with varying amounts of water flow per day will also be done, with the aim of achieving a mathematical model, which allows for theoretical simulations and calculations of Vertical Ecosystem unit sizes in relation to pollution load and expected greywater quantities. The Vertical Ecosystem can be scaled quite easily to accommodate different water cleaning demands, yet highly polluted large water flows will be a challenge for indoor treatment, especially considering the limiting factor of space and odour.

For the demEAUmed project, the incorporation of advanced monitoring and control systems and a decision support tool will ultimately define the best water management solutions for different specific practical cases by means of a database built upon the considered technological solutions. The Vertical Ecosystem and the data gained from concluded and on-going tests is an important part of this decision support tool.

The demEAUmed project

The project demEAUmed („Demonstrating integrated innovative technologies for an optimal and safe closed water cycle in Mediterranean tourist facilities", www.demeaumed.eu) demonstrates and promotes innovative technologies for an optimal and safe closed water cycle in Euro-Mediterranean tourist facilities. A resort placed in Catalonia, Spain, is considered the DEMO site, where a representative part of all inlet and outlet water flows will be characterised, treated with proper innovative technologies, and reused to reduce overall tap water consumption and the carbon footprint of water management through an integrated approach at demonstration level. Using alternative water sources, such as treated groundwater, treated rainwater or the reuse of treated greywaters and/or wastewaters within the resort will result in the reduction of fresh water consumption in hotel installations and the establishment of green and recreational areas. An exhaustive environmental and socio-economic assessment will be developed, an advanced monitoring and control systems and a decision support tool will be also implemented to define the best water management system.

demEAUmed will face two key challenges: the importance of tourism economy and the characteristics of water scarcity of the area. The project will be a critical platform for promoting the use of sustainable and innovative technologies in other Euro-Mediterranean tourist facilities not at last also in the light of the global tourism market. Finally, demEAUmed will also contribute to attain the main goals of European Innovation Partnership on waters: water reuse and recycling, water and wastewater treatment, including recovery of resources and the water-energy nexus ().

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Natural humidification by functional Green Walls and PrimaKlima® plants as resource-efficient and hygienic alternative or complement to technical devices

Special plants and Green Walls are able to create comfortable indoor climates by cold evaporation in transitional periods and winter, which can be calculated and predicted, has no health risks and is environmentally friendly.

Authors: Manfred Radtke, Andrea Zraunig

Abstract

To moisten rooms, plenty of water must be evaporated. For this purpose the used technical humidifiers require a lot of energy and usually cause hygiene problems by microbial contamination. Since the 1990s, special PrimaKlima® plants are well known to transpire considerable humidity during the winter and thus improve the room air. Because these plants require plenty of light, the Green Wall system was developed for humidification in darker locations in the beginning of 2000. Both systems provide the moisture passively by cold evaporation into the air. Hence there are no aerosols. The plants grow in hydroponics substrate, which is made of inorganic material that inhibits fungi and bacteria in their growth. The impact of these plants and green walls can be calculated. The integration into building services at the planning stage is required.

Introduction

The positive effect of plants on human beings is indisputable. Especially effects of interior planting on health and comfort among workers and schoolchildren (Fjeld, 2000) are still being studied. The lush greenery mainly has a positive effect on our psyche and makes a major contribution towards a sense of comfort. Beside the psychological effects, which were recently confirmed by a study of the Bavarian State Research Centre for Viticulture and Horticulture (LWG) (Reimherr and Kötter, 2000), houseplants are also regarded to have positive indoor climate effects and contribute to reducing pollutant gases in the air. NASA has found in pioneering studies in the 1990s, a clear reduction of air pollutants. Both by physical effects, such as attachment to the leaf surface and also not plant-generated effects, such as pollutant abatement by soil bacteria metabolization (Wolverton, 1996).

Further studies at the University of Cologne and the Research Centre for Environment and Health, GSF,

Technical data:

Green Wall for Humidification:

- modular system with planted plates 60 cm x 40 cm x 5 cm
- clipped on stainless steel skeleton
- wall mounting: constituent wall, insulation, sealing, stainless steel structure, planting plate
- design capacity indefinitely
- average water delivery (depending on environmental factors) of 3 L/m^2 x d

PrimaKlima® Cyperus:

- 2 m high and 1 m^2 floor space, bright to sunny location
- water levy in section 2 L/d
- all systems indoor

Expected indoor climate performance:

- room air humidity increases at least 10-15% points

Figure 1. PrimaKlima® plants from left to right: *Cyperus alternifolius, Hibiscus sinensis, Sparmannia africana, Musa acuminata*

Oberschleißheim (Kötter, 2004a) showed that the plant itself metabolizes some pollutants, albeit in limited amounts and insufficiently to remediate rooms with concerning amounts of contamination. Only the active passage of air through so-called plants filters results in a significant reduction. But mould spores or bacilli can be blown out of the root zone in the air and then cause similar problems, as could be seen in some technical humidifiers in the past.

Materials and methods

For effective humidification there are special PrimaKlima® plants e.g. *Cyperus alternifolius*, *Musa acuminata, Sparmannia africana* and *Hibiscus sinensis*, which raise the humidity in winter by 30% to 50% and ensure a pleasant indoor climate (Fig.1.). These species transpire intensively even in winter.

Practically all other plants have no significant effect on the indoor climate. In particular typical hydroponic plants tend to be economical in their water uptake, even if the name suggests something else. Hydroponics is accepted in offices, hospitals, nursing homes and even in schools (Frenzel et al., 2010) as quite sterile and as a cultivation form that causes little germs emissions. In a standard planting depth of 19 cm, the upper range of about 6 cm is dry and therefore hostile to fungi, bacteria and small animals such as flea beetles (*Chrysomela sp.*), etc. PrimaKlima® plants require a lot of light, therefore Green Walls for darker locations were developed in early 2000. Based on ideas of the French botanist Patrick Blanc, these vertical gardens were developed for light poor rooms and to increase the humidity by Bernhard Häring and Manfred Radtke. Important for the water delivery is the inorganic substrate and not the plants themselves. The foam glass was originally developed for propagating cuttings and has fungicidal and bactericidal properties. An important part of the development was the modular construction (Fig.2.). Dense and flat plant growth is produced on rectangular foam glass plates and clipped piece by piece to the carrying structure on the wall. If single plates need servicing or something needs to be placed behind the green wall, only the affected plates need to be removed or swapped out. In a short time the plants grow and intertwine and single panels are no longer recognizable.

The evaporation rates of Green Walls and PrimaKlima® plants are very well known and therefore they can be incorporated in the calculation of the indoor climate. The developed biotechnological humidification is based on own studies of biogeochemical cycles of various houseplants depending on climatic parameters of the

Figure 2. Green Wall Sparkassa Ingolstadt: modular system (left) and later the connate plates (right) (photo by B. Häring)

room (Radtke, 1986). Most indoor plants evapotranspirate too little water in order to achieve a significant effect on room climate. Often plants enter a hibernation period with little physiological activity, which may also be induced by the lack of light in central European latitudes. Yet humidification is specially needed in the light poor winter and transition time when the air is dry because of heating.

In winter at 80 % relative humidity, a cubic meter of air at 0 °C holds only about 4 grams of water. If this air is heated to 22 °C, one cubic meter could hold about 20 grams of water vapour. However, since only 4 grams are present, the relative humidity drops to 20 %. The dry air now draws water from any wet surface in order to get closer to a stable balance. This air dries the mucous membranes of people in the room and thus paves the way for germs and bacteria to enter and more easily infect the human body.

The well-known comfort diagram (Fig.3.) shows that a pleasant environment for plants is at about 21 °C and 40 % relative humidity (RH). For optimal function of the ciliated epithelium of bronchi even 45 % RH are necessary.

Results and discussion

Plants are located in the potential gradient (water vapour) between dry air and moist soil. Trough the transpiration of water from the stomata, the capillary water flow in the plant is induced. If the genetics of a plant determine high-capacity vascular bundles in the stems, it can evapotranspirate plenty of water, given an optimal water supply. This is the case precisely at PrimaKlima® plants.

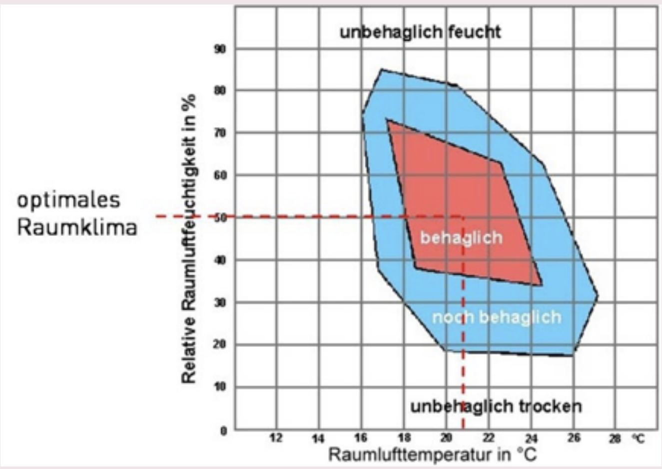

Figure 3. Comfort zone for the value pair room temperature - relative humidity (www.pluggit.com) [Optimales Raumklima = optimum room climate; Relative Raumluftfeuchtigkeit in % = relative indoor humidity in %; Raumlufttemperatur in °C = indoor air temperature in °C; Behaglich = comfortable; noch behaglich = yet comfortable; unbehaglich trocken = uncomfortably dry; unbehaglich feucht = uncomfortably humid]

Under favourable conditions one m^2 of „PrimaKlima® Cyperus“ delivers about 2 L/m²/d of water vapour, other PrimaKlima® types provide about 1.2 L/m²/d of water vapour. This is sufficient to moisten none-air-conditioned rooms for a size up to 65 m³. Depending on the air exchange an increase in relative humidity of 10-15% points is expected. The required amount of plants in offices with air-conditioning systems varies depending on air exchange, number of persons and other parameters. Calculations incorporating climate-functional parameters from the living plants provide the required dimensions of the plantings.

If there is a lack of space and/or light then the Green Walls offer an option for green humidification. Mainly tropical groundcovers like *Philodendron scandens, Ficus pumila, Peperomia sp.* among others are used, which are characterized by tolerance to low light conditions and are appealing decorative elements. The evaporation occurs mostly directly through the porous surface of the inorganic glass foam. The cooling effect of evaporation causes convexion movement in the surrounding air, ensuring that there is a constant air exchange that removes humid air masses and distributes them in the room. Thus, the water turnover of the Green Wall per planted area is much higher compared to horizontal systems. The water turnover depends on the ambient humidity; it decreases with increasing relative air humidity, but does not fall to zero. For this reason, it is important to adapt the dimensions of the green wall to structural building conditions. Overhumidification in rooms can cause mould, component corrosion and other condensation damage. In fact, a muggy room ambient caused by excessive air humidity is a burden on employees or residents.

On average, approximately 3 L/m²/d are evaporated from the Green Wall for humidification. Watering the thin substrate layers is a technical challenge. Since the overall construction depth of the Green Wall should not be more than 10 cm, the water must be applied in careful dosification. There are installations with 20 m height and 30 m width in operation and no excess water should drip out of the bottom sections while ensuring enough water for the plants and the evaporation effect. A patented water supply by means of groove-channels and capillary fleece is used. This fleece sucks just as much water out of the channel as is needed by an only 2 cm thick substrate layer. Through watering breaks the substrate dries again, preventing the formation of biofilms. The used water is first purified (desalinated) in an osmosis system and then plant nutrients (fertilizer solution) are added in a very precise manner. Untreated water causes efflorescence (even drinking water leaves salts behind after evaporating), nutrient deficiency problems in plants and eventually the loss of porosity of the substrate. Although roots and their exudates acidify the substrate solution slightly, they can’t “soften” the water nor desalinate it.

Figure 4. Vienna business agency – an office complex of the future (left) with Green Wall and PrimaKlima® plants (right)

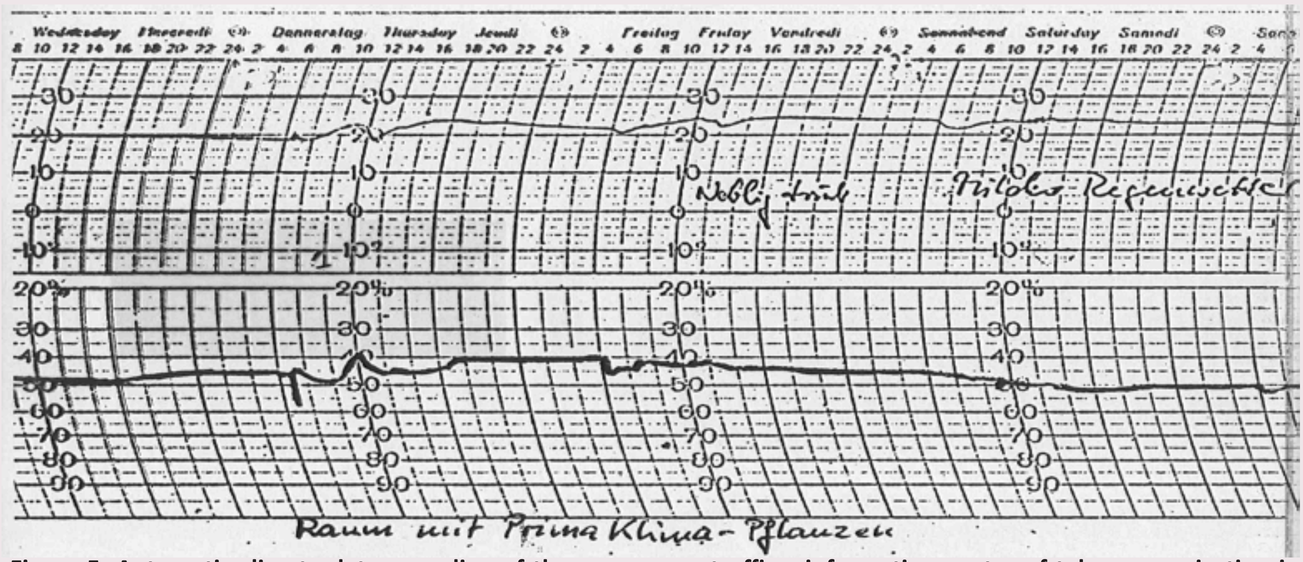

Figure 5. Automatic climate data recording of the german post office, information centre of telecommunication in Würzburg, Germany, 1988; thick line = humidity, thin line = temperature

Studies done by the FH Weihenstephan (Köhler et al., 2004) have shown that a significant air moistening of offices and homes with ordinary houseplants is not achieved. Practical research done by the Bavarian State Research Centre for Viticulture and Horticulture (LWG) with PrimaKlima® Cyperus in planters with water reservoir shows that the measured humidification of room air through Cyperus is enough for non-air-conditioned offices and homes (Hanke, 2005). Unfortunately, there are very few users, who are willing to publish their measurements. These include the electronic company „Gautzsch“ (Kötter, 2004b), „energy base“ in Vienna (Vienna Business Agency, 2008; Figure 4) as well as the German post office information centre of telecommunication in Würzburg. Figure 5 shows a plot of the indoor climate of a German post office. With PrimaKlima® plants a comfortable indoor climate was created by the humidity was constantly kept above 40% even during the winter months. In the years before (without plants) the humidity was less than 25%.

For the Green Walls only unpublished statements of well-known users exist, which although positive are scientifically of little value. Decisive for the success of all functional plant based systems is the patented calculation method of the water balance in rooms under given circumstances and choice of plants and system (DPMA, 2012). Thus, natural humidification of indoor ambient air through plants can be integrated into the planning of a building and its climate regulation technologies as shown e.g. in Figure 6 for the company Komsa, Hartmannsdorf, Germany.

Figure 6. OASE, KOMSA AG, Hartmannsdorf-Sachsen, 2012 Klimakonzept IB-HRP, Veitshöchheim, Germany (photo by B. Häring)

Conclusions and outlook

Functional greening is a resource-preserving, efficient solution to create a healthy, comfortable indoor climate during winter months. The cold evaporation is hygienic since no aerosols are created and the transformation from liquid to gaseous form occurs directly on the wet surface. Both PrimaKlima® plants and Green Walls for air humidification are decorative and have positive effects on the psyche of people through the visible living green highlights in the room.

Unfortunately, plagiarisms and over-promise in the green plant related sector are very frequent. For purely decoration purposes there are many possible and valid alternatives. Air-humidification though is a special subject, which can lead to major problems in buildings and disappointments by users if done without proper knowledge and expertise.

Acknowledgements

The bionic ideas of Dr. Ing. Max Mengeringhausen, MERO, Würzburg inspired me to start thinking this way, looking for solutions for our daily lives in natures examples. His central idea comes from closer inspection of grass blades. The nodes in the blades stiffen the plant although most of the blade is hollow. Without nodes the blades could not grow so long or they would have to be solid and heavier. A solution of nature, which Mr. Mengeringhausen applied in technology. MERO built with his MERO-nodes large cantilever space frames (e.g., Ericsson Globe Stockholm, 1987, Berlin main station, 2006) with minimal use of materials and excellent strength and stiffness. In a similar way, functional greening offers solutions based on natural models to supplement or replace technology.

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GrünAktivHaus:
Bauwerksbegrünung trifft erneuerbare und nachhaltige Energie- und Bautechnik.

Green roofs and living walls meet sustainable energy and building technologies

Buildings equipped with green roofs and living walls combined with solar architecture and renewable energy technology need an intense interdisciplinary planning process.

Authors: Ulrike Pitha and Bernhard Scharf

Abstract

The building industry identified an increasing need for professional knowledge, especially when renewable energy and construction technologies are combined with green roofs and living walls. During the construction phase of buildings a variety of professionals and highly specialised disciplines have to interact. But aims and demands of different involved technologies may come into conflict – a professional coordination is necessary. An interdisciplinary planning process provides remedy.

Introduction

Using sustainable building technologies combined with green roofs and living walls are in line with the actual trend. Professional know-how is needed for sustainable, efficient and green solutions.

Building physical, constructive and static conditions of roofs are crucial for their loading capacity. Depending on that selected green roof types (e.g. reduced extensive green roofs with vegetation mats or intensive greened roof gardens) can be applied. All involved trades like carpenters, roofers, tinsmiths and gardener have to be coordinated with architects, landscape architects or building physicists. An insufficient coordination leads to construction defects and dissatisfied costumers. The same applies to living walls: professionals for metal construction, façade construction, static, building physic elaborate together with landscape architects, gardeners and irrigation technicians solutions for efficient living walls.

The need of know-how and additional coordination increases rapidly if technologies of sustainable construction and greening is complemented with renewable energy production technologies like solar technology. A high sensitivity for the other trade’s demands is recommend if e.g. passive houses or plus energy houses are equipped with green roofs, living walls and solar power systems. Combined interfaces (e.g. anchoring of living wall on a passive house wall, installing of a green roof on a wooden roof truss) have to be identified and technically solved.

But how can the optimal solution be found?
One recommended problem-solving approach for the complex task of combining energy efficiency, , green infrastructure (as green roofs and living walls) and energy production technologies is an interdisciplinary, integral planning and construction process. Within a creative planning process experts of different disciplines pursue a defined planning objective like the solution of a technical building problem (Figure 1). During this iterative process together several variants of solutions will be developed

Key messages:

- Integral, interdisciplinary planning is essential to cope with complex planning processes.
- Investing in the planning phase helps to reduce building costs by identifying synergies in the processed and avoid design errors and associated additional costs in the realization phase.
- Living walls and green roofs need experts with special know-how in planning and construction.
- Green design elements like living walls and green roofs are sensitive constructions and need coordination with other building trades involved in building processes.
- Multilateral and building trades overarching knowledge transfer and exchange lead to sustainable, green buildings.

Figure 1. During an integral, interdisciplinary planning process experts of different disciplines generate together an efficient solution for a technical constructive problem.

as long as the planning objective is accomplished. In a following implementation phase using detailed building inspections the compliance of the targeted objective will be verified (Ackermann, 2014).

Additional to this described interdisciplinary process the Austrian Standard OENORM B 1801-1:2009 'Building costs – Cost breakdown' (ASI, 2009a) provides a detailed planning system for building projects with six identified project phases starting with developmental and preparing phases, preliminary draft and draft phases up to a construction phase and a finalization phase. For each phase the scope of quality, costs and time schedule can be fixed and controlled.

Kovacic (2014) explains integral planning plays a key function in complex planning processes. However this system isn't yet common in the planning reality. Methodological know-how is still missing and building contractors or investors don't accept high cost for planning in contrast to traditional planning processes. Whereas an intensive planning process pays well: Currently 20 % of life-circle costs of buildings are calculated for planning and construction. The Austrian official scale of fees for services by architects and engineers regulates the planning costs with 10 to 15 % of the construction costs. That corresponds to 3 % of life-circle costs. Kovacic (2014) concludes from that that 3 % planning costs essentially influence the remaining 97 % life-circle costs of buildings. This comparison shows clearly that the best time to influence the development of costs and building quality is the planning phase. In later phases optimization steps will be more expensive and less realizable.

Thus the approach of integral and interdisciplinary planning has to be promoted, especially for complex architectonical solutions like buildings with renewable energy technology and sustainable construction techniques combined with green roofs and living walls. New know-how has to be generated and provided for planning specialists as well as professionals of the building trades in order to minimize construction defects and to enhance the quality of building.

A new interdisciplinary network including a variety of competences

2012 a new consortium and network – named GruenAktivHaus – of economic specialists and researcher initiating by the Institute of Soil Bioengineering and Landscape Construction of the University of Natural Resources and Life Sciences, Vienna (BOKU) was founded with the aim to increase and exchange knowledge of solar architecture, energy technology, building physics and greening technology needed for sustainable and greened buildings. Together a new qualification training curse was developed and tested: Know-how in the fields of living walls, green roofs, indoor greening, irrigation technology, control technology, illumination technology, permeable road construction, metal construction, photovoltaic and solar technology, energy technology, solar architecture, timber technology, building physic, landscape architecture, architecture, landscape construction and gardening was intensively exchanged. Aim of this new training course is to involve all needed trades for a building, which combines sustainable, renewable construction and energy technology as well as green infrastructure elements like green roofs or living walls. Within an integral working process the 16 consortium partners identified the demands of their own trade and become informed and comprehend the other trade's requests.

The first part of the new training course was designed as a theoretical exchange and generation of knowledge in form of lectures and excursions. Additionally in the second part the participants were asked to use and test their new know-how by means of a real planning and construction process of a GruenAktivHaus-lighthouse project. The used integral and interdisciplinary planning process allowed a detailed identification of several interfaces between different for the construction of the lighthouse project necessary trades and an optimal coordination of them.

Introduction of the GruenAktivHaus-lighthouse project

The named lighthouse project acts not only as training element. It should help to promote the interdisciplinary approach. As potential location the research and competence centre for construction and energy Sonnenwelt in Grossschoenau, Lower Austria could be identified. Sonnenwelt (2015) distributes know-how about energy efficient and sustainable construction and sanitation technologies.

A building complex composed of three different buildings named lens, hall and interlink provides space for entrance, exhibition, rooms for events, conference rooms, office, merchandising shop and buffet. The whole complex is built with passive house technology. A photovoltaic power plant is installed on one roof and produces the electricity needed at Sonnenwelt.

Within the training course the participants of the consortium identified the southeast faced wall of the exhibition hall and the interlink building as ideal locations for testing their new knowledge in a real planning and building project. In a first step a general vision was identify: A lighthouse project should be planned and built with the aim to present innovative synergies and usage of green infrastructure, solar energy technology, LED technology and solar architecture.

Architects and landscape architects of the consortium implemented this vision in their draft and detailed planning. The joint project presents the different trades of the consortium and their new and innovative collaboration. The historical development of façade greening is presented in six frames (each 4 x 3 m) illuminated by LED technology and photovoltaic panels alternated arranged in a gently zigzag line along the hall wall. The project shows interested people the variety of innovative technologies (Figure 2). The first three frames display classical façade greening with espalier fruits, climbers supported by steel cables and trellis or self-clinging climbers. Frame 4, 5 and 6 hosts three different innovative living wall systems, two Austrian and one German product. Each frame has a metallic subconstruction established on point foundation. An anchorage towards the sensitive wall in passive house technology using special threaded rods allows to minimize the loss of insulation effects. The metallic subconstruction serves as anchorage element of the different façade greening systems. Finally like a picture frame wooden elements have been fixed on the subconstruction and put the living walls into focus.

All façade greening systems are equipped with an sensor based irrigation using drip irrigation or subsurface irrigation allowing an irrigation according to the water demand of the plants in the differnet greening systems.
The solar power plant is conceptualized to produce 1.100 kWh electric energy per year, enough to run the irrigation system and LED illumination. A way paved with a water permeable surface consolidation method leads along the living walls and photovoltaic panels and ends at four small wooden huts of the Sonnenwelt's adjacent playground. The steep roofs of these huts were equipped with extensive green roofs using vegetation mats fixed with a special technology for steep roofs.

Identification of interfaces

During the integral and interdisciplinary planning process of the descripted lighthouse-project the consortium identified a huge amount of interfaces between the involved building trades. Under the control of a sensitive and experienced project management solutions for each interface could be developed. In a several weeks lasting process with many planning and discussion meetings in different constellations of experiences and disciplines step by step construction details, processes, a chronological order of acting, time schedules, cost and financing plans were developed, discussed, scraped and decided (Figure 3).

Figure 2. The GruenAktivHaus-lighthouse project at Sonnenwelt, Grossschoenau, Lower Austria, Austria. Participants of the new developed training course used their new learned knowledge to plan und construct this building project presenting innovating synergies and usage of living walls and green roofs, solar energy technology, LED technology and solar architecture.

Figure 3. Specialists of the GruenAktivHaus consortium are working on an efficient solution for a technical detail under the control of the project management.

Table 1. Identified interfaces during the interdisciplinary planning process of the lighthouse project GruenAktivHaus

no	involved trades	interfaces
1	architect, landscape architect	coordination of vision, draft and planning
2	architect, landscape and all other trades	coordination of draft concerning technical and vegetation technical feasibility
3	earthworks, building construction	identification of existing building foundation for dimension of earthworks
4	earthwork, road construction	coordination of excavation and substructure
5	earthwork, metal construction	coordination of excavation and dimension of founding of the metallic subconstruction
6	earthwork, building services	coordination of existing supply line plan
7	road construction, building construction	coordination of consolidation of house entrance
8	metal construction, building construction	coordination of anchorage subconstruction towards house wall
9	metal construction, landscape construction	coordination of dimension of subconstruction, facade greening systems (assembling)
10	metal construction, wood construction	coordination of assembling (wooden frame, trellis)
11	metal construction, energy technology	coordination of assembling the PV-panels on subconstruction and supply lines
12	wood construction, landscape construction	coordination of trellis and demand of plants
13	wood construction and landscape construction	coordination of static properties of the huts‘ roofs - roof construction
14	irrigation technology, landscape construction	coordination of irrigation system, water demand of plants and greening systems
15	irrigation technology, building services	coordination of existing water supply system
16	energy technology, irrigation technology	coordination of demand and supply lines
17	energy technology, illumination technology	coordination of demand and supply lines
18	energy technology, lightning protection	coordination of assembling in existing lightning protection system
19	illumination technology, building services	coordination of assembling in existing supply system

Table 1 structures with respect to involved building trades and illustrates the high variety of identified interfaces. Figure 4 helps to understand the complexity of the descripted planning process.

The most intensive discussion work was needed for an assembling detail on the metallic subconstruction. This small assembling detail should provide space for the wooden frame fixed with a carriage bold, for different façade greening systems, for indirect LED illumination, for supply lines (electricity and water) as well as for assembling points of the photovoltaic panels. All involved specialists created together a solution elaborating planning details. At the end only a 1:1 scaled plan helped to find for all demands an appropriate assembling solution (Figure 5).

The participants of the training course learned that by complex building tasks like greened, sustainable and energy efficient buildings a range of interfaces exist. They are specific to each building task, but some of them could be use in general. Crucial is to identify the interfaces timely. For the participants the planning phase was the ideal point of time to react and find satisfying, efficient solutions.

Conclusion

An intensive exchange between all members of the interdisciplinary planning group allows to find solutions for all addressed interfaces of the lighthouse project. A major challenge of this planning process was to find a joint terminology. Each trade has it's own technical terms. To make them understandable for the others 'translations' have to be found.

Especially in the following building phase of the lighthouse project not only an understanding between the different trades using a joint terminology was challenging also different mother tongues need a sensitive joint social interaction. On the construction site German, English, Hungarian, Slovakian, Czech, Polish and Romanian was spoken. If the linguistic barrier was too large sketches and plans helped. Hence, plans are absolutely necessary

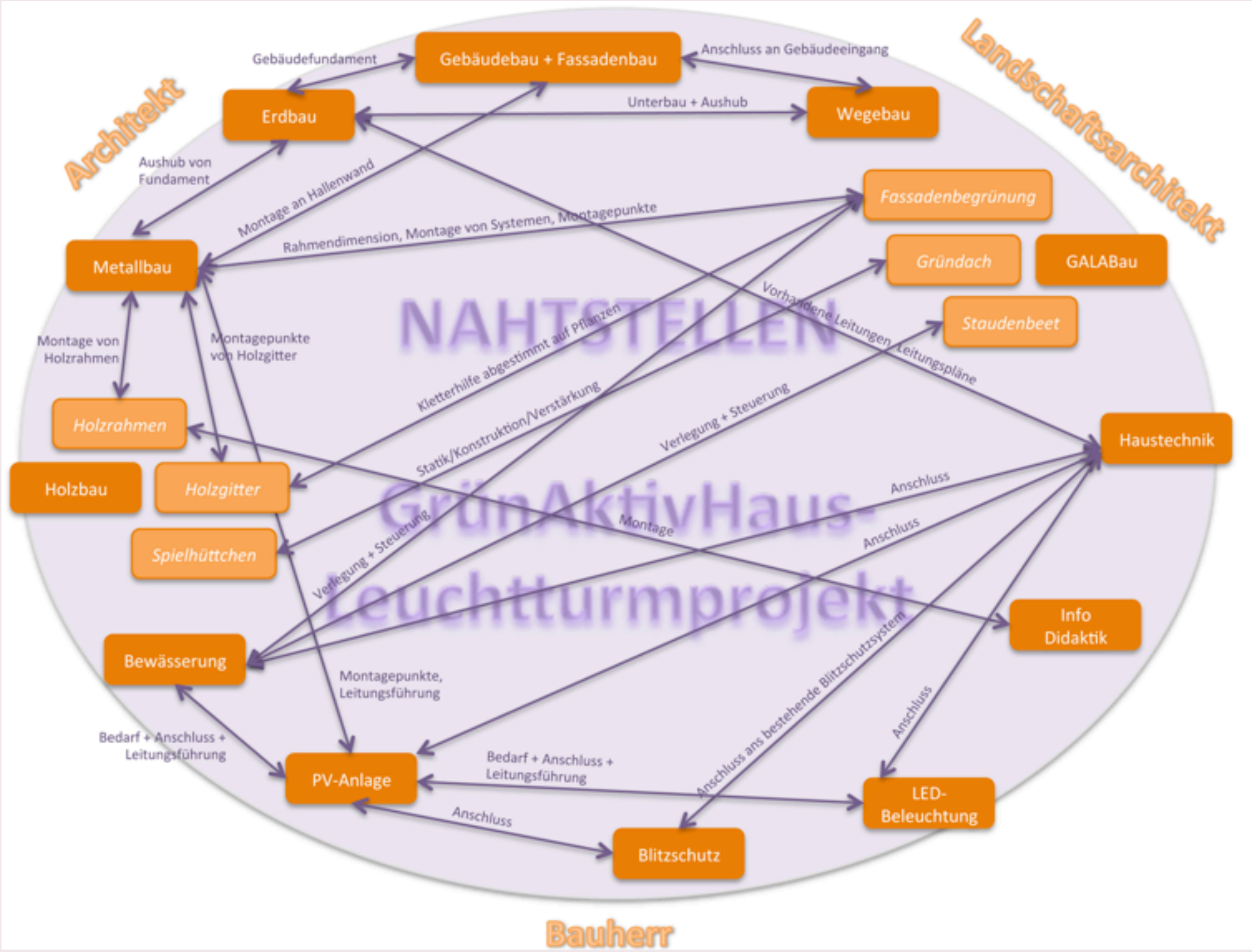

Figure 4. The complex interface diagram of the lighthouse project GruenAktivHaus

instruments for finding solutions of interfaces in the planning phase, but also to have a clear documentation of them for the following phase at the construction site. But a plan is not like another! Trades use different methods to map technical and constructive details. Some trades communicate without plans. In this situation a high competent project management is essential to coordinate all persons involved and to avoid misunderstandings.

An also interesting aspect of the interdisciplinary planning process was to get new insights of companies, their internal processes, communication strategies and mission statements. Additionally people have different characters and represent different personalities. This fact has also to be managed and coordinated.

At the end the participants of the training course evaluated clearly that the integral, interdisciplinary planning process of the GruenAktivHaus-lighthouse project and its higher effort was worth it. Especially complex technical and architectonical design of buildings with a combination of solar architecture, renewable energy production and green architecture with living walls and green roofs need such interdisciplinary work already in the planning phase. Creativity, spontaneity and flexibility but also soft skills like empathy, identification of the other trade's needs and an open communication will lead to best practices. Therefore specialists are needed who have an open mind about interdisciplinary knowledge transfer and new life-long-learning qualification methods.

Integral, interdisciplinary planning processes fix time, personal and cost resources, but leads to building objects with a high quality. This benefit should convince investors, decision makers, planners and companies of the building industry to invest more in planning phases in order to generate sustainable, energy efficient and green buildings with satisfied residents or users.

General information

Façade greening is quite common in Europe. Self-clinging climbers on houses have a long tradition as well as fruit trees trained as self-supporting espaliers. Modern façade greenings favour climbers supported by steel cables or trellis made of vertical and horizontal elements. Climber species developed different strategies of climbing: There are self-supporting woody plants trained as wall shrubs, climbers and plants that need support (rambles with and without thorns), true climbers with methods of attachment to supports (self-clinging climbers, climbers with aerial roots or suckers), twining climbers and climbers with specialized leaves for attachment (Dunnet and Kingsbury, 2010).

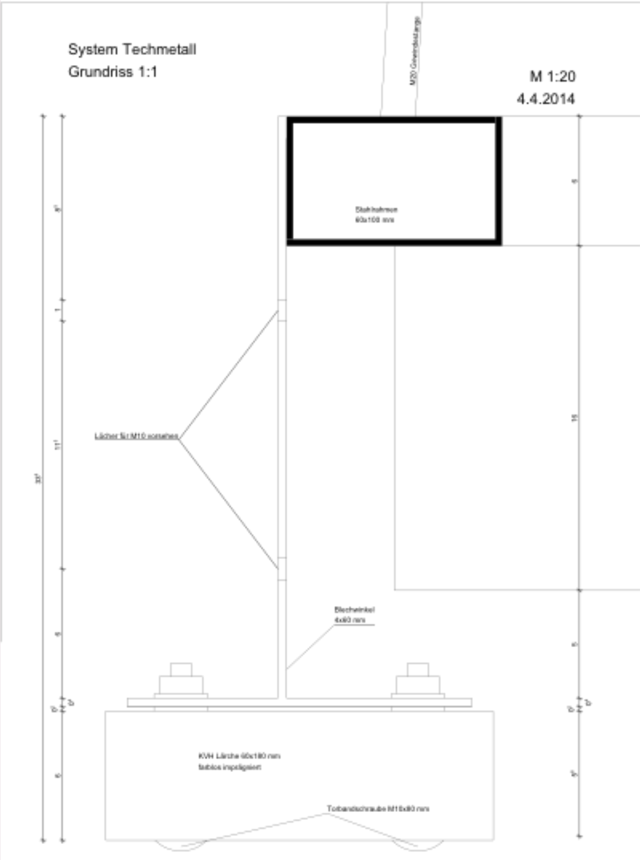

Figure 5. After several meetings the participants of the training course agreed on the above showed solution of a technical detail of the metallic subconstruction, an interface of five different trades.

Living walls represent a new type of covering walls with vegetation. Different form the descripted type of traditional façade greening with climbers rooting in surrounding soil or growing medium at the base of the wall, living walls allow plants to root totally within the living wall structure (Dunnet and Kingsbury, 2010). Shrubs and small woody plants grow vertically in retaining structures made of geotextiles, mineral wool or three-dimensional growing elements filled with specific growing medium or soil. Living walls are green high-tech systems with special needs.

But not only vertical walls of buildings can be greened. In Europe more and more roofs are greened. Modern Green roofing technology allows greening a broad variety of roof types. Plan roofs are suited as well as inclined roofs with an inclination of more than 40% (ASI, 2009a). Reliable constructions with different layers (soil layer, filter layer, drainage layer, protection layer) allow to plant roofs. Depending on the amount of maintenance two types of green roofs can be derived – intensive and extensive green roofs.

Intensive green roofs are more like roof gardens quite similar to gardens at the ground level. Shrubs and woody plants can be arranged additionally to recreation areas, sitting and rest areas and way structures. Soil depths in a range of 20 to more than 80 cm are required. The other type is an extensive green roof with thin soil layers (8 to 20 cm) made of light weight substrate materials and planted with moss species, sedums, grasses, herbs or small shrubs (ASI, 2009a). Extensive green roofs look like grasslands, are more ecological due to less maintenance and cheaper construction.

For further information about façade greening, living walls and green roofs please see:

- OENORM L1131 (2009-08-26): Quality assurance in green spaces – Green roof – Directives for planning, execution and maintenance, Austrian Standard Institute (ASI, 2009b)
- Leitfaden Fassadenbegruenung – A guideline for façade greening and living walls (2013), City of Vienna (OekoKauf Wien, 2013)
- Dachbegruenungsrichtlinie – A guideline for Green Roofs (2008), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL, 2008)
- Richtlinie Fassadenbegruenung – A guideline for façade greening (2000), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL, 2000)

GruenAktivHaus - Green roofs and living walls meet sustainable energy and building technologies

- aim and scope of the project: The aim of the GruenAktivHaus project was to initialize an economic and scientific multilateral exchange of know-how in the fields of solar architecture, energy technology, building physics and greening technology needed for sustainable and greened buildings. Therefore a new, all trades involved in sustainable and greened building design overarching training course with theoretical and practical course elements was developed in an participative process. In the practical course units the consortium members used their new learned knowledge to realise the GruenAktivHaus-lighthouse project in Grosschoenau, Lower Austria. This lighthouse project presenting an efficient combination of the above named specialist fields is open to public and can be visited at Sonnenwelt, Sonnenplatz 1, Grosschoenau, Lower Austria, Austria.
- time frame, ~dates of beginning and ending: 1.10.2012 – 30.9.2014
- country (town) the project is done in: Vienna, Austria and Grossschoenau, Lower Austria, Austria

- initiating organization: University of Natural Resources and Life Sciences, Vienna; Institute of Soil Bioengineering and Landscape Construction
- website: https://www.gruenaktivhaus.at

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Notes

Next issue:

Issue 24, April 2015: **„Financing of sanitation "**

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