PET GROWN

A SELF-SUSTAINING, MONO-MATERIAL & MULTI-FUNCTIONAL GREEN ROOF MODULE
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SOCIAL ENVIRONMENTAL MATERIAL USAGE IN BUILDING SECTOR

RESEARCH FRAMEWORK LITERATURE REVIEW DESIGN & EVALUATION FINAL DESIGN

SOCIAL ENVIRONMENTAL ECONOMICAL
THE WORLD'S ENERGY & MATERIALS FLOW

60% EXTRACTED LITHOSPHERE'S RAW MATERIAL

6% = 26 EJ GLOBAL FINAL ENERGY USE

13 – 30% TOTAL WASTE

1/6 FRESHWATER RESERVES
DOWN-CYCLED

DO NOT DECREASE THE NEED OF HIGH QUALITY RAW MATERIAL

DO NOT REDUCE THE WASTE GENERATION

INCREASE LIFESPAN
**PROBLEM**

The material usage in the building sector is unsustainable because of three main reasons:

The use of big amount of natural resources.
The non-efficient down-cycle of the building components.
The waste generation.

**SOLUTION - HYPOTHESIS**

Construct buildings made out of one fully recyclable material.
Disassembling will be a less complicated procedure.
Mass-recycling of only one material.
No or low waste generation.
MATERIAL SELECTION

Plastics: non-biodegradable material
in 2015: 6300 million tones of plastic waste & only 9% was recycled

Polyethylene Terephthalate (PET)
Has circular life-cycle.
Is widely used.
Exist in high quantities in plastic waste.
RESEARCH FRAMEWORK                      LITERATURE REVIEW                     DESIGN & EVALUATION                      FINAL DESIGN

RESEARCH AREA

GREEN ROOF

TINY HOUSE

UP-CYCLE

WASTE

TINY HOUSE

Material layers

Green roof

Roof

Tiny house
RESEARCH QUESTION

What is the feasibility of forming a self-sustaining, mono-material and multi-functional green roof system out of rPET?

HARD ASPECTS

100% recyclable
create a building component out of one material
ensure the plant survival

SOFT ASPECTS

integrate structural function
improve the indoor comfort
decrease of the heating and cooling energy consumption of the building

NOT RESEARCHED

a better material selection
acoustical analysis
structural optimization
fire-safety requirements
multi-functional

thermoplastics: shaping flexibility thermal & structural properties

limitations: manufacturing time printing quality size

it is essential to re-think the design
ADDITIVE MANUFACTURING

- digital data
- successive material addition
- material extrusion is used for thermoplastics
- optimize shape to reduce materials usage and printing time

RPET

- very good tensile strength
- very good impact strength
- the excellent process-ability
- clarity
- reasonable thermal stability
- UV sensitive
3D - PRINTING

- printing direction
- printing speed
- printing temperature
- overhangs & bridges
- workspace
- printing width & layer height
- material extrusion
- tool-path design

RESEARCH FRAMEWORK
LITERATURE REVIEW
DESIGN & EVALUATION
FINAL DESIGN
VEGETATION IN BUILDING ENVELOPE

GREEN WALL SYSTEMS
GREEN ROOF SYSTEMS
SELF-GROWING VEGETATION
GREEN WALL SYSTEMS

Green facade
- Traditional
  - Continuous Guides
  - Modular Trellis
- Living wall system
  - Lightweight screens
  - Trays, planter tiles etc.

GREEN ROOF SYSTEMS

Extensive
- Soil thickness < 15cm
Intensive
- Soil thickness > 15cm

SELF-GROWING VEGETATION

Encouraging factors:
- high moisture levels
- bird excrement
- accumulation of soil dust and organic materials

Dis-encouraging factors:
- texture
- pH
- nutrients levels
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SELF-GROWING VEGETATION

- Encouraging factors: high moisture levels, bird excrement, accumulation of soil, dust and organic materials
- Dis-encouraging factors: texture, pH, nutrients levels
<table>
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<th>WHAT?</th>
<th>WHY?</th>
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<tr>
<td>VEGETATION</td>
<td>Suitable plant community according to substrate.</td>
</tr>
<tr>
<td>GROWING MEDIUM</td>
<td>Medium in which the plants are established.</td>
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<tr>
<td>EROSION PROTECTION</td>
<td>Stabilize the soil. Roots’ aeration.</td>
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<tr>
<td>FILTERING &amp; DRAINING</td>
<td>Drains the excess water from the substrate. Filters the substrate from the water.</td>
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<tr>
<td>WATER RETENTION</td>
<td>Acts as passive irrigation system. Stores standing water under the substrate.</td>
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<tr>
<td>ROOT BARRIER</td>
<td>Blocks roots to pass through. Protects the layers underneath from root penetration.</td>
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<tr>
<td>WATERPROOFING</td>
<td>Do not allow water to pass throughout. Avoid any water damage in the structure.</td>
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<tr>
<td>THERMAL INSULATION</td>
<td>Ensures the thermal insulation of the roof.</td>
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<tr>
<td>STRUCTURAL LAYER</td>
<td>Supports the layers of the green roof. Act as structural support of the roof against all the applied forces.</td>
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The hydraulic behavior of the substrate is essential for the plant survival, and can be summarized in following steps:
- Rainwater is store in the field capacity of the soil [17].
- Once the moisture level of the soil reaches its field capacity the run off starts, but in small quantity [17].
- After a short amount of time, the run off gets equal to the rainfall [17].
- When the rain stops, the excess water in the substrate is drained by gravity [17].
- 50%-90% of the rainfall is retained, depending on the local climate conditions and the rainwater drainage provision [10].

Also, an efficient substrate should absorb and retain water, absorb and supply nutrients, have free-drainage properties, retain volume over time and provide anchorage to the roots and is lightweight, free-drainage and well aerated [12,38]. Research showed that the root aeration can be optimized by limiting the effective depth of the growing medium to the maximum plant roots depth [45] and air should be around 20% of the substrates total volume [12], so that the appropriate porosity of the substrate can be achieved. The thickness and water capacity of the substrate depend on its porosity and affect positively the thermal insulation properties [15]. The same applies also for the phenological conductivity, since it depends on the particle size distribution. The higher the percentage of the large particles (>1mm) is the higher is the hydrological conductivity [41]. Finally, the overall shape of the substrate may add functions to the system. For example, mountainous shapes encourage insects and birds habitat, like in the brown roofs [12].

The substrate layer contains following material layers from the bottom to top:
- granular materials: These materials are almost the same that are used in the drainage layer. They absorb water and create pores in the mixture. The most used materials of this type are extracted from the waste or already are down-cycled materials, like crushed clay bricks and furnace or incinerator waste [12,38]. In figure below, an overview of their characteristics can be seen.
- fine particles: Like sand [14]. They are necessary so that the water clings on them [12,38]
- organic matter: Such as peat moss and coir. This type of material can be found in low proportion, but is valuable because of its water retention properties and nutrients availability [12,38]. Specifically, no more than 20% of the total volume, so that fire risk is reduced, decomposition and oxidation shrinkage is minimized, and leaching of excess nutrients is avoided [12,41].

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The soil-based green roof system, because of its low weight, but not used as widely due to the fact that it dries out faster and depends on a regular nutrient supply. The soil-based one is called substrate and like in the brown roofs, it encourages insects and birds habitat, for example, mountainous shapes. Crushed clay bricks and furnace or incinerator waste are examples of cycled materials, like crushed clay bricks and furnace or incinerator waste. This system can be used as an example of how to integrate different materials into a green roof system.
VEGETATION

GROWING MEDIUM

EROSION PROTECTION

FILTERING & DRAINING

WATER RETENTION

ROOT BARRIER

WATERPROOFING

THERMAL INSULATION

STRUCTURAL LAYER

L=4m

weight load of rPET, saturated substrate, plants, stored water & snow load & live load

\[ \delta_{\text{MAX}} \leq 8 \text{ mm} \]

\[ 21.1 \text{ MPa} \leq [\sigma_1, \sigma_2] \leq 10.3 \text{ MPa} \]
Material positioning

Thermal requirements

\[ R \geq 6.0 \text{ m}^2\text{K/W} \]

\[ r_{th\_ins} \geq 5.36 \text{ m}^2\text{K/W} \]

Structural requirements

VEGETATION

GROWING MEDIUM

EROSION PROTECTION

FILTERING & DRAINING

WATER RETENTION

ROOT BARRIER

WATERPROOFING

THERMAL INSULATION

STRUCTURAL LAYER
VEGETATION

GROWING MEDIUM

EROSION PROTECTION — E

FILTERING & DRAINING — D

WATER RETENTION — C

ROOT BARRIER — B

WATERPROOFING

THERMAL INSULATION — A

STRUCTURAL LAYER

Bridging failures

Thermal conductivity

100 %

75 %

50 %
THERMAL INSULATION

STRUCTURAL LAYER

VEGETATION

GROWING MEDIUM

EROSION PROTECTION

FILTERING & DRAINING

WATER RETENTION

ROOT BARRIER

WATERPROOFING

<table>
<thead>
<tr>
<th>Name</th>
<th>Height (m)</th>
<th>Max. deformation (cm)</th>
<th>$\sigma_1$ (MPa)</th>
<th>$\sigma_2$ (MPa)</th>
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<tr>
<td>B1</td>
<td>0.41</td>
<td>14.3</td>
<td>-66.9 to 183.0</td>
<td>-170.0 to 65.1</td>
</tr>
<tr>
<td>B2</td>
<td>0.60</td>
<td>7.5</td>
<td>-52.1 to 147.0</td>
<td>-133.0 to 51.1</td>
</tr>
<tr>
<td>B3</td>
<td>0.80</td>
<td>5.0</td>
<td>-44.2 to 131.0</td>
<td>-113.0 to 44.5</td>
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<tr>
<td>B4</td>
<td>1.00</td>
<td>3.9</td>
<td>-39.2 to 123.0</td>
<td>-99.4 to 40.8</td>
</tr>
<tr>
<td>Required</td>
<td>0.8</td>
<td>- 21.1 MPa ≤ $\sigma_1$, $\sigma_2$ ≤ 10.3 MPa</td>
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STRUCTURAL LAYER

GEOMETRY A

Geometry A >0.41m

Similar to geometry B

Geome trying B
VEGETATION

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WATERPROOFING

THERMAL INSULATION — A

STRUCTURAL LAYER

bridging demands

water- / airtightness

root proof

Geometry A

Geometry A
VEGETATION

GROWING MEDIUM

EROSION PROTECTION — E

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WATERPROOFING

THERMAL INSULATION

STRUCTURAL LAYER — A

4 x layers of 0.4 mm height

1 x bridging layer of 0.8 mm height

Geometry A (gyroid shell structure)
VEGETATION
GROWING MEDIUM
EROSION PROTECTION
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WATER RETENTION
ROOT BARRIER
WATERPROOFING
THERMAL INSULATION
STRUCTURAL LAYER

RESEARCH FRAMEWORK
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Geometry A
Geometry B
Geometry C

13.5 l/m²
watertightness
remove excess water

resistance against ice expansion
transfer of structural loads

Geometry C
Geometry B
Geometry A
VEGETATION

GROWING MEDIUM

EROSION PROTECTION — E

FILTERING & DRAINING — D

WATER RETENTION — C

ROOT BARRIER — B

WATERPROOFING

THERMAL INSULATION — A

STRUCTURAL LAYER

3D-printability in small scale
1 x bridging layer of 0.8 mm height

Geometry C

4 x layer of 0.6 mm height
4 x layer of 1.2 mm height

Geometry D

VEGETATION
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WATER RETENTION — C
ROOT BARRIER — B
WATERPROOFING
THERMAL INSULATION — A
STRUCTURAL LAYER

integrate openings

transfer of structural loads

Geometry E
Geometry D
Geometry C
Geometry B
Geometry A
Functional layers:
ST: Structural
TH: Thermal
WP: Waterproofing
RB: Root barrier
WR: Water retention
DF: Draining & Filtering
EP: Erosion protection
GM: Growing medium
VG: Vegetation

PRS: printing settings
VEGETATION

GROWING MEDIUM

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Geometry A

Geometry B

Geometry C

Geometry D

Geometry E
THANK YOU