Modular system design for vegetated surfaces
A proposal for energy-efficient buildings

MARIA MANSO[1a], JOÃO CASTRO-GOMES[1b], PEDRO D. SILVA[1c], ANA LÍDIA VIRTUDES[1d], FERNANDA DELGADO[2e]

[1]C-MADE, Centre of Materials and Building Technologies, University of Beira Interior, Covilhã, Portugal
[2] Escola Superior Agrária do Instituto Politécnico de Castelo Branco, Castelo Branco, Portugal
[a] mcfmm@ubi.pt, [b] jpcg@ubi.pt, [c] dinho@ubi.pt, [d] almmsv@ubi.pt, [e] fdelgado@ipcb.pt

ABSTRACT: *A research project (GEOGREEN) is being developed based on the design concept of a modular system for vegetated surfaces suitable for new or retrofitted buildings. Designed to be demountable and adaptable to different surfaces and inclinations, it allows the creation of vegetated surfaces both in roofs, walls and other building elements. The modular system materials were selected to minimize the embodied energy and CO_2 emissions. It is based on alkaline activated binders (geopolymers), combining natural materials (insulation cork board) with the insertion of endemic vegetation resistant to dry mesomediterranean conditions.*
The system is being designed not only to achieve a good performance itself, but also to contribute to the thermal performance of buildings envelope through the application of materials as design characteristics that allow it to function as a passive design solution.

Keywords: Modular system, vegetated surfaces, recycled materials, endemic vegetation, passive design

1. INTRODUCTION

Buildings have a significant impact on energy use and on the environment, representing around 32% of total final energy consumption (IEA, 2013). In the European Union (EU) countries and in United States of America, residential and commercial sectors have a significant impact on energy use, achieving up to 40% of the total final energy consumption (EIA, 2012) (Eurostat, 2010).
Thus, it is important to find new strategies to reduce buildings energy dependency and greenhouse gas emissions.
The USA Department of Energy has already a classification system for net-zero energy buildings (NZEBs) considering the use of renewable sources and passive design strategies. The concept of NZEBs is used to classify residential or commercial buildings in which the energy needs can be supplied with renewable energy technologies (Pless and Torcellini, 2010).
In the EU all new buildings must be nearly zero-energy buildings by 2020. This target is focused on the Energy Performance of Buildings Directive (EPBD) from 2010 (AA.VV., 2010). It promotes the improvement of energy performance of new and existing buildings subjected to major renovations. To achieve this goal it is important to increase the use of efficient heating and cooling systems, renewable energy sources and passive design solutions.
Passive design solutions like, thermal insulation, thermal mass, natural ventilation (Carlos et al., 2010) and evaporative cooling (Pires et al., 2011), can contribute to interior comfort of buildings, minimizing their energy demands for heating or cooling, in particularly environmental conditions.
Green roof and green wall systems can have a significant impact on buildings energy efficiency, having the ability to be used as a passive design strategy (Pérez et al., 2011).
They are able to shadow the envelope, protecting it against direct solar radiation (Eumorfopoulou and Aravantinos, 1998) (Ip, 2010). Therefore, they contribute to the reduction of the heat flux through the envelope (Barrio, 1998).

They help reducing the energetic needs for cooling and heating (Liu and Baskaran, 2003) and contribute as an evaporative cooling system resulting from the evapotranspiration of plants and water evaporation from the substrate. Additionally, the implementation of green roofs or green walls can be an interesting strategy of greening in dense urban areas with lack of free space, considering the fact that they allow the integration of vegetation in buildings without soil occupancy (Virtudes and Manso, 2011).

On the other hand, green roofs or walls can reduce urban pollution. Plants have the ability to absorb CO_2 and heavy metals (Bruse et al., 1999), and trap dust particles circulating in the air (Köhler, 2008). Therefore, urban air quality can be improved by the filtering effect of green surfaces. Studies have also proven that green areas with a considerable dimension have the ability to cool the surrounding atmosphere (Oliveira et al., 2011).

Vegetation absorbs sunlight to develop its vital functions (e.g. photosynthesis, respiration and evapotranspiration) while it protects buildings envelope from external agents (e.g. sun, wind, rain). This avoids overheating and degradation of external materials, increasing their life expectancy (Luckett, 2009).

Thus the integration of vegetated surfaces in the urban environment apart from contributing as a passive design strategy to save energy in buildings, they have other advantages.

In fact, several researchers have been studying the multiple benefits of different green roof and green wall systems to buildings performance, as summarized in Figure 1.

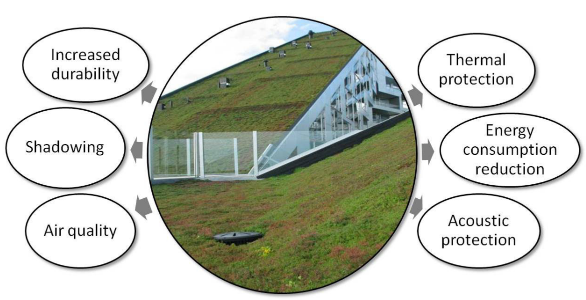

Fig. 1: Benefits of vegetated surfaces to buildings performance

2. EXISTING SOLUTIONS FOR VEGETATED SURFACES

There are several systems on market to create vegetated surfaces in buildings. These are generally known as Green Roofs and Green Walls. The selection of which is more appropriate to a certain project depends on the building characteristics (e.g. scale, type of building, construction techniques, load capacity) and the surrounding conditions (solar exposure, localization, accessibility and local climate).

Green roofs can be defined as extensive, intensive or semi-intensive, depending on their composition. The system selection depends of available depth for the substrate layer, plant selection and irrigation and maintenance needs.

Current developments on green roofs are centered on lighter systems, either modular or continuous, using resistant and adapted vegetation with low irrigation and maintenance needs.

Green Walls can be classified as Green Facades and Living Walls (Köhler, 2008).

Green facades include climbing plants, evergreen or deciduous, growing in the soil or in vessels, which cover a vertical surface by attaching themselves with their adhesive suckers or climbing roots to the vertical surface or a complementary support structure.

Living walls can be subdivided as Vertical Gardens and Modular Systems. These systems allow the application of a wider variety of plants and the creation of green walls with higher dimensions than Green Facades.

Vertical Gardens are continuous systems based on the application of a lightweight elements and an external permeable screen where plants are inserted individually in pockets. These are usually hydroponic systems, where water and nutrients permanently supplied by the irrigation system. The most known work in this field is from the French botanist Patrick Blanc, who has several examples all over the world.

Modular Living Wall Systems are mostly trays fixed to a support structure attached to the vertical surface. Most modular systems include a container filled with growing medium where plants can grow.

A literature review was based on the analysis of several green roof and green wall systems, studying their features, construction techniques and materials. It is now possible to understand the main difficulties for their implementation.

Their limitations are mostly centered in the installation and maintenance (Manso et al., 2012).

Intensive green roofs and living wall systems like Vertical Gardens enable the creation of vegetated surfaces with a wider variety of plant species. However, they are usually expensive, requiring periodical maintenance and high irrigation levels. In the case of intensive green roofs we must also take into account the building load capacity, and consider that it can require structural reinforcement, which represents an additional cost to the building construction.

Simpler solutions as extensive continuous green roofs and green façades including climbing species are more cost-effective, but have limitations in plants diversity. When there is the necessity of plants replacement, these systems show difficulties in ensuring vegetation continuity. In the case of green façades we must also consider the fact that climbing plants have some growing limitations. Some species achieve 5 or 6 meters, others 10 meters and some 25 meters heigh (Dunnet and Kingsbury, 2004). Most of them take around 3 to 5 years to achieve full coverage (AA.VV., 2008).

The alternative to these solutions can be the application of modular green roof and green wall systems. Modular systems are still relatively new (Dunnet and Kingsbury, 2008). They enable the installation and removal of each module individually. This can be beneficial, considering that it allows the integration of different plant species to create vegetated designed surfaces and simplifies the system maintenance.

From the analysis of all types of green roofs and green wall systems, it appears that most solutions focus on solving one constructive solution. In fact most solutions are not able to function as green roofs and green walls simultaneously (Manso et al., 2012).

3. SYSTEM DESIGN

An on-going research project is based on the design concept of a modular system for vegetated surfaces.

The main goals of the GEOGREEN modular system (Fig. 2) design are: adaptability to different supports; simplification of the construction and maintenance processes; ensure continuity and uniformity of the vegetal layer; minimization of plant irrigation; minimization of its environmental impact and improvement of buildings characteristics.

Designed to be more versatile then the existing green roofs and green walls, this system intends to allow the creation of green roofs and green walls simultaneously, considering the particularities of each surface. It can be suitable in new buildings and retrofitting and adaptable to surfaces with different shapes, sizes, inclinations or accessibilities. Therefore, it must be taken into account the materials selected and the operational requirements of the system when applied to different surfaces.

Designed to simplify the installation and maintenance processes, it allows the insertion and substitution of each module individually when in normal functioning.

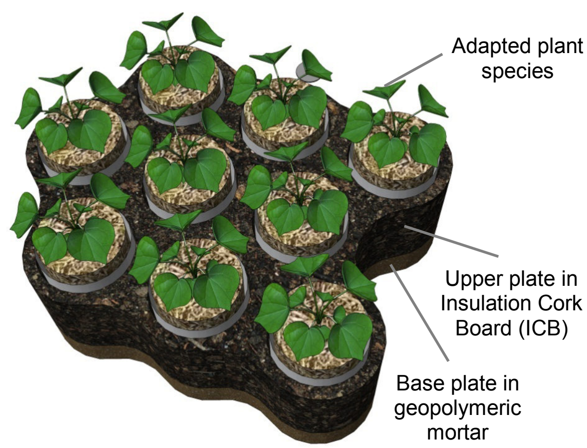

Fig. 2: GEOGREEN modular system design

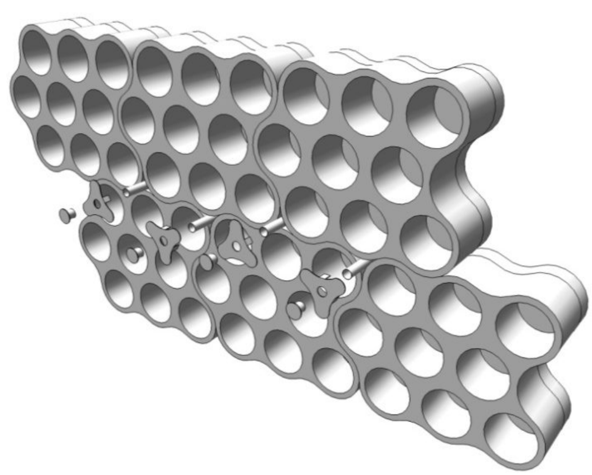

Fig. 3: GEOGREEN interlocking system

Each GEOGREEN module comprises 9 circular openings for substrate and plants insertion. The openings are aligned in each row and unaligned in different rows.
The application process consists in placing the modules parallel one to the other in the same row and mismatched between rows, so that they remain locked together.
In vertical or sloped surfaces, each module can be hold by a support structure inserted in the voids between them and sustained by locking pieces (Fig. 3).
This solution allows the system continuity and a reinforcement of its stability in vertical position.
The GEOGREEN modular system is based on pre-fabricated panels incorporating pre-planted vegetation. One of the developed studies consists in the selection of autochthonous or endemic plant species that are able to minimize the system irrigation and maintenance needs.
The intention of GEOGREEN modular system is to develop a passive cooling solution with environmentally sustainable concerns.
One of the purposes is to find strategies that allow the minimization of its environmental impact, by reducing the system embodied energy and therefore the CO_2 emissions. Furthermore, this solution combines the application of local recycled materials with endemic vegetation.

4. ELEMENTS SELECTION

The intention of the GEOGREEN modular system is to promote materials recycling through the development of a high value product from waste materials. The purpose is to provide unique properties to the system with the selected materials and contribute to a more sustainable solution.
It aims to differ from other systems based on the application of non-conventional materials, introducing certain thermal, acoustic and environmental benefits that other systems do not integrate.
Each module comprises two main elements (Fig. 2): a geopolymer base plate; and an upper plate made with Insulation Cork Board (ICB).
The study is complemented by the selection of endemic vegetation, adapted to the Beira Interior Region were the project is being developed.

4.1. Base plate

Previous studies have shown that mine waste mud from Panasqueira mines is rich in alumino-silicates and can be used to produce alkaline activated binders (geopolymers) (Torgal et al., 2008).
Geopolymers reveal excellent properties, in particular on their durability, resistance to acidic attack, behavior at high temperatures and fire resistance, resistance to frost attack (Rangan, 2009). Studies based on the development of geopolymers using mine waste mud from Panasqueira mines as precursor show that alkaline activation is a secure process of encapsulation of heavy metals (Torgal, et al., 2009) (Torgal, et al., September 2010).
In this research, the base plate is being developed with alkaline activated binders (geopolymers) using a blend of mine waste mud and other waste materials. Preliminary results indicated that a compressive strength of 6 MPa can be obtained, after 7 days of curing at a temperature of 60ºC in a ventilated oven.
The geopolymeric mixes have a capillary absorption coefficient between 0,63 and 1,33 $Kg.m^{-2}. h^{0,5}$.
Introducing expanded cork granules in the mix can minimize the density of these plates. A percentage of 50% cork enables a final density of 1.3 g/cm^3. This corresponds to 2.4 Kg per module and a total weight of 26 Kg/m^2.
So, the base plate final properties combine good water absorption, low density and good mechanical resistance.
The water absorption rate shows that the geopolymer plate can absorb the water quickly and supplying it to the plant substrate, minimizing the irrigation needs.

4.2. Upper plate

Insulation Cork Board (ICB) is a natural eco-friendly material made from the agglomeration of expanded cork granules.
The upper plate is made by cutting ICB boards with a density of 160 Kg/m^3 and 8 cm (3,15 inches) thickness, with the shape presented in Figure 2. Each upper plate presents a weight of 0,650 Kg, comprising a total weight of 7Kg/m^2.
The main advantages of using ICB are the fact that it is a sustainable material, with low density, which is capable to support the substrate and plants.
We believe that considering that ICB is an insulation material with a heat transfer coefficient

of 0.5 $W/m^2.K$, it will contribute to increase the thermal performance of buildings envelope.

4.3. Plant species

Plant selection was based on the study of herbaceous and shrubby associations adapted to local climate conditions (Delgado et al., 2011) and construction restrictions. Consisting of plant species resistant to the Beira Interior Region climate, with dry mesomediterranean conditions, it was given privilege to autochthonous or endemic species with different leave forms and textures and variations in blooming periods.

The main purposes are the promotion of biodiversity, while minimizing adaptation problems and irrigation requirements.

The tests were based on survival rate evaluation of ten samples of sixteen selected plant species for each irrigation period and each substrate.

These plants were submitted to three irrigation periods of ten minutes using micro sprinklers (daily watering, three times weekly watering and once weekly watering).

They were also installed in three different substrates: Siroroof substrate, available on market, with 60% organic and 40% inorganic components; *Sedum* substrate, containing 30% organic and 70% inorganic components (mainly expanded clay); and *Inverted Sedum* substrate with 30% organic and 70% inorganic components (mainly volcanic rock).

The results show that *Achillea millefolium* and some of the *Thymus* species survived to three times watering per week and *Sedum* species survived to watering once per week. However, most plant species can only resist to a daily irrigation in the first year of growth.

From the tested substrates we can conclude that *Siroroof* substrate showed greater results in most plant species.

Based on these conclusions, next phase consists in the evaluation of selected species adaptation to the materials, considering their pH conditions.

5. CONCLUSION

Green roof and green wall systems must evolve to: more sustainable solutions; simpler to install and maintain; made with materials with less incorporated energy and CO_2 emissions; including climate adapted plant species with less irrigation needs.

Considering the benefits of vegetated surfaces, these systems must be designed to complement the thermal performance of buildings envelope. And therefore, contribute to the reduction of buildings energy consumption, for heating or cooling.

The GEOGREEN modular system is designed to contribute as a passive design solution for buildings, associating the benefits of adapted vegetation with the thermal, acoustic and environmental characteristics of the associated materials.

The following work will consist in identifying the geopolymer mixture with best combination of porosity, density and compressive strength; understand if the ICB layer is effective; and evaluate the performance of the selected plant species when in contact with the system materials.

Finally, it should be noted real climate studies will be carried on in future to evaluate the thermal performance of the GEOGREEN system and its contribution as a passive design solution.

The real climate studies can be of particular interest for the application both Portugal and other countries with similar weather conditions.

6. ACKNOWLEDGEMENTS.

This research project is partially financed by the Portuguese Foundation for Science and Technology, FCT.

Cork materials supply is being supported by ISOCOR/SOFALCA.

7. REFERENCES

AA.VV, 2008. *Introduction to Green Walls Technology, Benefits & Design*, Green Roofs for Healthy Cities, September.

AA.VV. 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast). *Official Journal of the European Union*.

Barrio, E. P. 1998. Analysis of the green roofs cooling potential in buildings. *Energy and Buildings*, Vol. 27, pp. 179-193.

Bruse, M. Thönnessen, M. Radke, U. 1999. Practical and theoretical investigation of the influence of facade greening on the distribution of heavy metals in urban streets, viewed 17

January, 2012, <http://www.envi-met.com/documents/papers/facade1999.pdf >

Carlos, J. S. Corvacho, H. Silva, P. D. Castro-Gomes, J.P. 2010. Real climate experimental study of two double window systems with preheating of ventilation air. *Energy and Buildings*, Vol. 42, pp. 928–934.

Delgado, F., Amaro, C., Seco, F. & Ribeiro, S. 2011. Vegetação autóctone aplicada a painéis de cobertura e fachadas verdes de edifícios urbanos – “Projeto GEOGREEN”. In: Actas Portuguesas de Horticultura. 19: 125-129.

Dunnet, N. and Kingsbury, N. 2008. *Planting Green roofs and Living Walls*. Timber Press, Portland/London.

EIA 2012. Annual energy review 2011. Independent statistics and analysis U.S. Energy Information Administration, viewed 18 April 2013,<http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf>

Eumorfopoulou, E. Aravantinos, D. 1998. The contribution of a planted roof to the thermal protection of buildings in Greece. *Energy and Buildings*, Vol. 27, pp. 29-36.

Eurostat 2010. Consumption of energy, viewed 21 January 2013, <http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Consumption_of_energy>IEA 2013.

IEA 2013. International Energy Agency. FAQs: Energy Efficiency, viewed 18 April 2013, <http://www.iea.org/aboutus/faqs/energyefficiency/>

Ip, K. Lam, M. Miller, A. 2010. Shading performance of a vertical deciduous climbing plant canopy. *Building and Environment*, Vol. 45, pp. 81-88.

Köhler, M. 2008. Green facades - a view back and some visions. *Urban Ecosystems*, Vol. 11, Issue 4, pp 423-436.

Liu, K. Baskaran, B. 2003. Thermal performance of green roofs through field evaluation. In: Proceedings First North American Green Roof Infraestructure Conference, Chicago, USA, May 29-30, pp. 1-10.

Luckett, K. 2009. *Green roof construction and maintenance*. Mc Graw Hill, United States of America.

Manso, M. Virtudes, A. Castro-Gomes, J.P. 2012. Development of a modular system for vegetated surfaces in new buildings and retrofitting. World Green Roof Congress, Copenhagen, Denmark, September 19-21.

Oliveira, S. Andrade, H. Vaz, T. 2011. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Building and Environment*, Vol. 46, pp. 2186-2194.

Pérez, G. Rincón, L. Vila, A. González, J.M. Cabeza, L.F. 2011. Green vertical systems for buildings as passive systems for energy savings. *Applied Energy*, Vol. 88, pp. 4854-4859.

Pires, L. Silva, P. D. Castro-Gomes, J.P. 2011. Performance of textile and building materials for a particular evaporative cooling purpose. *Experimental Thermal and Fluid Science*, Vol. 35, pp. 670–675.

Pless, S. Torcellini, P. 2010. Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options, Technical Report NREL/TP-550-44586. National Renewable Energy Laboratory, USA.

Rangan, B.V. 2009. *Engineering properties of geopolymer concrete. Geopolymers: Structure, processing, properties and applications*. Provis and Jannie S.j. van Deventer, Woodhead Publishing Ltd., pp. 211-226.

Torgal, F.P. Castro-Gomes, J.P. Jalali, S. 2008. Properties of tungsten mine waste geopolymeric binder, *Construction and Building Materials*, Vol. 22, pp. 1201-1211.

Torgal, F. P., Castro-Gomes, J. P. Jalali, S. 2009. *Geopolymers: Structure, Processing, Properties and Applications*, *Chapter 18 - Utilization of mining wastes*. Provis, Jonh, Van Deventer, J. (Eds.), Woodhead Publishing.

Torgal, F. P. Castro-Gomes, J. Jalali, S. 2010. Durability and Environmental Performance of Alkali-activated Tungsten Mine Waste Mud Mortars. *Journal of Materials in Civil Engineering* – ASCE, Vol.1, Issue 9, pp. 897-904.

Virtudes, A. Manso, M. 2011. Green façades: as a feature in urban design. In: Proceedings ICEUBI, International Conference on Engineering, University of Beira Interior, Covilhã, Portugal, November 28-30.