Structural soil in dense city areas - functions and chances for urban greenways development

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Introduction

The densest parts of cities, parts with the most infrastructure, are losing green areas and trees. The majority of urban site conditions for trees often do not provide them with enough opportunity for healthy growth and development and allow only a few years of vegetation. Visible symptoms of health issues in trees are usually lesions within the crown or stem and are mainly due to the impact of unfavourable factors which have been exerted upon the root system. The most severe causes of poor health in trees are associated with the intense growing environment in urban areas and damaging impact of anthropogenic activities, which affects the properties of the soil environment. Since the 1970s researchers worldwide have been looking for new techniques. During this time are being researched techniques, the application of which would allow the proper development of trees in difficult urban sites, growth comparable to that these trees would experience in their natural habitat. In recent years, throughout Poland there has been an increase in awareness of the high value of trees in urban areas and necessity of using alternative methods of planting to sustain growth. Attempts to solve the problem of short-lived trees in towns and cities have included efforts to provide maximum space for tree rooting along with developing solutions to prevent compaction of the soil. Technology that would potentially provide a solution to both problems may be to use a structural substrate.

Background

Human activity has resulted in; the appearance of a large built-up urban areas, which are not biologically active; a presence of dense underground infrastructure network; formation of impermeable surfaces which imped the access of oxygen and water to the roots of trees (Mullins 1991; Craul, 1994). A strong human intervention within the urban landscape leads to the formation of anthropogenic soils with characteristics that hinder proper growth and development of vegetation, particularly for trees. Soil degradation is an irreversible process, because there is no effective and fast method to restore its structure and properties. The effects of construction work are the negative impact on the soil and the root system of trees as well, mechanical damage and soil compaction (Suchocka, 2009; Suchocka 2010). The development of the tree roots is dependent upon favorable conditions allowing steady growth, since only a thin, continuously growing feeding roots have the ability to absorb water and minerals (Szczepanowska, 2001). Gilbertson and Bradshaw (1990), reported that 23% of newly planted trees in Liverpool had died after three growing seasons. The presence of a limited volume of soil and increased compaction of said soil are considered as the main stress factors eliminating the possibility of long term health and safe growth of trees. One of the most important factors is soil density. Mullins (1991) states that for many soil types, root growth is seriously limited when bulk densities exceed 1.6 g/cm3 and the common situation is that soil in urban areas is compacted more, especially close to roads.

In order to introduce trees in hard site conditions, often in places where it would be impossible for trees to survive, different anti-compression systems are tested in terms of their beneficial effects to tree vitality (Smiley at. all 2006, Buhler at. all 2007, Trowbridge Bassuk 2004). In Poland attempts have been made to apply solutions that were supposed to provide proper habitat conditions for trees. The analysis of chosen techniques between 1999-2012, barriers, opportunities and appropriateness of their use in Poland were all measured (Suchocka, Milanowska 2013). This allowed the identification of methods which have long term beneficial effects to trees planted in limited urban soil, the application of which would affect extension of tree's life spam. The studies have compared the expenses for tree care with those of each technical solution and an assessment of the trees condition at the end. Tests showed that the use of load-bearing stone-soil blends had the best impact on vitality, chances of survival and lengthening of a tree's life span. This is confirmed by other studies. Smiley reported, that the second best twig growth rate on elm trees was found in the gravel/soil treatment and it was nearly equal to the non-compacted treatment. The structural soil idea was described and tested by Grabowski and Bassuk (1995). In Poland professional structural soil has not been applied on a production scale, except of one attempt in Poznań (Suchocka, Milanowska 2013), therefore work on the technical specifications based on local substrate materials are pioneering.

Barriers to the application of the gravel/soil method reported by people involved in the decision making process; architects, public officers and builders, include in their opinion higher costs of the planting technology as well as the non-standard, therefore problematic in implementation, solutions (Suchocka, Milanowska 2013).

Goals and objectives

In the presented studies, work was undertaken to develop load-bearing stone-soil blend technology. The scope of work included the development of technical parameters of aggregates used for construction of structural soil and mineral-organic substrate to fill skeleton (supporting layer surface) of that anti-compaction system. The field test was conducted to define technical features and difficulties in the installation of structural soil built as a load-bearing stone-soil blend. In Poland this method is not used as a standard solution owing to the popular belief that the cost of certificated materials from foreign producers is too high and there lack of sufficient technical ability in construction by this method. The aim of work was to disprove these commonly held Polish beliefs and test if an urban greenway made from structural soil based on local, commonly used materials is both econmonically viable aswell as being able to provide an easily appliable method to increasing the lifespan of trees in urban areas.

Method

The work involved, identify the optimal aggregate and substrate parameters as well as determining the optimal construction technology of the structural substrate and its bearing capacity. As a result of the analysis an optimal pH, abrasion, frost hardiness, resistance to crushing and water absorption was identified. During the anaysis aggregates were selected which fulfilled the technical conditions and structural soil prototype was tested in laboratory tests and load (VSS test) in the field. The experimental section had dimentiones 5x5,5m. On the basis of these studies and field tests the production requirements were developed. The experimental section was prepared using the following profile: 20 cm of aeration layer build by crushed dolomite 31,5-63 mm stone and 30 cm of vegetation layer build of 63-120 mm gravel. The vegetation layer was filled with water (washed down) by 25-30% mineral-organic substrate. Every structural soil layer was tested on the experimental plot separately with the use of VSS method in order to determin the load bearing capacity and depending on that parameter possibility of use in urban areas.

Results

The structural substrate comprises of a blend of substrate and aggregates. Crushed stone forms a frame, which supports the construction of the pavement’s surface. The use of Mac Adam's aggregate, that is crushed, ensures stability and at the same time creates empty spaces for penetrating feeding roots that allows for the movement of air and water. The friction between the aggregate ensures the durability. In the profile vegetation layer (fraction 31,5-63 mm) is located directly on an aeration layer of 63-120 mm fraction. Such a layout provides a uniform system of high porosity after compacting. The use of broken stone increases the porosity further.

Table 1 Comparison of crushed stone technical parameters form Komorniki and Bukowa Góra mine

Characteristics	Komorniki	Bukowa Góra
pH	7,8	6,59-7,8
abrasion, MDE	26,3-33,0 (MDE 35)	12 (MDE 20)
resistance to crushing, LA	31,6-35,7 (LA 40)	24,5 (LA 25)
the density of grains, Mg/m3 qa qrd gssd	2,71 2,70 2,72	2,63 2,59 2,61
water absorption, %	0,6	0,7
frost hardiness, F%	-	0,1 (F1)

Crushed stone is a bearing element, therefore tests were carried out on the stone, chosen as one which meets regional standards regarding the stability and strength of grains, determined for the basic requirements for roads and pavements construction. The second basic parameter determining feeding roots growth is pH level, it must range between 3,5-8,2. Two local mines Komorniki i Bukowa Góra were identified for tests on the basis of technical agrreates parameters analyses. Basic parameters of aggregates from both mines such as abrasion, frost hardiness and water absorption are more than sufficient in terms of strength and durability to use rock from these mines as road bases. To the experimental section was used crashed stone from the mine in Komorniki, because its pH was uniformed and amounted to 7.8, while the aggregate from the mine in Bukowa Gora had a pH in the range 6,59-7,8 (not all grains had the same pH).

The chosen substrate which was used for the test meets the requirements concerning suitable pH for plant growth, which oscillates in the range 5.0-6.5.

The recommendations (Alven et al. 2009) also set the value of certain microelements and the substrate should include phosphorus in the range 40-80 mg/dm^3, potassium 80-160 mg/dm^3, magnesium 40-80 mg/dm^3. The used substrate contains 25 mg/dm^3, 235 mg/dm^3, 129 mg/dm^3 of these elements, so there is little need for phosphorus suplementation.

The substrate should guarantee a good habitat for tree rooting and at the same time meet the requirements for load bearing capacity in areas with heavy traffic. These criteria are met, when the skeleton of the structural material is filled with a substrate, in which the clay content does not exceed 8% by weight of (Alven et al. 2009), therefore for the field test a substrate with such properties was prepared.

The process of filling the substrate into the vegetation layer with use of water is most effective when the thin layer of substrate is applied onto a surface with a thickness of 1 cm and this operation is repeated until full filling the space between the grains of aggregate (fig. 1).

To the structural substrate should be added a slow release fertilizer. In the test there was the manual application of Plantacote 8M fertilizer which decomposes over a period of approximatly 8 months. It is a slow acting fertilizer, containing magnesium and trace elements. Plantacote fertilizer is a granulate mineral salt coated with a thin layer of material, operating through the permeable membrane. Individual granules of fertilizer relise minerals after absorbing water which penetrates into the interior of the grain and dissolves the minerals contained therein. The dissolved minerals penetrate slowly through the coating to the soil where they are taken up by the plant roots. The type of substrate, its pH, salinity and humidity have no direct impact on the rate of release of minerals.

Figure 1. Filling the vegetation layer with substrate using the water

As mentioned before to test have been used the following aggregates: (1) fraction of 63-120 mm (aeration layer of 30 cm) (2) fraction 31,5-63 mm (vegetative layer - 20 cm). Both layers were compacted using a vibrating plate followed by the VSS load bearing capacity test (fig. 2).

The result of VSS test on 30 cm layer of 63-120 mm fraction coarse aggregate have shown that the bottom layer of the structural soil withstands the load-bearing capacity of 80 MPa.

The upper layer of the structural soil, constructed by 20 cm of 31,5-63 mm aggregate fraction resulted in 130 MPa load capacity on this layer.

According to a study load capacity reached at the upper layer of the profile was E2 = 132 MPa, which testifies to the fulfillment of the requirements for the substructure under roads with heavy traffic E2> 120 MPa. In addition, the obtained deformation ratio (E2 / E1 = 2.18) provides the proper compaction of the layer. The top of the structural soil should be considered as base to the wear layer. On the subgrade will be sited the road surface suited to the character of the use.

The lower layer is also characterized by high load carrying capacity with a modulus E2 = 80 MPa. The measured deformation ratio E2 / E1 = 3.32 indicates that the layers are properly compacted. In the case of coarse clastic aggregates, and such has been applied to the lower layer, it can be assumed density criterion E2 / E1 <4.0 according to PN-S-02205.

Figure 2. Bearing capacity examination of coarse aggregate layer

Road subgrade is standardized in 3 classes of load bearing capacity, depending on the traffic load: (1) for "light" road traffic, load capacity of> 80 MPa. (2) for "average" road traffic load capacity of> 100 MPa. (3) for "heavy" road traffic load capacity of> 120 MPa. In the case of cycle, pedestrian and driving use E2 should reach the > 60 Mpa value (GDDKIA, 2014). The examination showed that the tested structural soil, based on dolomite as the crushed stone has a bearing capacity suitable for all types of road traffic. The material and installation of the pavement substructure is done with standard devices and in comparable time to traditional methods. Only substrate washed into skeletal stones requires additional work and takes more time.

Discussion

The structural soil has to fulfil requirements concerning physical and technical parameters providing proper bare load capacity and site conditions suitable for tree root grow. Incorrect reaction, i.e. high pH value, provides for an environment for alkalization which reduces the availability of mineral nutrients (Thowbridge, Bassuk, 2004). The optimal pH for the development of most trees is 5.5 - 6.3 (Breś, 2008). Watson (1995) and Coder (2000) determine the range of pH limits for root growth at 3.5 to 8.2. Accordingly, the pH of both the substrate and the aggregates is in a broader range but still in line with this.

However, the richness of the substrate in nutrients is different than in the recommendations (Alvem at all. 2009), which state that it should be 2-5% in weight of the dry weight of organic matter or 5-8% in weight of humus. The used substrate comprises 84% of organic matter, therefore its composition is modified by indigenous soil.

The substrate slightly exceeded the acceptable limit of salt concentration which should not exceed 1.0 ml of a salt dissolved in water, and which in case substrate being used is 1.11 g / dm^3. However, it should take into consideration the fact that the substrate used is not composed of loamy clay, as reported in Tree Planting Standards (Bloomberg 2008), and with a mixture of high peat, intermediate and low which resulted in a slight modification of its properties.

Conclusion

The product developed as a result of this research can be used for both newly planted trees and to improve habitat of the existing trees. The structural soil based on McAdams aggregate of crashed, angular stones should be an alternative to that previously used in the cities, which is an ineffective way of planting and maintaining trees in hard site conditions. This technology can be used both for newly planted trees near the pits designated for planting and existing young street trees (upto 30 years old) with low condition and slow growth as well. The structural soil may also be used for large street trees which have a shallow root system. Other situations where it is advisable to use structural soil are trees with roots uplifted on paved surface.

Establishing the pavement subgrade and compacting the layers should be done in a standardised way, which does not increase the costs of the whole system building. Additional and customized activity is the only process of mixing substrate into foundation layer by using water. In the case of construction in the root system of existing trees, an extra cost is also the need for customized diging of the trench in root system, which raises the cost of construction. However, it should be taken into consideration that trees planted in the ground are structurally viable and grow for a long time which reduces the cost of their care and eventual replacement. This method also allows an improvement in the habitat of the existing trees and extend their livespam.

Additional research should be done to standardise the substrate. Technical details also need developing, these details would include the development of modifications to curb installation next to mature tree root collar and drainage wells.

The technology of structural soil allows presents a viable case to tackle pressures from investors in the context of greenways protection. The knowledge of the most suitable technologies in terms of trees survival rate and costs is crucial in a proper tree management on hard site conditions and by limitation of space. Proper construction of greenways in difficult urban environment is a chance to keep trees alive and to deliver ecosystem services, like the improvement of: human health, comfort of living, water management and help to decrease pollution within city. Greenways support sustainable development and resilience of cities thanks to have trees within.

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