SmartSoils®: A decade of research on biological ground improvement

Introduction
Major leakage events during the construction of several underground constructions in The Netherlands in the late 1990s inspired researchers at Geodelft (now part of Deltares) to search for unconventional solutions: What if we could stimulate the soil to transform? What if the soil properties could be engineered on demand by stimulating natural processes? In situ? During and after construction? Without disturbing the soils functionality? This dream became the concept of SmartSoils, which Deltares launched in 2003.

Sealing leaks in water-retaining structures
In bioremediation projects in the 1980s researchers observed that when they injected nutrients to stimulate bacteria in the underground to break down contaminants, the biochemical conversions often led to local clogging of pores, which reduced the permeability and affected the transport of nutrients towards the contaminated sites. Embroidering on this experience, the idea arose to inject these nutrients in the proximity of a leaking construction. Converging groundwater flows would transport the nutrients towards the leak, where bacteria would induce clogging and reduce the flow rate through the leaking structure.

In 1999 GeoDelft started in collaboration with contractor Visser en Smit Bouw and Delft University of Technology a research project on this new method of biological sealing of water-retaining structures. Within 4 years the idea was developed from lab scale experiments to a field experiment. In this full scale experiment perforated sea containers were used representing small sheet pile supported excavations. The flow rate into a leaking construction (buried sea-container) was reduced by a factor 5 within 6 weeks and eventually by a factor 30. The permeability reduction remained for at least three months. In 2005 the technique was named BioSealing, and applied to stop leakages in natural clay and peat-layers that were damaged during construction of the aqueduct for the High Speed Railway Amsterdam-Paris (Van Beek et al. 2008) and recently a pilot has been carried out to seal leakages in levees along the Danube in Austria.

Microbes turning sand into sandstone in 12 days
In the mean time, it was observed that the embankment of existing railway lines suffered under dynamic loading and required extensive maintenance. Consequently, unpredictable interruption of services had to be accepted on these lines, but engineers wondered: Are there any alternatives? In 2001 a Dutch newspaper reported about research in Australia where bacteria were used to strengthen sand and renovate monuments. At first sight the possibility of microbial soil improvement sounded rather remote for civil engineers, however things got serious after a bag of sand was returned from Australia as a column of solidified sand, resembling calcareous sandstone. The bio-cemented sample, later named BioGrout, was extensively tested and one of the properties that caught the attention was the minor reduction in permeability, while it had gained an unconfined compressive strength (UCS) of several MPa. This is a unique advantage compared to traditional (chemical) grout injections where all pores are stuffed with cement, polymer gel or resin. In contrast to existing techniques, the preservation of permeability enables multiple treatments, the use of low injection pressures and obtaining a larger treated volume per injection point. BioGrout enables in situ treatment of soils.

Summary
Building on and in soft, unconsolidated soils involves large risks, as the behaviour of soils is difficult to predict. In 2003 Deltares launched the concept of SmartSoils: changing soil properties on demand by stimulating naturally occurring biochemical processes in the subsurface. Using microbial activity in the underground, methods were developed to seal leakages in water-retaining structures and cement sand into sandstone using waste as cement. This paper summarizes these SmartSoils developments and current investigations, which will be presented during the 17th ICSMGE conference (Den Hamer et al. 2009; Molendijk et al. 2009; Van Paassen 2009a, b).
investigated. Denitrification is one of these carbonate precipitation processes is being improvement for other microbial induced prepared. Meanwhile, the potential for ground strength up to 12 MPa (Van Paassen et al. 2009b).

Currently, suitable pilot projects are being development resulted in a 100m³ scale experiment, in which 40 m² of sandstone was produced within 12 days reaching unconfined compressive strength up to 12 MPa (Van Paassen et al. 2009b). Currently, suitable pilot projects are being prepared. Meanwhile, the potential for ground improvement for other microbial induced carbonate precipitation processes is being investigated. Denitrification is one of these processes. When nitrate is completely reduced, nitrogen gas is the only side product, emphasizing the sustainability of this new ground improvement method. (Van Paassen et al. 2009a).

**Strengthening peat?**

SmartSoils® research has resulted also in other innovative concepts such as strengthened sludge – a method to speed up hardening of dredged sludge so it can be used as a building material –, and biodegradable drilling mud to enable construction of horizontal water extraction wells. The latest idea involves biological strengthening of peat. Explorative experiments have shown that when a solution of silicates and sugars is mixed with peat, the silicate crystallizes on the peat fibers due to biological acidification, reducing the compressibility and oxidation potential of the peat significantly (Den Hamer et al. 2009).

**Conclusion**

Ten years of SmartSoils® research and consequential industrial scale up has uncovered numerous opportunities for adaptation of the engineering approach for complex constructions, building environments and ground conditions (Molendijk et al. 2009). Involvement of many different stakeholders, from industry, government and university proved essential for developments in such a cross-disciplinary field. Still, tenacious steps in coupled research and industrial scale up, for at least another five to ten years, are still required to expose and harvest the full potential of bio-geo-engineering.

**References**


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![Figure 3](image3.png) **Figure 3** The exposed cemented sandbody in the 100m³ BioGrout container test.

![Figure 4](image4.png) **Figure 4** Application of BioSealing in a dike along river Danube in Austria.

![Figure 5](image5.png) **Figure 5** Numerical simulation showing the normalized distribution of reagents in the 100 m³ BioGrout experiment after 10 hours of flushing corresponds with the contours of the cemented sand body.