Bio-active concrete tile

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Abstract. The aim of this work is to design and fabricate bio-active concrete tiles which encourage rapid plant coverage of building walls and urban spaces with vegetation. A design comprises two different types of tile, which one of them intends to be used as a planter for a variety of climbing vegetation. Through the process of designing and manufacturing suitable mould for tiles, a complex macro pattern was developed to ensure water retention on the structural surface. The results of this work provide an alternative solution to the existing green wall systems by implementation of a bioreceptive cementitious material.

1. Introduction

Today, more than half of the world's population live in the cities. With the rapid growth of the population, this number is still increasing and the situation in the urban areas are getting worse. Cities have become a huge built impervious environment, and they are facing enormous problems connected with the loss of natural green areas. A dense city infrastructure leaves no space for implementing the greenery on a ground level. This has resulted in the high demand for the green walls and roofs since they required little or no ground space. In particular, the living walls effectively uses vertical spaces as an opportunity for greenery. Their environmental and health benefits, as well as appealing aesthetics positively influence life in the urban area and lessen the environmental impact of the city. Unfortunately, the problem regarding these living walls rests on their usually very costly and demanding maintained system. The plants need a supporting structure with the complex watering system and sometimes the costs might outweigh the benefits. Therefore, an innovative new solution is needed. [1], [2], [3]

As opposed to the typical green walls a new approach of integrating the vegetation directly on the building surfaces has been developed. By altering the physical and chemical properties of traditional concrete a new type of biologically receptive concrete has been produced. This concrete encourages and sustain the growth of the microorganisms such as mosses lichens and algae directly on its surface and thus increases the cryptogamic cover of the material. The bioreceptive concrete supports a plant life to thrive on buildings in a way that is both more sustainable and more efficient than existing green walls. [4], [5] It brings an interdisciplinary approach of architecture, engineering and biology.

The aim of this work is to describe the design and the production technology of the bio-active concrete tile. The tile consists of two layers – the inner structural layer is made from concrete with the ordinary Portland cement and the outer bioreceptive layer is made from magnesium phosphate cement concrete to create an environment for plant growth. The production quality is also discussed and alternative solution is suggested.
2. Design and Production of the Tiles

2.1. Shape of the tile and numerical analysis

In order to maximize the green coverage and biodiversity, it was decided to combine two green walls technologies - green facades and green walls [6]. A vision to create a wall that will support climbing plants and at the same time serve as a module for pre-vegetated rich flora led to the decision of designing two types of tiles, Standard tile and Planter (Pocket) tile (figures 1 and 2). The size and shape of the tile units could be modified according to specific requirements of the area.

The tile represents an elevated 3D design for microflora to be established and proliferates on its surface. The tile consists of two-layered concrete. The structural layer is 10 mm thick, while the outer bioreceptive layer consists of multilevelled steps ranging from 5–20 mm. (figure 1)

![Figure 1. Shape of the Standard tile.](image)

The planter tile or so-called pocket tile represents the same elevated 3D design, however, the pocket for planting is added in order to keep a wide variety of plants and to control the density of greenery covering the walls. A structural part creates a pocket for seeding with the thickness 10 mm. The front face layer is designed to be out of the bioreceptive concrete with the thickness varying from 10–30 mm. The volume of the pocket is 3 litres which are suitable for providing enough soil for a variety of climbing vegetation. At the bottom of the tile two drainage holes were designed as a precaution for over-watering, as well as for decreasing the risk of damage from freeze-thaw action (figure 2).

There are two ways of attaching tiles to the building structure, adhering and anchoring. Tiles could be attached directly to the wall structure by wall tiles adhesives. However, due to the weight of the concrete tiles, the installation would be more complicated and precaution of the slipping should be in concern. With mechanical anchoring, the tile would be attached to the wall by a suitable anchor.

Numerical modelling in program SCIA Engineering was used to analyse the behaviour of planter tile under the load action of soil and water inside the tile. The tile was considered as fully fix supported on the backside. The lateral soil and water pressure were applied on the three sides of the tile and the vertical load on the bottom of the tile. There were considered following load cases: permanent load (self-weight, soil pressure) and variable load (water pressure).

Numerical simulation results were obtained for the main stresses at both surfaces of the tile. Greatest tension strength was 0.3 MPa and 0.9 MPa at compression at the inner surface. For the outer surface, the highest tension was 0.9 MPa and 0.1 MPa at compression.
2.2. Design and fabrication of tile forms

The planter tile was made out of flexible silicone rubber after mixing with the catalyst at normal room temperature. This silicone rubber is suited as a mould for casting of various materials, in my case for concrete.

Firstly, the envisioned tile model was made out of XPS material (figure 3). The model was placed in enclosed space and the silicon (Lukopren N1522) was poured into it. The hardened silicon created a front face and side walls of the tile form (figure 4). The inner fill for the designed hollow space of the pocket tile was made out of XPS and its surface was covered with a fluid sealant of Lukopren S3782 as a separation layer. This assembly was secured with clamps for rigidity and tightness of the form. The mould made out of silicon benefits from its easy unforming due to its flexible structure. However, the replica model has to be made very precise in order to obtain an exact shape that we wished for. Special care should be during the mixing of Lukopren with catalyst, where exact amounts are necessary for suitable form structure.

Figure 2. Shape of the Planter tile.

Figure 3. Model of Planter tile.

Figure 4. Silicon tile form.
Regarding the form for Standard tile, it was decided to use digital fabrication for this model. In a case of digital fabrication, digital data drives manufacturing equipment such as 3D printers, laser cutters and CNC machines, to form various geometrical shapes.

The first step was creating a virtual model of a tile form using Fusion 360 software (figure 5). The model served as an input for the fabrication tool, in my case CNC milling machine. (CNC - Konečný s. r. o) In the machine, the tool-paths were generated to guide the cutting tool (figure 6). A solid block of XPS polystyrene of thickness 80 mm was used for the fabricated model. The XPS block was shaped by removing material through cutting, drilling, boring and grinding (figure 7). The form was cut in the middle into two pieces for later easier unforming. The finishing layer of silicon sealant, Lukopren S3782, was used as a separation layer between XPS form and concrete.

One of the advantages of using digital fabrication is that it makes more precise shapes and details for a model which could be easily altered in the future if necessary. Work is more efficient and previewing and simulating the tool-paths prevents future problems during manufacturing. On the other hand, the design is limited to the size of the manufacturing machines and the thickness of the material.
By utilizing novel design and digital fabrication methods, multileveled surface and elevations were created to improve the facade performance. All of the designed formwork is repeatable and can be used for further series production.

2.3. Concreting of tiles
The concreting of the Standard tile was carried out in the two following phases. The first layer of magnesium phosphate cement concrete was poured. The substance had dry consistency and was spread across the tile form by hand, not to consolidate it much in order to maximize the porous structure. For the better bonding connection of two layers, the surface of magnesium phosphate cement was roughened. After that, the second layer of ordinary Portland cement concrete was poured on top of it. The anchor with bolt was embedded into the fresh concrete (figure 8).

Figure 8. Concreting procedure of Standard tile.
The Planter tile was concreted in a horizontal position. The first layer of magnesium phosphate cement concrete was placed into the silicon form. Right after, the XPS pocket form was placed and attached in the form, leaving a free space of 1 mm underneath. The mixture of ordinary Portland cement concrete needed to be very fluid in order to fill the space beneath the XPS form. The problem became when the concrete was filling the space under the pocket form and at the same time started to uplift form from its position. As a result, an alteration of the form was necessary and the four points, for pressing and holding the form in the right position, were installed. This has created the four holes on the tile backside. Another problem becomes while unmolding the tile. The inner part of the tile form was not able to be taken off. Therefore, it was necessary to dig it out (figure 9).

![Concreting and removing of Planter tile form.](image)

3. Results and Discussion of Production Quality

In the end, two types of bio-active concrete tile were fabricated - Standard tile (figure 10) and Planter tile (figure 11). Both tiles are made out of two-layered concrete. Layers can be distinguished due to their different colouring. The first, structure layer made out of ordinary Portland cement with the reinforcement of dispersed PVA fibers has grey colour adjusted by the presence of microsilica. The second, bioreceptive layer of magnesium phosphate cement mixture was successfully designed in
order to support microorganism growth on its surface. The brown colour of the layer is due to the natural colour of magnesium phosphate cement. The colour of tiles could be altered by concrete pigments, or by addition of microsilica.

Figure 10. Standard tile.

Figure 11. Planter tile.

As a result of complications during the concreting of Planter tile, few imperfections were detected (figure 12). The ordinary Portland cement mixture did not entirely pass under the inner part of the tile form, creating a small area with only one layer of magnesium phosphate concrete.

Another unexpected result of concreting is the presence of four holes caused by fixing of inner form against the uplift. However, these holes could be used for anchoring of the tile as well for the drainage of water at the bottom of the tile.
To overcome the problems in the future, an alternative solution for tile manufacturing is suggested (figure 13.). The new inner part of tile form is hollow and made out of wood. The concreting of the tile will be proceeding in a vertical position for better form fixing and space controlling around the inner form.

![Image](image1.png)

Figure 12. Defects of Planter tile.

![Image](image2.png)

Figure 13. New form for Planter tile.

4. Conclusion

This work presents an alternative to the traditional green wall systems by designing and producing a bio-active concrete tile. The tile is made of two concrete layers, a structural (load-bearing) layer and a bioreceptive layer. Two types of a tile were designed. One is of the regular flat shape and the other serves as a planter box enabling growth of variety of plants.

An environmentally driven design with a multileveled surface structure creates suitable niches for plant embedding and at the same time increases the ability of the climbing plants to adhere to the surface of the wall. Moreover, the combination of various elevated steps helps to retain and accumulate water necessary for bio-colonisation.

Regarding manufacturing of the tile moulds, the digital fabrication, which utilized CNC milling for shaping the XPS-based moulds, proved to be very effective and precise compared to the hand-made silicon forming which required tedious modification due its imperfection. A disadvantage of the digital fabrication was its manufacturing dimensional limitations. The advantage was the precision of
CNC milling which ensured desired angling the sides of the moulds so that the moulds could be reused for further concreting.

The tiles will be installed in the outdoor environment for observation of plant coverage development as well as to analysed the long-term performance of the tile. Further investigation would be necessary for evaluating the benefits of the entire wall composed out of the bio-active concrete tiles.

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