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“Green Integrated Structural Elements for Retrofitting and New Construction of Buildings”

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<th>Name</th>
<th>Date Approved</th>
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<td>Work Package leader</td>
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<td>Coordinator</td>
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1 Project Summary

The Green INSTRUCT (GI) project will develop a prefabricated modular structural building block that is superior to conventional precast reinforced concrete panels by virtue of its reduced weight, improved acoustic and thermal performance and multiple functionalities. The GI block consists of over 70% of CDW in weight.

The GI project will:

(i) achieve sustainability and cost savings through CDW sourced materials,
(ii) develop efficient, robust, eco-friendly and replicable processes,
(iii) enable novel cost efficient products and new supply chains,
(iv) develop a building block that renders refurbished or new buildings safe and energy efficient and
(v) safeguard comfortable, healthy and productive environment.

They can be achieved by defining the structural, thermal and acoustic performance of our final product to be competitive to similar products in the market. The types and sources of CDW are carefully identified, selected and processed while the supply chain from the sources, processing, fabrication units to assembly site of the whole modular panel will be optimized.

The project is guided by a holistic view through building information modelling and optimal overall performance. This includes considering the life cycle analysis, weight, structural performance, thermal and acoustic insulation, connectivity among modular panels and other structural/non-structural components as well as the compatibility of different internal parts of each modular panel. In order to homogenize the production process, all individual elements are fabricated by extrusion, which is a proven cost effective, reliable, scalable and high yield manufacturing technique. The concept, viability and performance of developed modular panels will be verified and demonstrated in two field trials in test cells.

This document aims to provide the guidelines and the preliminary basic features of the GI in order to define the bases for the development and allow, in the next advanced phase of the project, further improvements and optimization of the green panel.
## 2 Glossary of Terms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
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<tr>
<td>C2C</td>
<td>Cradle to Cradle ®</td>
</tr>
<tr>
<td>CDW</td>
<td>Construction and Demolition Wastes</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
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<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>GI</td>
<td>Green INSTRUCT</td>
</tr>
<tr>
<td>MOC</td>
<td>Magnesium Oxide Cement</td>
</tr>
<tr>
<td>PU foam</td>
<td>Polyurethane foam</td>
</tr>
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</table>
3 Description of Work

Deliverable 2.1 “End user requirements” reports the work performed in the framework of Task 2.1 “Finalization on end user requirements”:

The aim of this analysis is to set the end user requirements encompassing the functional and non-functional ones as well as user specific needs in order to properly steer design & development of Gi Panel.

In detail, task 2.1 shall define a consistent set of requirements related to the integration of a green wall technology on outer surface of both existing and new buildings. Gi main targets are:

- Increase of the energy efficiency of buildings;
- Substantial minimization of on-site work, when compared to state-of-the-art prefabrication techniques, through the development of a modular product, aimed to easy and fast assembling, simple transport and storage and, at the same time, to plain maintenance and dismantling at the end of product lifetime;
- Social potential acceptance of Construction and Demolition Wastes (CDW) utilization in prefabrication industry and components recyclability, at the end of product lifetime, in a Cradle to Cradle ® (C2C) approach;
- Pre-fabrication of components through mainly extrusion techniques, which are continuous and much simpler to use than many other conventional methods, being therefore most suitable for industrial-scale mass production;
- Effective reduction of production costs.

The overall approach shall take into account, together with fire resistance and structural performance, all functionalities connected to the integration of the Green Wall such as:

- CO₂ capture during the lifetime of the plants in green wall;
- Aesthetic value-added;
- Greywater cleaning integrated at the building;
- Positive microclimatic effects and increased biodiversity on-site;
- Positive acoustic effects, mainly in terms of noise absorption;
- Additional thermal insulation for the building;
- Indoor air pollution abatement, through the use of functional photocatalytic coating.

Specific attention will be spent on functional and structural requirements of the connection schemes of the Gi panel to building façades, in order to make it possible to:

- adapt to both new and existing structures;
- individual removal layer for maintenance purpose or complete replacement.
This specific task has been performed by the Linked Third Part D'Appolonia with the coordination of STRESS.
3.1 **Methodology proposed**

As schematically shown in Fig.1, as the first step of Task 2.1 workflow, a detailed analysis of the GI concept has been performed in order to identify main features and potential critical issues for each layer, internal and external. Such preliminary analysis has been the result of a close cooperation with all GI Consortium partners.

Once identified, main features and general arrangement of all layers, a deep assessment of materials to be used in mass production process as well as an evaluation of main innovative aspects of each component have been carried out in order to highlight the main advantages of GI, with respect to the benchmark solutions available on the market.

In parallel to the identification of the GI characteristics and functionalities, potential target stakeholders have been selected among:

- End user of the product: green companies etc.
- Consultants for end users of the product: architects
- Seller of the product: prefabricating construction, retrofitting, building materials, deconstruction, sorting and recycling of construction materials sector, etc.

On the basis of above described evaluations, a questionnaire has been prepared in order to retrieve any piece of information about all end user requirements, as well as indications and suggestion for the following stages of GI development. This questionnaire has been addressed to all target stakeholders, through an online LimeSurvey.

As final step of the process, end users requirements and recommendations for the product developer have been collected and pointed out.

![Figure 1: Sequence of the analysis process](image-url)
4 Green INSTRUCT overview

In this chapter, an overview of GI technology and of its advancements, respect to the solutions available on the market, are briefly given. Preliminary configuration and technical information about GI panel is reported. During research and development, the final design may be updated in line with technical development as well as according to the results of end-user requirements out from this task.

The project goal is to produce a set of prefabricated structural components, assembled as a modular unit, for buildings envelopes, suitable for both retrofitting and new construction.

This modular panel consists in two layers, one internal and another external. The two panels are held together through aluminium frame, or alternative material, that works as structural backbone. The internal layer provides excellent thermal and acoustic insulation and indoor air quality cleaning characteristics. The external layer consists of an easily extrudable and recyclable material such as a geopolymer, wood-plastic-composite or similar. The substrate acting as a growing media for the plants in the vertical green wall and it will consist of a recycled hydrophilic material and fibres that will optimise weight issues and support the substrate structure. More details are reported in the Fig.2.

![Figure 2: Green INSTRUCT General Scheme](image)

Figure 2 describes the preliminary representation of Green Instruct panel; this configuration could be modified during the development of the project.
GI panel can be installed as a cladding. The module will form a façade as well as structural element in new buildings.

GI shall be designed to have appropriate structural and fire resistance, and shall be optimised to comply with EUROCODES (i.e. Eurocode 9, for aluminium frame structural resistance and Eurocode 8, for seismic performance assessment).

From the structural point of view, magnesium oxychloride internal panel, aluminium frame and geopolymer external panel contribute to the structural capacity of the whole panel.

In the following sub-chapters, all GI constituting elements are analysed along with main references, given by all partners involved in the project:

### 4.1 External layer

The external layer of the panel is the green wall-based vertical ecosystem shown in Fig.3). It is, basically, a living wall consisting of small-growing plants with favourable root growth and includes perennial herbaceous and non woody-species. Species are chosen after an appropriate analysis, accordingly to climatic conditions and sun exposure performing tests, to be completed after the definition of site characteristics. The special feature of the green façade is its ability to purify arising greywater and stormwater conducted through the external vertical ecosystem. Pre-tests include development and analysis of various piping systems, e.g. vertical channels or horizontal cascades.

No soil layer is necessary; a substrate made of perlite, zeolite, clay and/or recycled fibres acts as root support and water storage. Plant roots grow in channels or along cascades, inside the extruded external layer. Final dimensions shall be set in future stage after the first trial. These channels shall be used also for irrigation, together with a water diversion gutter at the top. Water will be injected at the top of the panel and collected at the bottom. Roots, i.e. the rhizobacteria, shall clean greywater, to be used for irrigation by means of a recirculating system.

**Figure 3: Channel-based option of external layer**

Additional considerations about external layer are:

- Maintenance shall be considered regarding water path clogging by means of stiff wires or pressured air
- The external panel with the green infrastructure unit is non-structural. It is self-supportive but the structure is carried by the inner panel.
- The exterior panel must be easily replaceable in case of dysfunctionality
• Geopolymer encasing shall be hydrophobic if possible, since water absorption would increase material degradation and overall weight. Moisture of water permeable material of encasing affects inner panel. A waterproof layer to protect the inner panel or alternatively an air gap becomes necessary if the substrate encasing system is not waterproof. Waterproofing shall be applied on the internal surface of the external layer if necessary.
• Roots penetration in the material can decrease the expected life time of the layer
• Waterproofing shall be applied to the internal surface of the external layer, to avoid the water penetration thought the different layers.

4.2 Intermediate gap layer (PU foam layer)

This layer is mainly designed to improve thermal and acoustic insulation of the entire system.

The air gap also allows ventilation, avoiding humidity and mould growth problems.

In order to analyse the overall system performances, simulations are essential in the later stage of design to assess the necessity to include this layer and set gap thickness ranges to match required performances.

4.3 Internal layer

The internal layer consists mainly in magnesium oxychloride cement (MOC). The MOC panel is a structural element and it is able to take horizontal loads.

The thickness of the insulation system shall be designed in order to match different thermal and acoustic requirements, depending on site climatic and sun exposure parameters.

A metallic frame, complying with structural requirements, shall connect the different elements of the system and shall work as the interlocking system, able to accommodate additional elements to increase the overall stiffness of the panels.

4.4 General characteristic and main features

In this sub-chapter the different main featured of the system are summarized.

The following reuse rate is the target of the GI project:

• Recovery from CDW percentage and future reuse percentage of each component. 70-100% recycling rate and 80% reuse rate.

For the raw material the minimum quality is requested:

• PU foam: New but scratched.
• Polymer: No oil, clean, in small pellet form.
• Glass, brick: in sand-size powder form.
• Concrete: in coarse aggregate, 2-10 mm size.
• Wood dust: raw and ash.

The main material characteristics are listed in the following bullet points:

• Thermal insulation (conductivity):
- Acoustic protection:
  - ≥50 dB
- Fire resistance (class of resistance):
  - PU foam = C to F
  - Geopolymer = good
- Mechanical properties (compressive strength):
  - MOC = 10 MPa
  - Geopolymer = 20-40 MPa
- Physical properties (density):
  - PU foam = 100 kg/m³
  - MOC = 1.6-1.8 specific gravity
  - Geopolymer = 1.8-2.0 specific gravity
- Water absorption, vapour diffusion of the outer layers:
  - MOC = poor water resistance
  - Geopolymer = Water absorption: 5.8% w/w in a 100% RH chamber, 10% w/w immersed in water, both after 120 days. Sorptivity 0.15 (mm/min0.5)

With reference to the geopolymer some issues shall be taken in consideration:

- It must be reconsidered if it is acceptable to have irrigation channels within the extruded geopolymer. This irrigation for the green wall shall be probably studied as a combination of rain water use, to be generally preferred during wet period, and greywater recirculation system, as stated in the DoA, to be generally preferred during dry period (to be decided even in a later stage of design activities);
- Dimensions: The geopolymer layer is supposed to be a big panel, about the normal floor height of a retrofitted or new construction building, or can be constituted by a system of small interconnected elements that will facilitate the installation, replacement and maintenance;
- Application: The mechanical strength of the geopolymer layer is one critical point to be developed. The strength (shear and tensile) is important to accommodate the eventual metallic connectors (which connect the inner and outer layers of the panel), otherwise another system shall be studied to be fixed to another layer (for example a metallic mesh). Another issue from the application of the eventual metallic connectors is how it is done without the geopolymer material in the channels, this point will be taken into account in the design process;
- Water issues: Another concern relates to whether or not the geopolymer layer can allow the presence of water without deterioration. In this case the geopolymer and the green layer can be combined in one cork based layer acting as the substrate, this could be a possibility.

The geopolymer material thermal conductivity values and fire resistant behaviour differ sensibly between partners’ estimation (BRUNEL and NTUA). These estimations shall be clearly defined in order to comply with the material (These estimations could be done in a later stage).
From a general point of view, one of the major concerns is that the vegetation layer should not be water dependent because a huge degradations could appear during warm periods of the year, compromising the visual aspect of the façades. Therefore, an imbeded irrigation system could not be the first option because it can be a major source for possible problems in the future. Inner wall problems can be a major concern in this project. If it is necessary for a water system, it may be solely based on rain waters and gravitational scattering to avoid the use of pumps.

The substrate for the green layer shall neither be too thin so that it can grow something, nor too thick so that it compromises the panel weight, which is already a major concern.

With reference to the geometry of the panel, the dimensions of the panels shall be between 2.5-3 m height per 1-2 m width. The thickness varies depending on structural, thermal and acoustic insulation requirements under definition. The weight shall be low enough to avoid lifting systems that would increase the cost of the panel installation.

Geometry of the panel shall also be customizable so that functional requirements could be fulfilled for different boundary conditions. The GI panel shall be modular in order to be easily assembled, transported and stored including particularly the substantial minimization of on-site installation works and subsequent costs.

Since structural use (new buildings) and cladding use (existing buildings) may require two very different designs, it may bring a double effort, potentially conflicting with GI initial scope.

With this first approach and in order to develop a versatile and flexible solution for new and existing buildings, one approximation is that the panel should work as an independent façade (i.e. curtain wall), thus is able to be placed on virtually any pre-existent façade in the following way (as suggested in the Fig.4):

1. Supported by an anchoring system at each floor level (e.g.: metallic L-profile).
2. Fixed to the pre-existent façade elements (beams, columns and walls) by means of the insertion of discrete metallic connectors, joining the inner and outer layers of the panel to the existent building.
1. Solution for new buildings.
Use of aluminium honeycomb layer to increase the panel stiffness, if necessary. Although supported by the L-profiles, the panel may as well be fixed to the existent structural elements through the metallic connectors.

2. Solution for pre-existent buildings.
Use of longer metallic connectors to fix the panel to the existent wall and structure. The panel could work as a structural retrofitting for the existent wall. No need for interior face finishing.

Figure 4 Panel solution for new and existing buildings

A design decision about this matter will be resolved in order to comply with the objectives of the project and also comply with the requirements of the building and the GI system.

One possible improvement for reinforcement is the addition of a mesh for the MOC panel in order to increase its resistance; this consideration has to be studied in detail.

Regarding the MOC panel, average thickness on the detail 20-40mm combined with the average density 1600-1800 kg/m\(^3\), on a regular module 3 m high and 0.6 m wide, will amount to a 60 kg layer which may result in a very poorly competitive weight/area ratio. To develop a competitive system, this ratio is key to a successful product. The standard panel consists of a 1.2m X 3.0m module weighing at roughly 80 kg, which would make the GI panel around 4 times heavier.

Preliminary consideration was performed in order to identify the connections among external and internal GI panels through probably aluminium connectors, or anchor like structural ties, with distance holder for the air gap.

With reference to the connections between panel and panels building, the panel shall be the same for both typologies. Connectors or anchoring of the panel to the building shall prevent thermal bridges along the façade. Regardless of anchoring technology (used to connect the panel to the main structure), wind and seismic loads are assumed to be transferred in the first place to the main structure through the connectors, with no overall benefit to structural stiffness. Although the overall benefit of the panel in terms of increasing the structure’s stiffness may be negligible (if not properly connected to the building), the wall panels, if properly distributed and considered in the design of new structures, can have a beneficial effect. Not considering enclosure walls can lead to important inaccuracies in the evaluation of the structural response, since they can change stiffness, strength, cause torsional effects, energy dissipation of the global structure and induce local mechanisms. In this framework, appropriate measures to improve the wall panel performance and both in-plane and out-of-plane integrity under horizontal actions should be addressed. Finally, anchoring technology to be adopted for installation have to take into account the analysis reported within the previous paragraphs.

In order to develop the panel, the following ISO/EN NORMS and STANDARDS will be taken into account:

- EN 196-1 Methods of testing cement. Determination of strength.
- ASTM C140 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.
- EN 1015-18 Methods of test for mortar for masonry. Determination of water absorption coefficient due to capillary action of hardened mortar.
5 Solution available on the market

Green wall technology is now enjoying success because of the rediscovery of ecological, hygienic, environmental and climatic potential of natural vegetation.

It is possible to distinguish, in particular, three different categories for constructive and operating characteristics, namely:

- Green façades;
- Vegetated vertical closures;
- Living walls;

Each of them has different characteristics, which help refurbish abandoned buildings. Green Façade technology does not consist of just applying a green coating to an already existing closure, but in the creation of a façade in which the plant portion is an integral part, inseparable from the building.

5.1 Green Façades

Plant coating (shown in Fig.5) is the most historicized form of green walls, known since ancient times and indicating something that is leaned over something else. This technology is rather simple and easy to manufacture, since it enables the plant to cling directly to the wall surface, or through a support be prepended to the façade.

The types of plants that can be used with this system are limited and mainly climbing species are being used. In some cases there may be problems in the interaction of the vegetation with the façade cladding.

5.2 Vegetated vertical enclosures

Vegetated vertical enclosures (shown in Fig.6) are a newly technical application, developed in recent years and much evolved from the agro-technical point of view. Unlike green façades, vegetated closures are much more complex and difficult to implement from a technical point of view, since there is a complete integration system between the plants and the building envelope. Plants become an integral part of the façade; a homogeneous and continuous layer of plants is created to cover the entire façade. This technique allows the use of nearly all existing plant species (herbaceous structure, shrubs, moss, evergreen to foliation), providing that the physiological and environmental needs are met.

A peculiarity of vegetated vertical enclosures is to protect the interstitial layers from moisture through a waterproofing layer.
This technique involves the construction of pre-vegetated modules in nurseries, which are then mounted on the façade and fed through an irrigation or fertigation system which has the task of ensuring an adequate nutrition of the plants. The pre-vegetated module gives the façade a very smooth appearance.

![Vegetated vertical enclosure](image)

**Figure 6: Vegetated vertical enclosure**

### 5.3 Living walls

Living walls (shown in Fig.7) are a subtype of the vegetated vertical enclosures. Although this system has many features in common with the other two technologies, it presents some peculiarities.

The Green INSTRUCT project is aimed at developing an innovative panel considering the living wall technology; this technology differs from green façades in that the plants root in a structural support which is fastened to the wall itself. Nutrients and water are provided to the plants through an irrigation system instead of from the ground.

The most important difference consists in the realization technology; in fact, the realization of a living wall implies a greater design and construction activity, and is required a much higher man presence during operational stages. There is a constant control by the executor of the green wall during both design and construction phase and there is a chance to experience many forms and vegetation combinations. The living wall can host almost all types of plant species, with the only conditions being the climatic characteristics, exposure or sunshine.

The inventor of this type of green wall is the French botanist Patrick Blanc whose system will be described later.
Figure 7: Green wall
5.4 Benchmark

In order to investigate the different solutions proposed by suppliers of green wall systems, around the world, it has been conducted a preliminary analysis about the main features and technologies available. This analysis had the purpose to highlight the most important aspects prosecuted by manufacturers and define main benchmark for the GI panels in the reference market.

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<thead>
<tr>
<th>Product and Technology</th>
<th>Specific features of green wall</th>
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<tbody>
<tr>
<td>Florawall (Austria):</td>
<td>- Indoor wall of living evergreen plants</td>
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<tr>
<td>hydroponic technology with fleece, sensors for water regulation</td>
<td>- Hydroponic plants without soil and substrate</td>
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<td></td>
<td>- CO$_2$ concentration reduction in rooms and filtering out of indoor air pollutants, including nicotine and formaldehyde</td>
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<tr>
<td>Price and website</td>
<td>- More than 100 different plants typologies;</td>
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<td></td>
<td>- Different types of irrigation system, from manual refilling to total automation</td>
</tr>
<tr>
<td>950 Euro/m$^2$</td>
<td>- Very low thicknesses and minimum space requirements</td>
</tr>
<tr>
<td><a href="http://www.florawall.at">www.florawall.at</a></td>
<td>- High-tech sensors for plants humidity detection or nutrients need notification</td>
</tr>
<tr>
<td></td>
<td>- Possibility to increase the level of air humidity to a pre-defined target, up to 25%</td>
</tr>
<tr>
<td></td>
<td>- Reduction of reverberation times audibly</td>
</tr>
<tr>
<td></td>
<td>- Failure monitoring system designed to monitor the Florawall installation H24</td>
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<thead>
<tr>
<th>Product and Technology</th>
<th>Specific features of green wall</th>
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<tbody>
<tr>
<td>Green Wall Tec GmbH (Austria):</td>
<td>-Vegetable substrate composed by moss</td>
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<tr>
<td>Moss on cork or MDF panels for indoor and outdoor use without watering or modular flower panels for outdoor decoration</td>
<td>-Moss walls remove fine dust particles, cools and insulate building;</td>
</tr>
<tr>
<td></td>
<td>-Moss panel contributes to reduction of CO$_2$</td>
</tr>
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<td></td>
<td>-Moss has no roots and gets all substances it need to live directly from the air</td>
</tr>
<tr>
<td>Price and website</td>
<td>-It is capable to pull out up to 75% of fine particles suspended in the air</td>
</tr>
<tr>
<td>980 Euro/m$^2$ (all Inn)</td>
<td>-Moss panel are suitable for indoor and outdoor installations</td>
</tr>
<tr>
<td><a href="http://www.greenwalltec.eu">www.greenwalltec.eu</a></td>
<td>-3 cm and 6 cm of installation heights respectively for outdoor and indoor panels</td>
</tr>
<tr>
<td></td>
<td>-No soil and no additional watering needed</td>
</tr>
<tr>
<td></td>
<td>-Noise reduction properties</td>
</tr>
<tr>
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<td>-Thickness of the system without vegetation: approx. 10 cm</td>
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<thead>
<tr>
<th>Product and Technology</th>
<th>Specific features of green wall</th>
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<tbody>
<tr>
<td>ANS Group Global (UK, Ireland, New Zealand, Slovakia &amp; Hungary)</td>
<td>-Modular system means easy installation and maintenance</td>
</tr>
<tr>
<td><strong>Product and Technology</strong></td>
<td><strong>Specific features of green wall</strong></td>
</tr>
<tr>
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| Sage Vertical Gardens (UK) | - Hydroponic plants without soil and substrate  
|                           | - Minimum 40% recycled content  
|                           | - "Biotiles" are modular and heat and freeze resistant  
|                           | - Reduction of water consumption up to 75%  
|                           | - "Biotiles" are suitable for create desired matrix to create any composition  
|                           | - Patented growing system >80% more water efficient than traditional soil  
|                           | - Automatic irrigation control box to supply waters & fertilizers  
|                           | - Recirculating tank with pump and timers, no need to tap in to water lines  
|                           | - Indoor and outdoor applications  

| Biotecture (UK) | - Intelligent water management. Average water use in a typical UK installation is 1 litre per m² per day  
|                | - Patented hydroponic system that allows a high precision level for plants growth  
|                | - Living walls, or green walls, are attached to a free-standing frame or to the exterior or interior of a building  
|                | - Plants are placed within panels that contain an inert growing medium  
|                | - Wind resistant to 140 mph  
|                | - Up to 96 plants per m²  
|                | - Manufactured from 100% recycled material  
|                | - Fire rating - Class ‘A’  
|                | - Suitable for customized design in order to select the favorite mix of plants  
|                | - All living walls require a maintenance schedule in order to remove any airborne weeds, dead leaves and check for pests or diseases;  
|                | - Air quality improvement  
|                | - The combination of plants and soil provides effective protection against rain and wind, furthermore 50% of solar energy is absorbed by foliage and a further 30% is reflected  
|                | - Sounds levels can be reduced by around 10 decibels  
|                | - Green walls act as insulation helping to regulate a building’s temperature, keeping it warmer in Winter and cooler in Summer  

| Pre-build green wall, integrated design with automatic irrigation with pump and tank, can be filled by hand. | - Living wall system includes a built-in irrigation system through hidden pipes. It normally uses only 1 to 1.5 litres of water per square meter each time the irrigation is applied  
| Potential competitor as they try to develop also greywater cleaning | - Modular system allows to install the living wall pre-planted  
| Price and website | - Wind resistant to 140 mph  
| 900-970 Euro/m² | - Up to 96 plants per m²  
| www.ansgroupglobal.com | - Manufactured from 100% recycled material  
| | - Fire rating - Class ‘A’  
| Website | - Suitable for customized design in order to select the favorite mix of plants  
| www.sageverticalgardens.com | - All living walls require a maintenance schedule in order to remove any airborne weeds, dead leaves and check for pests or diseases;  
| information@sageall.com | - Air quality improvement  
| | - The combination of plants and soil provides effective protection against rain and wind, furthermore 50% of solar energy is absorbed by foliage and a further 30% is reflected  
| | - Sounds levels can be reduced by around 10 decibels  
| | - Green walls act as insulation helping to regulate a building’s temperature, keeping it warmer in Winter and cooler in Summer  

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## Website

<table>
<thead>
<tr>
<th>Green INSTRUCT – Grant Agreement No: 723825</th>
<th>EEB-04-2016</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Website</strong></td>
<td>medium called Grodan made from stone wool</td>
</tr>
<tr>
<td><a href="http://www.biotecture.uk.com">www.biotecture.uk.com</a></td>
<td>- Shorter installation times because most of the work has been carried out off-site</td>
</tr>
<tr>
<td><a href="mailto:enquiries@biotecture.uk.com">enquiries@biotecture.uk.com</a></td>
<td>- Ability to “pre-grow” the walls off-site</td>
</tr>
<tr>
<td></td>
<td>- The plants are nurtured in the panels in order to obtain a precision growth</td>
</tr>
<tr>
<td></td>
<td>- Patented unique modular hydroponic system</td>
</tr>
</tbody>
</table>

## Product and Technology

<table>
<thead>
<tr>
<th>Green Over Grey (Canada)</th>
<th>Specific features of green wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>While installation no damage done to the building, the lightest green wall system on the market today, non-modular, no soil, big plants, indoor and outdoor</td>
<td>- Utilization of hundreds of different types of plants to create unique patterns</td>
</tr>
<tr>
<td></td>
<td>- System consists of a frame built in front of a pre-existing wall and attached at various points</td>
</tr>
<tr>
<td></td>
<td>- A waterproof panels are mounted to the frame; these are rigid and provide structural support</td>
</tr>
<tr>
<td></td>
<td>- Between the building and the panels is left a layer of air. This adds beneficial insulating properties and acts like rain-screening to protect the building envelop</td>
</tr>
</tbody>
</table>

## Website

| www.greenovergrey.com | - Low maintenance thanks to an automatic irrigation system |
| info@greenovergrey.com | - Hydroponic makes panels very clean and eliminates the possibility of soil borne pathogens |
|                       | - Soil is replaced by lightweight porous material. This allows to have walls very light, weighing less than 20 kg/m² |
|                       | - Patented Green over Grey™ system |
|                       | - A thin layer of patented material, placed on vertical walls, retains moisture and nutrients allowing the plants to thrive |
|                       | - Green walls enhance building protection, reducing temperature fluctuation, providing a rain screening and protection from UV radiation |

## Product and Technology

<table>
<thead>
<tr>
<th>GSKY (USA)</th>
<th>Specific features of green wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior environment can be used outdoors seasonally, patented tray system waters plants</td>
<td>- Pre-growth of the panels in a nursery</td>
</tr>
<tr>
<td></td>
<td>- Modular system</td>
</tr>
<tr>
<td></td>
<td>- Requires maintenance on all walls for the first year</td>
</tr>
</tbody>
</table>

## Price and website

| http://gsky.com | 1300-1800 Euro/m² |

## Product and Technology

<table>
<thead>
<tr>
<th>Sempergreen (Netherlands), Projects worldwide</th>
<th>Specific features of green wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product range: vegetation blanket, plant mat, sedum tray,</td>
<td>- 1 m² of living wall extracts 2.3 kg of CO₂ per annum from the air and produces 1.7 kg of oxygen</td>
</tr>
<tr>
<td></td>
<td>- Plants absorb sunlight, 50% is absorbed and 30% reflected; so, this helps to create a cooler and more pleasant climate</td>
</tr>
</tbody>
</table>
Sempergreenwall, flexipanel, frame panel, moving hedge.

**Website**
www.sempergreen.com
info@sempergreen.com

A living wall acts as a sound barrier to your building. It absorbs 41% more sound than a traditional facade. This results in a reduction of 8 dB

- Living wall creates a natural fire-resistant layer. Sempergreen living wall system meets the highest class European fire safety standard B-s2, d0
- A living wall offers protection from external influences such as the sun, rain, wind and temperature fluctuations and extends the life span of your façade

**Product and Technology**

Pilot Vertical filter wall (Norway)

Daily dosing rate (3 months long)
war 1000 L/m² - impressing reduction rates (SVETE 2012)

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**Specific features of green wall**

- The inner part of the wall is inert and porous, through this media, the water to be purified percolates, just like in hydroponic growing
- The roots of the plants grow into the porous material and use the nutrients in the water. With the bacteria growing on the medium, this will become a very effective system for water purification
- In the bottom of the wall, water is collected in a tank and used in the household or pumped to the top of the wall again
- This system allows the water re-use and the purification of the percolating greywater

**Price and website**

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**Product and Technology**

Green Roofs for Healthy Cities (Canada)

Stakeholder Community offering information on Onsite Wastewater Treatment, through a green wall with plants and filters, gravel-> irrigation use or discharge storm water use.

**Website**

http://www.greenroofs.org

**Specific features of green wall**

- Living wall systems are composed of pre-vegetated panels, modules, planted blankets or bags that are affixed to a structural wall or free-standing frame
- Modules can be made of plastic, expanded polystyrene, synthetic fabric, clay, and concrete and support a greater diversity and density of plant species than green façades
- These processes remove airborne pollutants such as toluene, ethyl benzene, xylene, and other volatile organic compounds
- The vegetated surface provided by strategic urban greenery such as green walls and roofs will block high frequency sounds, and when constructed with a substrate or growing medium support can also block low-frequency noises
- Temperature fluctuations over a building’s lifetime can be damaging to organic construction materials in building façades. Green walls limit thermal fluctuations
- Green walls protect exterior finishes and masonry from UV radiation and rain

**Price and website**

- 

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**Product and Technology**

The ModuloGreen® living wall

**Website**

http://www.modulogreen.ca/

**Specific features of green wall**

- The living wall can be attached to any surface, through its light and secure structure made of stainless steel, aluminium or composite materials
- Modules are made of polypropylene, which resists temperatures Varying from -40°C to +120°C
- System is watertight and creates a space between the façade and
The analysis of the main characteristics arising from analysis and resulting common to most products is listed in the following. In detail these benchmarks are related to:

- Hydroponic technology using a method for growing plants without soil, feeding mineral nutrient solutions in a water solvent
- Built-in irrigation system suitable to recycle grey water production (water consumption declared by Biotecture is 1 L/m²/day)
- Thermal Insulation properties with and without using of an air gap between the layers;
- Air Biofiltration properties
- Noise reduction features (reduction of 10 decibels declared by ANS Group Global)
- Low maintenance; several vendors include in the supply at the signing of a maintenance contract
- Lower thickness of the whole panel
- Modular system and easy installation and maintenance

As alternative Green Wall Technology propose a solution with vegetal substrate composed by moss. All substances required by moss are supplied directly from the ambient air. Thickness of moss solution, without vegetation, is approximately 10 cm.

5.5 Advancements respect to the state of the art

Based on the overview of GI technology and the outcomes given by benchmark analysis have been defined the most relevant innovative aspects that will feature the new product. Such aspects, listed below, should be taken into consideration in the further steps of the project.

- High quality prefabrication, containing more than 70% per weight of recycled material from construction and demolition wastes (CDW)
- Panels shall be customizable in order to allow the coating of surfaces with non-conventional shapes. They could also have reduced dimensions and weight and will be used in both new and existing buildings, as specified in the DoA
- Production process optimized, for energy and resource efficiency, using extrusion systems, which enables flexibility in fast fabrication, low porosity, enhanced mechanical properties and shortening of curing time for cement-based products
- Modularity of the product, 30% lighter than conventional envelope walls of the same size, 15-30% faster to install and at the same time easy to maintain and dismantle at the end of life
- Easy replacement of each element that composes the Green façade
- Applicability of the product to both new and existing buildings
- CO₂ is captured during the lifetime of the plants, and also after it recycles the dead plants, in the green wall external layer
- Aesthetic added value
- Cost effective technology with a potential price less than 500 €/m²
- Combination of rain water use and greywater cleaning system integrated at building level
- Positive acoustic effects (noise absorption) sensible improved respect to the solution available on the market e.g. benchmark 8-18 dB
- Additional thermal insulation for the building
- Integration of services like air and water cleaning into the building
- Indoor photocatalytic coating
- Positive microclimatic effects and increasing the biodiversity on-site
6 Identification of target stakeholders

In order to identify most relevant aspects of the new green panel for the stakeholders, a survey campaign has been conducted.

Careful analysis and selection of stakeholders has been carried out, referencing the scale and type of project. Some key definitions to facilitate the process of stakeholder engagement and management are presented below:

- Identification and classification of stakeholders as contributors, designers, consumers, etc.;
- Consideration of their likely influence over or interest in the project;

The first step was the adoption a process to identify the stakeholders in order to make a list of the stakeholder categories. In detail the survey has been addressed to following categories:

a. End user of the product: green companies;

b. Sellers of the product: prefabricating construction, retrofitting, building materials, deconstruction, sorting and recycling of construction materials sector, etc.;

c. Consultant for end users of the product: architects;

d. Designers and Researchers;

e. Manufacturers

f. Project partners

For each category, it is important to analyse the level of influence and interest in the project, so stakeholders must be mapped to an influence/interest grid and then classified.

![Figure 8: Example of Influence/Interest grid](image-url)
A stakeholder’s position suggests an approach to take with them during the survey. Following classification might be used to describe the location of each stakeholder in the grid:

- High influence/high interest; fully involve and make the greatest efforts to satisfy the project targets;
- High influence/lower interest: consult them in their interest areas;
- Low influence/high interest: keep them informed and request their input to relevant areas;
- Low influence/low interest: monitor and keep them informed about further developments.

Based on previous evaluations following target stakeholders, categories have been identified.

- Green Companies;
- Architects;
- Prefabricating construction companies;
- Sorting and Construction Recycling Companies;
- Retrofitting Manufacturers;
- Building Material Sellers;

In the following paragraphs the questionnaire given to stakeholders is attached and a brief analysis of the results achieved is shown.
7 Interview

The focal point of the survey was to gather data about the features analysed in order to obtain comparable information. Each stakeholder has been requested to fill some general fields with professional data and assign a value between 1 and 5 (1 low importance-5 high importance) to the main features specified in the present document.

The questionnaire is composed of 21 fields to be completed and it can be completed in only a few minutes. The scope of that survey is to assign an order of magnitude for each of the most important feature of the GI.

The following listed panel features have been considered in the questionnaire submitted to the stakeholders, taking into account of D’Appolonia experience in engineering consulting activities in panel and energy efficiency building:

- thermal insulation
- acoustic insulation
- reuse of construction and demolition wastes
- aesthetic impact in living wall technology
- environmental impact
- cost impact
- ease of installation
- installation time span
- effective service life
- installation costs
- ease of maintenance
- living wall irrigation
- existing building/new building applications
- visibility and prestige

Hence the questions regarding the above listed features have been reflected in the questions asked in the questionnaire as the following:

The circulated questionnaire is reported here below.

1. Name of your company ____________________________________________
2. Your business task in the company________________________________
3. Which of the following categories you belong to?
   a. End user of the product;
   b. Consultant for end users of the product;
   c. Seller of the product.
4. On a scale from 1 to 5, how important do you rate thermal insulation characteristics in a cladding panel such as Green INSTRUCT?
5. On a scale from 1 to 5, how important do you rate acoustic insulation characteristics in a cladding panel such as Green INSTRUCT?
6. On a scale from 1 to 5, how important do you rate reuse of construction and demolition wastes in civil and architectural enhancements, of new and existing building, like the ones Green INSTRUCT can ensure?

7. On a scale from 1 to 5, how important do you rate aesthetic impact in living wall technology?

8. On a scale from 1 to 5, how important do you rate environmental impact and advantages of living wall utilization (e.g. CO$_2$ absorption etc.)?

9. On a scale from 1 to 5, how important do you rate cost impact in living wall technology?

10. On a scale from 1 to 5, how important do you rate ease of installation in living wall technology?

11. On the basis of your experience, which range of installation time span can be acceptable?

12. On a scale from 1 to 5, how important do you rate cheapness of installation in living wall technology?

13. On the basis of your experience, which range of installation costs can be acceptable?

14. On a scale from 1 to 5, how important do you rate ease of maintenance in living wall technology?

15. On a scale from 1 to 5, how important do you rate effective service life of living wall panels?

16. On the basis of your experience, which range of average service life of living wall panels can be acceptable?

17. On the basis of your experience, which contribution would you rather choose for living wall irrigation?
   a. Rain water;
   b. Potable water;
   c. Grey water (coming from building wastes).

18. Which characteristics of Green INSTRUCT would lead you to choose it in existing building finishing?

19. Which characteristics of Green INSTRUCT would lead you to choose it in new building finishing?

20. With reference to your working place, do you think that living wall installation would affect and improve visibility and prestige of your company?

21. Comments and suggestions? _____________________________________________
7.1 Survey Results

The survey has been realized using the application software LimeSurvey\(^3\) and through the circulation of the questionnaire web address by e-mail. This communication has been sent to all GI Consortium partners and from them further spread to others stakeholders.

Of all the disseminated questionnaires, 51 have been returned. 18 of them have been fully completed while the remaining only partially. The empty fields exclusively concern suggestions and qualitative answers. The retrieved answers allow us to obtain the following categories:

- 5 End Users;
- 13 Consultants
- 1 Seller

The remaining 32 interviewees have answered only partially to the questions.

From the data received, a ranking of the various topics highlighted in the questionnaire has been established, on the basis of importance given by each individual questioned.

Results have been analysed on a basis of arithmetic average of the votes cast for the most important focal points. All interviewees have assigned a numerical evaluation to each focal point.

The results have been ranked from the most important to the least important:

<table>
<thead>
<tr>
<th>Features</th>
<th>Assigned Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) aesthetic impact</td>
<td>4,63</td>
</tr>
<tr>
<td>2) environmental impact</td>
<td>4,58</td>
</tr>
<tr>
<td>3) effective service life</td>
<td>4,47</td>
</tr>
<tr>
<td>4) ease of maintenance</td>
<td>4,42</td>
</tr>
<tr>
<td>5) thermal insulation</td>
<td>4,37</td>
</tr>
<tr>
<td>6) reuse of construction</td>
<td>4,26</td>
</tr>
<tr>
<td>7) ease of installation</td>
<td>4,26</td>
</tr>
<tr>
<td>8) cost impact</td>
<td>4,16</td>
</tr>
<tr>
<td>9) acoustic insulation</td>
<td>3,95</td>
</tr>
<tr>
<td>10) cost of installation</td>
<td>3,84</td>
</tr>
</tbody>
</table>

The previous list pointed out the most important features according to the requirement of interviewees.

According to work programme and GI adherence the following 5 (out of 10) feature has been selected to be used in a weighted sensitivity analysis:

---

\(^3\) https://www.limesurvey.org/
• Reuse of Construction;
• Cost Impact;
• Environmental impact;
• Thermal Insulation;
• Cost of installation.

<table>
<thead>
<tr>
<th>Features</th>
<th>Assigned Value</th>
<th>Assigned Weight</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) environmental impact</td>
<td>4,58</td>
<td>15%</td>
<td>5,27</td>
</tr>
<tr>
<td>2) thermal insulation</td>
<td>4,37</td>
<td>15%</td>
<td>5,02</td>
</tr>
<tr>
<td>3) reuse of construction</td>
<td>4,26</td>
<td>15%</td>
<td>4,90</td>
</tr>
<tr>
<td>4) aesthetic impact</td>
<td>4,63</td>
<td>5%</td>
<td>4,86</td>
</tr>
<tr>
<td>5) cost impact</td>
<td>4,16</td>
<td>15%</td>
<td>4,78</td>
</tr>
<tr>
<td>6) effective service life</td>
<td>4,47</td>
<td>5%</td>
<td>4,70</td>
</tr>
<tr>
<td>7) ease of maintenance</td>
<td>4,42</td>
<td>5%</td>
<td>4,64</td>
</tr>
<tr>
<td>8) ease of installation</td>
<td>4,26</td>
<td>5%</td>
<td>4,48</td>
</tr>
<tr>
<td>9) Cost of installation</td>
<td>3,84</td>
<td>15%</td>
<td>4,42</td>
</tr>
<tr>
<td>10) acoustic insulation</td>
<td>3,95</td>
<td>5%</td>
<td>4,14</td>
</tr>
</tbody>
</table>

Other suggestions arising from the stakeholders have been related to the installation operation, service life and irrigation system.

In detail for most part of interviewees, the new element should have:

• Installation time and cost less or equal to other similar systems;
• Service life should be higher than other similar available market products.

The survey results do not give a preferred solution between rain water and grey water for the irrigation system; a good solution could be to propose two different types of panels, with rain water and with grey water, in order to supply the optimal solution according to the functional needs of each specific building and installation environment.

In addition, one other point of interest is related to the opportunity to arrange elements having different modular shapes, in order to be more flexible and with high adaptability to the surfaces to be coated.
8 Conclusions and Recommendations

The work reported in the previous chapters are the main base, considerations, issues and elements to be taken into account in which the decision making process to be followed in the project from now. This decision making process will be based on technical and design requirement considerations that will be responsible among the GI partners. This process, initiated in this document, will ensure the quality of the final product developed in the GI project.

The feedback from the stakeholders highlights the great importance of environmental aspects of both considering materials (secondary raw material from C&DW) as well as thermal insulation.

Additional feedback is related to the installation and maintenance costs, which based on the analysis, do not seem to have a high priority for this niche product. In any case, it will be wise to have the overall cost of the solution comparable in order to keep it attractive for the market.

In addition, a further key element will be the selection of the lightest and high strength material for the structural elements, in order to reduce the overall weight of the panel and make it lighter than conventional green walls of the same size.
9 References

References year 2017

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- www.sempergreen.com
- http://www.greenroofs.org
- http://www.modulogreen.ca/

10 Annexes

Questionnaires data Collection
11 Acknowledgment

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