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Indoor Climate Remediation Based on Multidisciplinary University Research Open Innovation - From innovation process to technical results

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Abstract

This paper describes the preliminary technical results of an untraditional innovation and development project that was initiated by the Capital Region of Denmark in August 2011. The on-going project named NYMIND aims at finding new and innovative ways of solving indoor climate problems in houses situated on contaminated soil and/or groundwater. The new approach was presented at the IKT13 Conference in Derry in April 2013: New Innovative Ways of Multidisciplinary University Research Based Open Innovation – Comprehensive case study within indoor climate remediation [4]. The project has now reached a decisive stage where two technical tracks, which show promising results, have concluded the pre-project phase and are in the process of being formulated as comprehensive research and development projects. The innovation process and the preliminary technical results will be presented here.

Key Words: Contaminated Soil and Groundwater, Indoor Climate, University Research Based Open Innovation, Multidisciplinary Team Innovation, Creative Tools for Innovation.

1. Background and Introduction

Denmark underwent a substantial industrialisation following the 2nd World War. The country now suffers from the effects in terms of environmental pollution. A large number of contaminated sites are left behind in the wake of this industrialisation, and groundwater – the primary source for drinking water in Denmark - is being or has already been contaminated at several locations. Based on this, remediation of the thousands of contaminated sites has been a top priority in Danish environmental legislation and management over the last 30 years. The Danish Regional Authorities have been the leading authorities within this area since 2007.

The Capital Region of Denmark covers the Greater Copenhagen Area in the eastern part of Zealand and contains the largest number of contaminated sites due to the heavy industrialisation around the capital in the 1950s and 60s. Following this, the Region has put a lot of effort in developing new, cost effective and intelligent solutions for cleaning up these sites with an annual budget around 1 million €. This has since 2007 resulted in substantial emphasis on innovation and development projects in cooperation with consulting engineers, entrepreneurs, and research and development institutions including universities. The overall and underlying strategy for this development process has been to develop solutions, which represent a full-clean-up, in the sense that the contamination at a site has been removed or neutralised. Based on this, a number of new and innovative remediating methods and processes have been developed for the so-called open sites – sites without constructions above the pollution.

A substantial number of houses have subsequently been built on contaminated site in the Greater Copenhagen Area, which makes it very difficult to apply the full-clean-up concepts. On these sites toxic volatile gasses from the contaminated soil and/or groundwater create indoor climate problems in form of vapor intrusion through leaks in constructions and through sewers. Therefore, a special innovation and development process for these sites was launched in 2009. This process however only provided a variety of incremental innovations in terms of refining and further developing already known methods and processes. The result was fairly traditional abatement systems with no final solution to the problem and including the need for establishment of permanent monitoring systems. The solutions that were developed would be very costly and create daily nuisance for the people living in the houses. Furthermore, the buildings in question would be stigmatised in relation to daily use and functionality and future sale.

Based on this, the *Capital Region of Denmark* decided to search for new innovative ways based on the *full-clean-up* and *non-monitoring* basic concept. In consequence of this the *NYMIND Project – creating safe indoor environments* was born in August 2011 (NYMIND is a Danish abbreviation of *new methods for in-door climate* and plays on the English *New Mind*).The objective of NYMIND, which is on-going, is to plan an intensive and cross-disciplinary innovation process with the aim of identifying *once-and-for-all solutions* (the full-clean-up concept) to indoor climate problems created by contaminated soil and/or contaminated groundwater, where the major pollutant is chlorinated ethenes (CEs). We define *once-and-for-all solutions* as solutions with a maximum impact horizon of 5 years that will ensure a permanent healthy indoor climate with no need for further measures including monitoring.

Consequently, a new approach was required in order to deepen and broaden the innovation perspective based on the earlier more traditional approach, which did not give satisfactory results. For more details of the innovation process and the results of the first part of the project reference is made to [2, 3, 4]. Focus in these papers is on the further research and elaboration of the solution tracks coming out

of the said innovation process, and consequently which ones will be prioritised for further research and development and possibly prototyping, and finally full scale implementation.

2. The Innovation Process

The interested reader is referred to the previous mentioned paper, where a full description of the background for, the innovation concept and approach, and the planning and implementation of the innovation process is given. An overview of the full innovation process is given in Figure 1 below. As can be seen the 4th Core Group Meeting concluded that the following three tracks should be further investigated funded by the Capital Region of Denmark:

1. The symbiotic use of fungi and bacteria for degradation of the contaminant should be further investigated through literature and field work.
2. The injection of dissolved minerals for barrier creation on top of the contamination should be further investigated through modelling and lab work.
3. The establishment of intelligent ventilation for removal of in-house toxic volatiles should be further investigated through literature and field work.

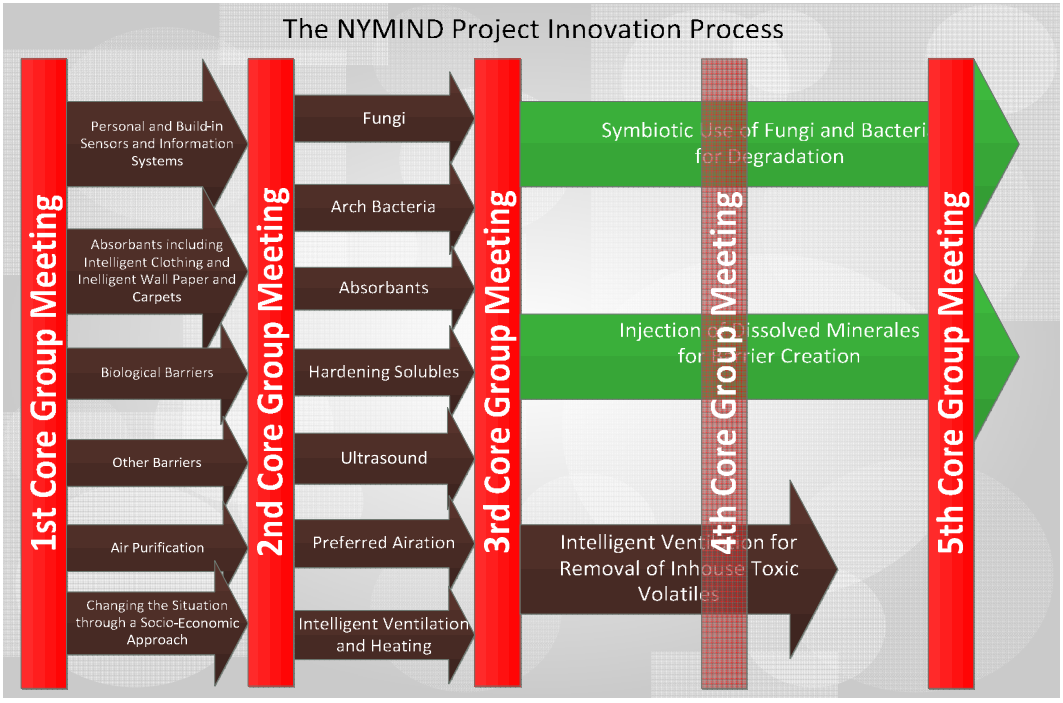

Figure 1: The NYMIND Project Innovation Process

The pre-project period was concluded in December 2013 with the 5th and last Core Group Meeting (se Figure 1 on the previous page). During the course of the pre-project period the ventilation track (Track 3) was abandon on the basis of a comprehensive literature research report, which revealed that technical solutions within this track could never meet the basic requirements namely that it should be a *once-and-for-all solution* with no monitoring. Consequently this track was closed in August 2013.

The two other tracks were completed successfully in the beginning of 2014 with research reports based on literature review, modelling work and laboratory work. In the following is given an overview of the research done, which is promising in relation to formulating and launching full research projects, and which could possible lead to practical solutions. Consequently this paper focuses on the technical results coming out of the innovation process while the INKT13 Paper focused on the innovation process. For specific lessons learned in relation to the innovation process reference is made to the INKT13 Paper. The further innovation process since the INKT13 Paper only confirmed the lessons learned and the conclusion from the said paper. Especially the need for seasoned process as well as innovation consults for these kinds of ground breaking innovation processes, and the importance of the visualisation part. Further it confirmed that the non-topic scientist approach gives viable results which were not provided by topic scientists. Results, which afterwards was confirmed as promising by practical topic specialists.

This is basically an innovation process and knowledge transfer paper. For technical details concerning the results of the two pre-projects including the literature review, the modelling and the lab work, the technical interested reader is referred to the technical pre-project background reports [1, 5]. Unfortunately these are presently only available in Danish, but interested parties can contact the corresponding author with technical questions.

3. Solution Tracks

The basic problem that the innovation process is addressing, and which is described in the beginning of this paper, could basically be illustrated as given in Figure 2 overleaf. A house is situated on contaminated soil and/or ground water and toxic volatile compounds seeps into the house and creates an unhealthy indoor climate. The aim is to prevent this by applying the basic principle for the NYMIND Innovation Project. Namely that it should be a *once-and-for-all solution* with no need for further measures including monitoring. As shown in Figure 1 overleaf the innovation process has identified two different solution tracks, which have been researched:

- The first track is a *Barrier Track* in the sense that this track aims at creating a barrier between the house and the contamination by injecting selected dissolved minerals, which will precipitate to create a compact layer/horizon

above the contamination through which the flux of contaminants will be limited to acceptable levels.

- The second one is a *Degradation Track* in the sense that a soil environment is created above, in, and around the contamination, where fungi and bacteria in symbiotic co-ordination degrade the contaminants in question.

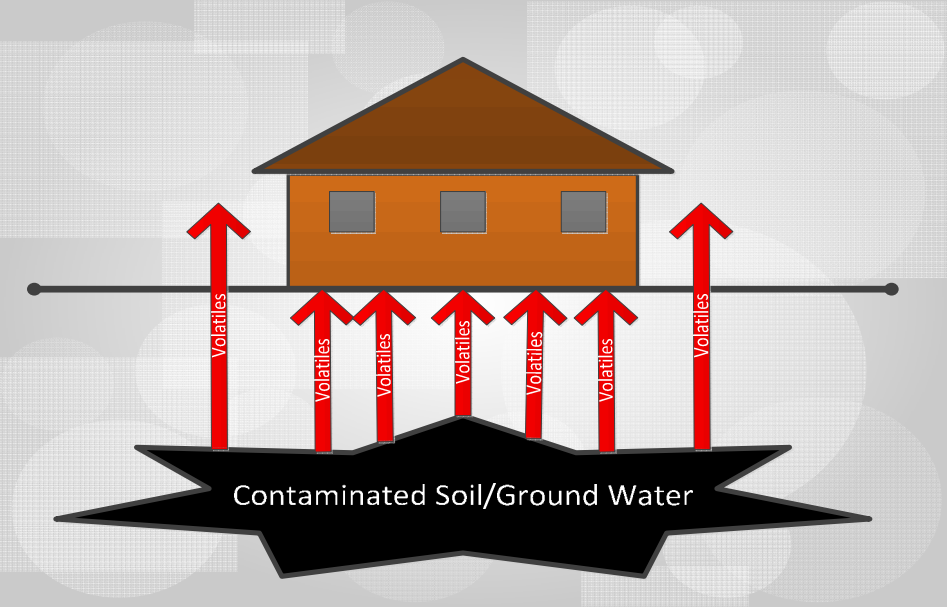

Figure 2: The NYMIND Innovation Problem

In the following is given the research results from the pre-projects of the above two solutions tracks. As mentioned previously it will focus on the solutions as results of the innovation process and not give specific and detailed technical information, which can be found in [1, 5].

4. Injection of Dissolved Minerals

The principle of the Minerals Barrier is illustrated in Figure 3 overleaf. The basic principle behind this track is that a mineral/geologic barrier is created in the soil over the contaminated soil/ground water by injecting different minerals dissolved in water in at structured sequence, which in the end will result in mineral precipitation in the soil pore volume. This will physically prevent the volatiles/vapour from entering the house through the floor by limiting the pathways in the soil for the volatiles to reach the bottom of the house. The technical principle concerning the sequenced injection is illustrated in the more technical Figure 4 overleaf.

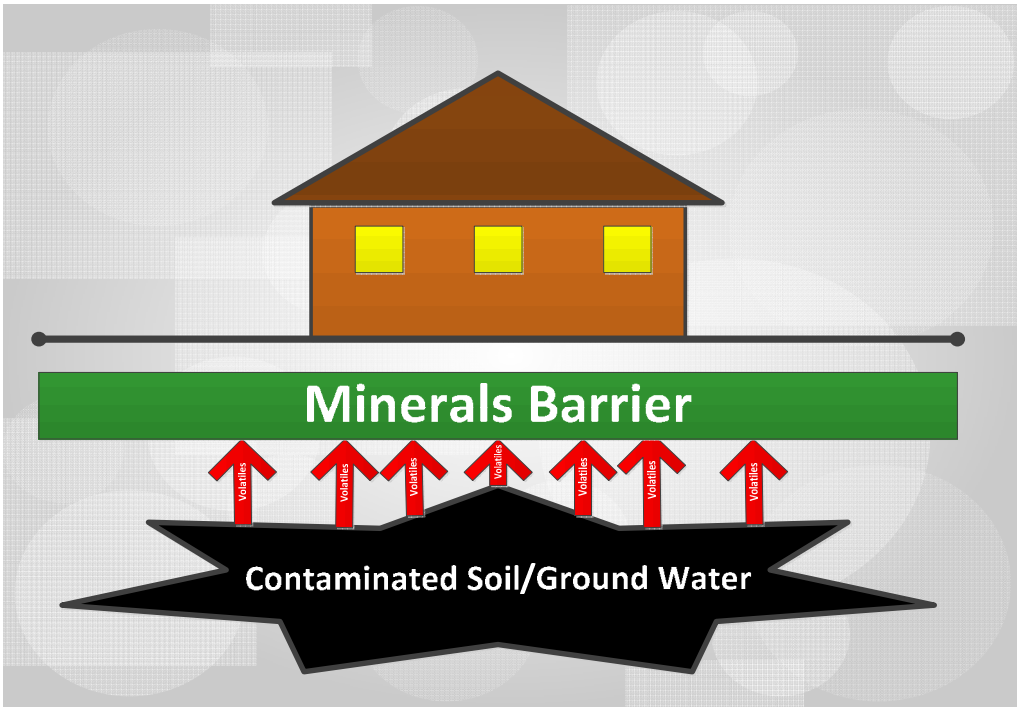

Figure 3: The NYMIND Minerals Barrier

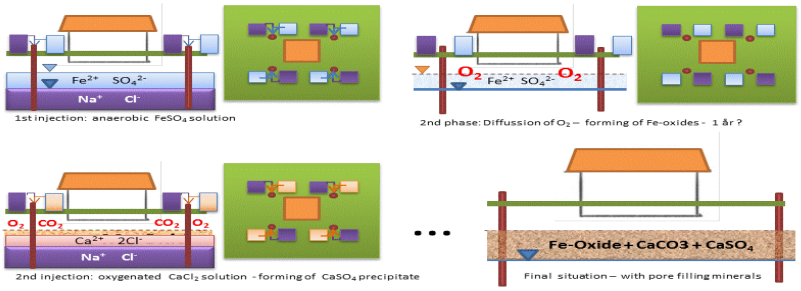

Figure 4: The Sequenced Injection

In a non-technical language the process is as follows concerning the sequenced injection:

- Firstly oxygen free water with dissolved iron compounds is injected in the layers above the contamination.
- Secondly this is left to react for maybe up to one year.
- Thirdly oxygen rich water with a dissolved calcium compound is injected in the layers above the contamination in order to interact with the sulfate left in the soil from the previous injection.
- Finally as a result of the injection sequence a barrier is created comprising Fe-oxides (rust) and gypsum, which clogs the pores of the soil forming the diffusion conduits, and consequently the toxic volatiles are to a certain extent prevented from reaching the house.

In this pre-project, which has been conducted at GEUS (The National Geological Survey of Denmark and Greenland), the above has been investigated by literature review, laboratory column tests and modelling. The results from this shows that it is possible to reduce the diffusive flux of gas in different kinds of soil normally found in Denmark (moraine clay and sand). In conclusion the method is so promising that is should be tested in real field situation not only in the laboratory. However, before that further laboratory test are needed.

5. Symbiotic Functioning of Fungi and Bacteria

The degradation track using the naturally occurring fungi and bacteria in the contaminated soil in a symbiotic way is illustrated in Figure 5 below. The basic principle behind this track is that the contamination should be degraded by a symbiotic working consortium of fungi and bacteria already available in normal soil. Consequently this will prevent the volatiles from entering the house through the floor. The symbiotic hypothesis is that CE tolerant fungi can grow in the contaminated soil by the spreading of their mycelia. The bacteria, which can degrade the CE, can be piggybacked on the mycelium of the fungi and in this way be transported to the contaminants, where they can do their work.

In this pre-project, which has been conducted as a pre-bachelor project at the Technical University of Denmark, the fungal tolerance to TCE and growth through compact moraine clay have been investigated by literature review and laboratory testing. The results show that fungal adaptation to the symbiotic bioremediation is feasible to the extent that these results justifies investigation of further more in-depth and comprehensive laboratory and field work concerning the fungi transportation part. Naturally this should be supplemented with the bacteria degradation part, which has yet to be started.

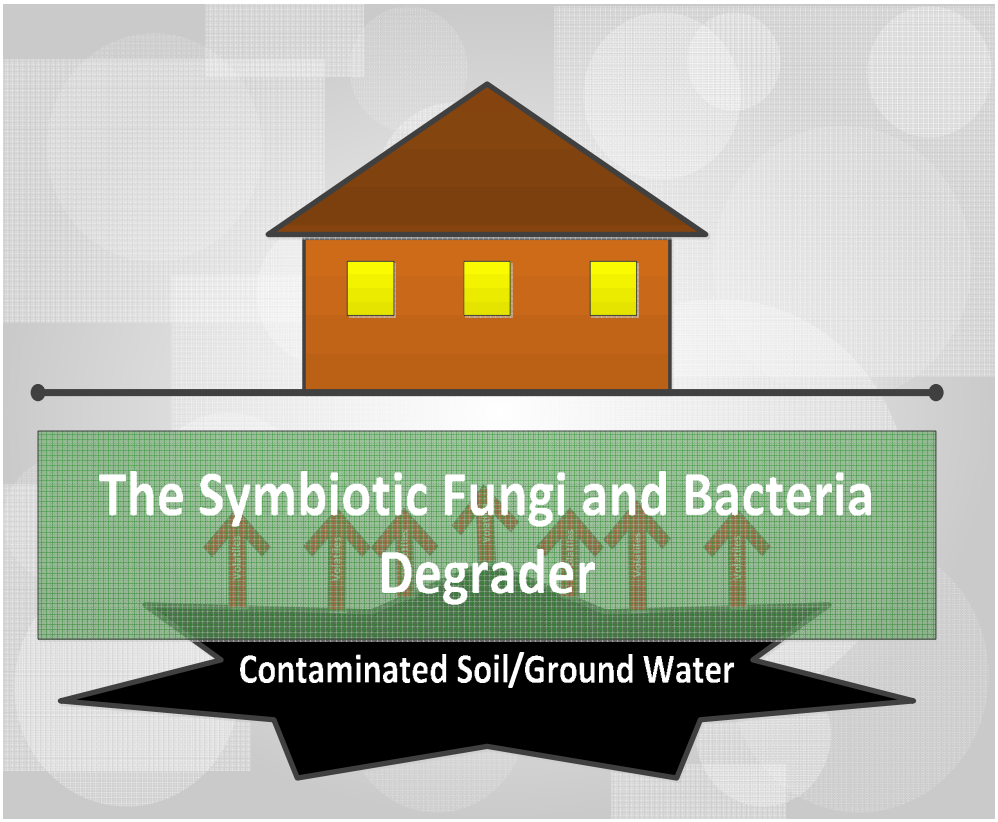

Figure 5: The NYMIND Symbiotic Fungi and Bacteria Degrader

6. Discussion and Conclusion

In the following is given a condensed summary, without the literature discussion, of the discussion and conclusion from the previous NYMIND Paper.

The NYMIND Project has been successful in establishing and facilitating a multidisciplinary innovation process based mainly of the work of non-topic scientists from Universities who are top scientists in their own field, but have never worked with soil and/or water contamination. The Project has in this connection been successful in relation to the fairly hard core selection and recruiting process based mainly on personal network. Application of a team with three facilitators all with technical and natural science background including the visualisation expert has shown successful.

One process consultant was responsible for overseeing and supervising the overall innovation process as well as supporting the innovation process at individual meetings. One innovation consultant was responsible for the innovation process at meetings using fairly simple innovation tools acceptable for the natural science

scientists. And last but not least an innovation visualisation consultant was responsible for continuously visualising the ideas, the discussion and the solution possibilities, and in this way facilitating and supporting the innovation process. This included the reporting of each meeting which was done cartoon wise. This concept was appreciated by the participating scientists and gave tangible results in terms of solution possibilities. These findings were confirmed through the further process as this continued with the above team approach.

With two innovative and untraditional solution tracks, which have shown promising results in the pre-project period, and which did not come out of a traditional innovation process, the NYMIND approach has shown its viability. Consequently this approach will, when feasible, be applied to other areas where there is a need for a broader and deeper innovation perspective.

7. References

[1] Jacobsen, R.: (2013) *NYMIND Phase III Project: Reduction of gas transportation by mineral precipitation. A short description of experimental results* (in Danish).

[2] Karlby, L.T. et al (2013). *Innovating Solutions to Prevent In-door Air Quality Problems Caused by Soil Contamination*. In: Proceedings of the AquaConsoil international conference in Barcelona, April 2013, Barcelona, Spain.

[3] Lønholdt, J.R. et al: (2012) *Next – Practice in University Research Based Open Innovation – from push to pull: case studies from Denmark*. Paper presented at the IKT12 Conference in Bournemouth, April 2012, Bournemouth Great Britain.

[4] Lønholdt, J.R. et al: (2013) *New Innovative Ways of Multidisciplinary University Research Based Open Innovation – Comprehensive case study within in-door climate remediation Next*. Paper presented at the IKT13 Conference in Derry, April 2013, Derry Northern Ireland. InImpact: The Journal of Innovation Impact.

[5] Nielsen, C.F.: (2014) *Isolation and Screening for TEC tolerant soil fungi. Pre-bachelor Project at the Technical University of Denmark* (in Danish).