Streamlined Life Cycle Case Studies: Utilising Surplus Soils in Civil Engineering Applications in Three Different Pilot Cases

Tarja NIEMELIN[1*], Marjo RONKAINEN[1], Kata KREFT-BURMAN[2], Juha FORSMAN[2], Mikko SUOMINEN[3]

[1] Ramboll Finland, Vohlisaarentie 2B, 36760 Luopioinen, Finland
[2] Ramboll Finland, PL 25, 02610 Espoo, Finland
[3]City of Helsinki, PL 1508, 00099 Helsingin kaupunki, Finland
** Tarja Niemelin: Vohlisaarentie 2B, 36760 Luopioinen, Finland, tarja.niemelin@ramboll.fi*

Abstract

Streamlined Life Cycle Assessments were performed for three construction sites; Dog Park (Espoo), Arcada (Helsinki) and Jätkäsaari (Helsinki). The pilots were carried out in the framework of the LIFE+ ABSOILS project (Sustainable Methods and Processes to Convert Abandoned Low-Quality Soil into Construction Materials). The project concentrated on the utilisation of surplus soils and fly ash in civil engineering applications. The low quality soft soils in the pilots were stabilised with fly ash and cement and hereby the geotechnical quality of the soils was improved. In the LCAs, the stabilisation with fly ash was compared to stabilisation with pure cement and to a conventional method. The results show that the use of fly ash as a binder in stabilisation exerts less environmental impacts compared to the use of cement.

The ABSOILS project has been carried out in co-operation with Lemminkäinen Oy, Rudus Oy and Ramboll Finland Oy. The project is supported by the cities of Helsinki, Espoo and Vantaa as city developers/constructors and the Ministry of the Environment. The aim of the project is to decrease landfilling of usable materials and the depletion of virgin natural resources. The project is co-financed by the EU LIFE+ Environmental Policy & Governance programme (LIFE09 ENV/FI/000575).

Keywords: life cycle assessment; surplus soils; waste utilisation; mass stabilisation

1 Introduction

Surplus clays are a major problem in the capital region of Finland (cities of Helsinki, Espoo and Vantaa). The low quality clay, silt and mud are too soft for geotechnical purposes as such, and the shortage of soil landfills and their distant location from the capital region cause great costs in civil engineering projects. Long transportations also generate vast amounts of carbon dioxide and other greenhouse gas emissions. There is also a shortage of virgin rock materials in the Helsinki region. Aggregates needed in construction are transported from the provinces around Helsinki. This is very expensive and also generates airborne emissions. Crushing of aggregates also demands a lot of energy (Niemelin & Kreft-Burman, 2015).

The ABSOILS project (2010-2015) has been funded by the EU Life+ programme (LIFE09 ENV/FI/575) and the project's beneficiaries. The purpose of the project has been to verify the utilisation potential of surplus soils in different civil engineering applications.

2 Goal definition and scope of the study

The purpose of the LCA is to determine and compare the potential environmental impacts of different alternatives. Primary attention is paid to the depletion of natural resources and global warming potential which are chosen for the environmental impact categories to be calculated. The consumption of energy of the studied processes is the major reason for the global warming potential, and the choice of materials for the depletion of natural resources. The choice of the categories was influenced by the fact that they constitute the major impacts from infrastructure construction and because of the availability of general data on the relevant discharges from the individual processes (mainly because of the energy consumption). Cement is one of the construction materials that need relatively large amounts of natural resources and energy for its production. In this project, fly ash - a by-product from energy production - is used as a substituent for cement in order to decrease the total global warming potential and the depletion of natural resources of some of the demonstrated pilots (Niemelin & Kreft-Burman, 2015). Other reason for the use of fly ash as a binder is to obtain more homogeneous stabilised material than with pure cement. In the case of the fly ash + cement binder, the total amount of the binder is higher and therefore, it is easier to achieve a good quality mixture of binder and soil. In the case of pure cement, more cement is needed but the total amount of binder is lower and it is not so easy to make a good mixture of cement and soil.

It was expected that the results of the verification procedure prove that the surplus soils after stabilisation are feasible and competitive materials for the construction markets and that their use as construction materials involves significant environmental and economic benefits for the European societies (Niemelin & Kreft-Burman, 2015).

The Streamlined LCA compares the results of the alternative pilot structures and a chosen conventional alternative that are predicted to have identical technical performance. The alternatives for the pilot structures have been chosen on the basis of experience, results of the past studies, and with the help of experts designing the structures. The product system of the pilots is presented in Figure 1. The Functional Unit (FU) for the LCA and LCC calculations has been chosen to be 100 m^2 of the construction for the Arcada II and Dog Park pilots, and 1 m^3 for the Jätkäsaari (West Harbour) pilot.

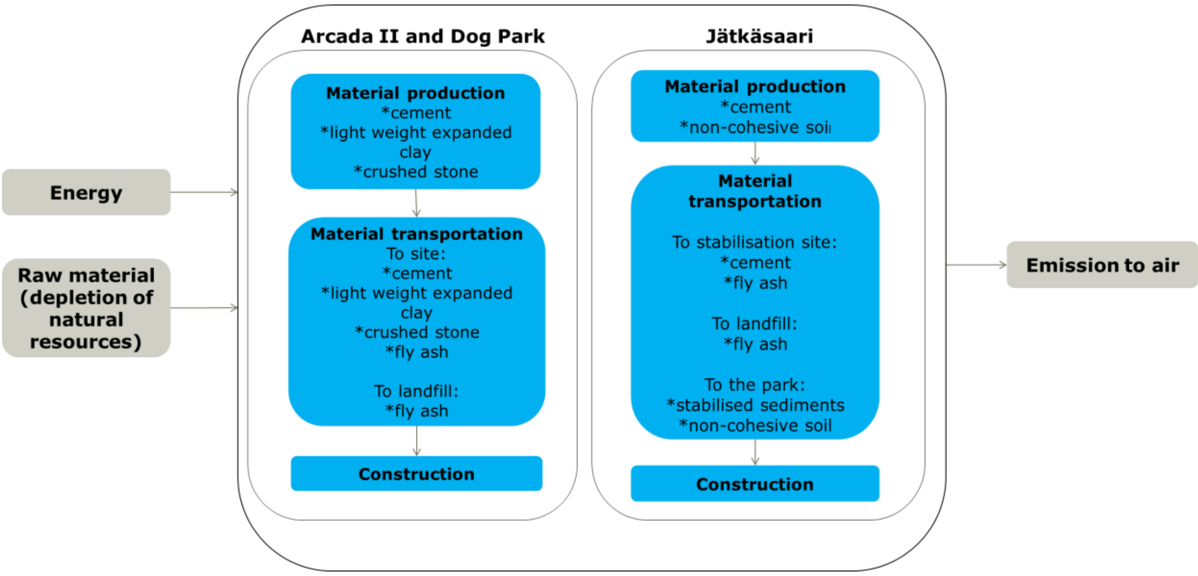

Figure 1. Product system for the ABSOILS pilots.

2.1 Assumptions

The short lifetime period, the narrow product system and the few inputs and outputs from the individual processes that have been chosen for practical reasons will result in only rough estimates about the environmental, technical and economical characteristics of the different types of products. This will be emphasised because of certain assumptions for the LCA studies (Niemelin & Kreft-Burman, 2015):

1. Emissions from the by-products and waste (like surplus soil and fly ash) generated from a production process are assumed to be zero as all emissions from the main production are allocated to the actual products. This is a typical methodology as the fly ash and surplus soils are meant to substitute the virgin natural aggregates.
2. The design works of the projects are not included in these calculations. The design work is executed in the office as desk work and it is not possible to allocate any energy or space consumption to an individual project of a relatively short duration.
3. The laboratory work is not included in these calculations because the relatively extensive laboratory studies for ABSOILS' purposes will not be needed for any project of established infrastructure construction.
4. The production of factories, production plants and landfills (concerning e.g. productions of fuel, materials, transport vehicles and vehicles for works) are not included as these investments have not been made for the needs of this individual project.
5. The production of the vehicles or machines used in transportation and construction has not been included in the product system for the same reason as above.
6. Production and transportation of fuels are not included for the same reason as above. (Note: the fuel consumptions for material transportations and construction are calculated).

Life cycle analysis is calculated for the stages of material production, material transportation, construction and the sum of the previous.

3 Pilot introduction and life cycle analysis results

3.1 Pilot Arcada

Arcada II pilot in Helsinki includes the construction of the street Kyläsaarenkuja to a pile slab, the removal of contaminated soils and the existing blasted rock embankment, filling with mass stabilised surplus soils and the construction of a new driveway connection to the Hermanninrantatie road. The area had low stability and load bearing capacity. In the pilot project, the rock aggregate was removed from the site and was replaced with a light weight structure utilising surplus clay (Forsman et al. 2012). Figure 2 presents the Arcada alternative structures examined in the LCA (Niemelin & Kreft-Burman, 2015).

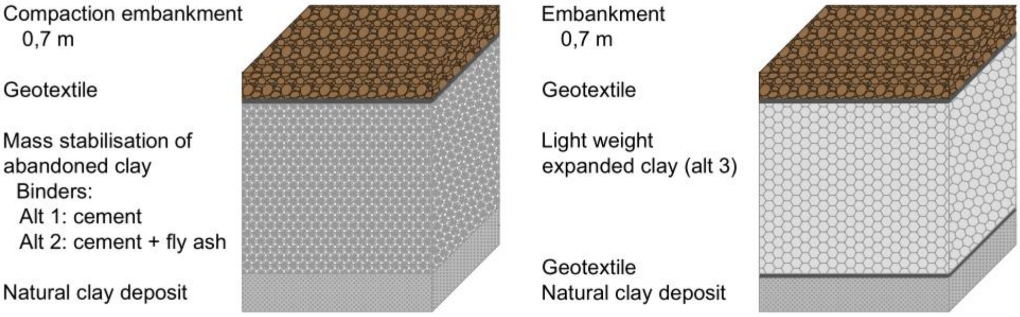

Figure 2. The structure alternatives in the Arcada II pilot.

The life cycle analysis results are presented in Table 1. The last column presents the sum of the environmental impacts and it is without dimension. The results show that the Alt2 (mass stabilisation with cement and fly ash) has least environmental impacts.

Table 1. LCA calculation results for Arcada environmental impacts.

Alternative	**Global warming potential [CO_2 kg equiv. / FU]**	**Energy consumption [MJ/FU]**	**Depletion of natural resources [kg/FU]**	**Total [no dimension]**
Alt1	45 034	224 341	248 587	517 962
Alt2	24 610	134 698	204 985	364 293
Alt3	47 737	311 009	362 406	721 152

3.2 Pilot Dog Park

The Dog Park in Espoo covers the area of approximately 4500 m^2 and is located in a zone prone for flooding. The soil of the area which used to be a sea bed was soft clay and the site had been classified as a very difficult constructing target due to its low load bearing capacity. The pilot structure is an embankment raised to the level +2…2.5 meters to prevent flooding. In order to prevent mass exchange and landfilling of the site's soft soils, the original clay and some surplus soils from an adjacent construction site were stabilised. (Forsman et al. 2013) Figure 3 presents the Dog Park alternative structures examined in the LCA (Niemelin & Kreft-Burman, 2015).

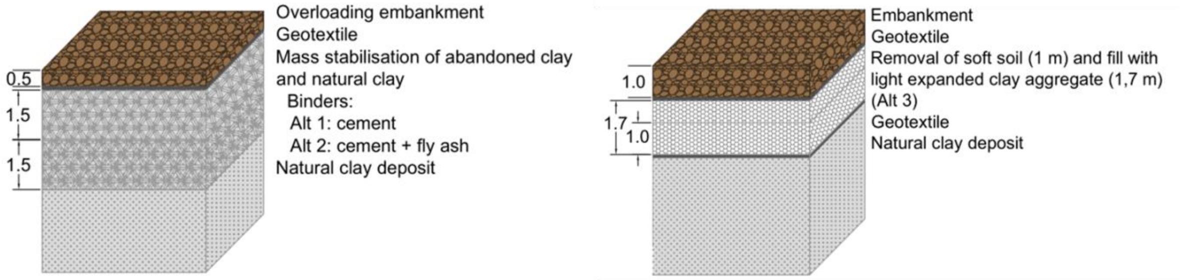

Figure 3. The structure alternatives in Dog Park pilot.

The life cycle analysis results are presented in the Table 2. In the Dog Park case too, the mass stabilisation with cement and fly ash exerts less environmental impacts than other alternatives.

Table 2. LCA calculation results for the Dog Park environmental impacts.

Alternative	Global warming potential [CO_2 kg equiv. / FU]	Energy consumption [kg/FU]	Depletion of natural resources [kg/FU]	Total [no dimension]
Alt1	20 130	2 857	138 113	161 100
Alt2	15 171	2 616	127 735	145 522
Alt3	23 128	6 201	200 651	229 980

3.3 Pilot Jätkäsaari

In the Jätkäsaari pilot in Helsinki, the dredged sediments from the sea were mass stabilised and utilised in the nearby park (Hyväntoivonpuisto). This is mainly a theoretical study as the environmental permit applications of the park did not include the use of mass stabilised sediments so in reality, this could not be done. The Jätkäsaari sediments have been utilised in other parks in Helsinki area. The sediments were stabilised in the stabilisation basins. (Forsman et al. 2015) The sediments were mildly contaminated and the metal and organic contents exceeded the level 1 limit values of the dredging and dumping instructions (Ministry of the Environment, 2004). The stabilised sediments were transported to the park and used there for landscaping purposes (Niemelin & Kreft-Burman, 2015). Figure 4 present the utilisation principal of the contaminated sediments.

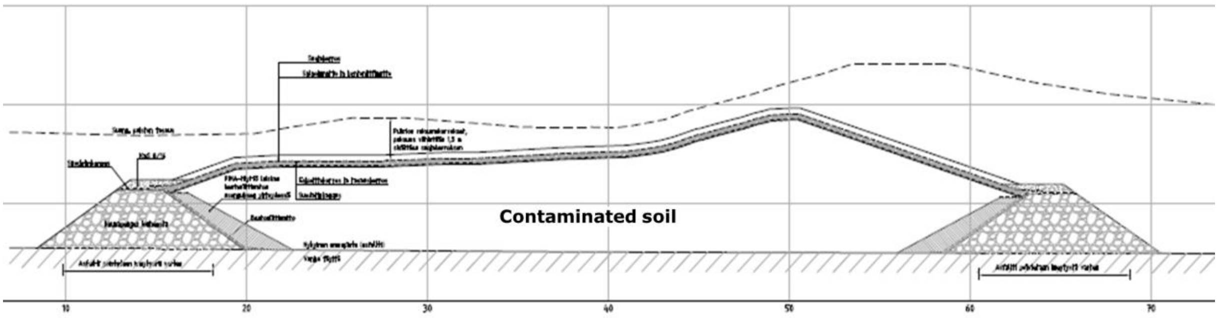

Figure 4. The principle of utilisation of the contaminated sediment in the park of Hyväntoivonpuisto. Jätkäsaari (West Harbour).

The life cycle analysis results are presented in Table 3. The highest environmental load is exerted by Alt1 where the sediments are stabilised with cement, and the lowest load is generated in Alt2 where part of the cement is substituted with fly ash.

Table 3. LCA calculation results for Dog Park environmental impacts.

Alternative	Global warming potential [CO_2 kg equiv. / FU]	Energy consumption [kg/FU]	Depletion of natural resources [kg/FU]	Total [no dimension]
Alt1	46	207	94	347
Alt2	28	124	58	210
Alt3	33	214	54	301

The total results are presented in Figure 5 for every pilot. It can be seen that the environmental impacts vary between the pilots. All in all, the results indicate that by substituting part of the cement with fly ash the environmental load can be diminished. In the Jätkäsaari case, the energy consumption was highest in Alt3 where the sediments are transported to the landfill but the result was in the same scale with Alt1 as the transportation distance of cement to the site is long.

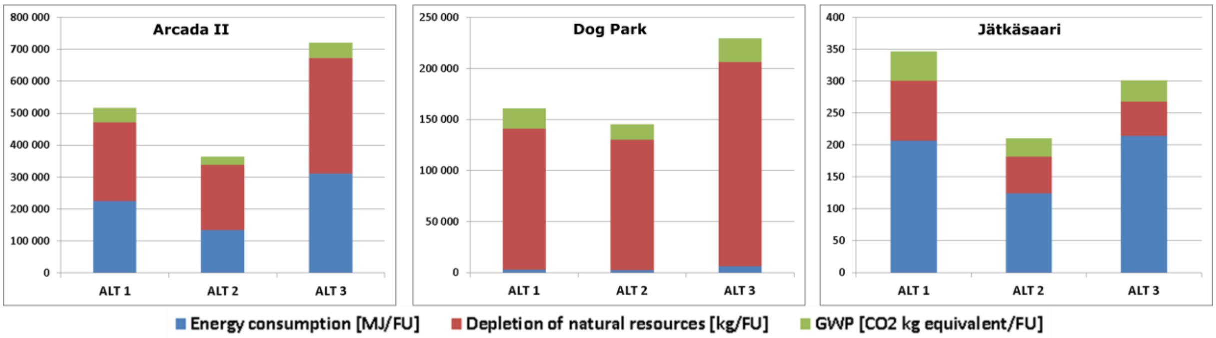

Figure 5. Total results of the environmental impacts.

4 Discussion

According to the LCA results of the three studied pilots, by substituting part of the cement with fly ash (or with other industrial by-product which can be regarded as 0-emission product) the environmental impacts can be significantly decreased. Cement manufacturing consumes a lot of energy and natural resources. In Finland, cement manufacturing constitutes 1,2 % of all greenhouse gas emissions. The environmental impacts from cement manufacturing are centralised especially to the area where the main ingredient, limestone, is quarried. Moreover, cement transportations and high temperatures (~1400-1500 °C) in rotary kilns generate a lot of airborne emissions and consume a lot of energy (Finnsementti, 2012).

The utilisation of surplus soils significantly decreases the depletion of natural resources, energy consumption and global warming potential. In Finland, the annual use of natural aggregates is approximately 22 ton/person. There is a shortage of rock material in the capital region, so the natural aggregates are transported from other counties. The transportation distances can be over 30 km. Transportation of 1 ton of natural aggregates consumes 7 kWh energy. As 1 kWh energy produces approximately 0.27 kg CO_2 emissions, 1 km more of a transportation distance results in 7 million kg of CO_2 emissions (Confederation of Finnish Construction Industries RT and Infra Contractors Association in Finland. 2014). The amount of surplus soils generated annually in Helsinki is approximately 100 000 – 150 000 m^3. The landfill capacity for surplus soils has been exhausted and part of the surplus soils are transported outside Helsinki. As the results of this study indicate, stabilisation of soft surplus soils that allows for their utilization as earth construction materials is an environmentally feasible solution the utilisation of surplus soils is an environmentally feasible solution.

5 Conclusions

- The environmental impacts in the pilots are both local (e.g. changes in land use) and global (airborne release of greenhouse gases)
- The studied environmental impacts were lower in the pilot structures compared to the alternatives that applied more conventional structures
- The results indicate that the utilisation possibilities of surplus soil should always be studied as an alternative when planning civil engineering projects where earth construction and surplus soils are included
- Surplus soils can be used in new areal development projects, road and field structures, landscaping, harbour structures, noise barriers, and other structures where natural aggregates are normally used

Acknowledgements

Special thanks to the EU LIFE+ programme for co-funding of the ABSOILS project (LIFE09 ENV/FI/000575). The knowledge concerning utilising surplus soils is needed all over Europe. The experience of this project will foster the promotion of new pilots and technologies using low quality soft soils and industrial by-products.

References

Forsman, J., Lindroos, N. and Korkiala-Tanttu, L. 2015. Three mass stabilization phases in the west harbor of Helsinki, Finland – geotechnical and environmental properties of mass stabilized dredged sediments as construction material. Deep mixing 2015 conference, 2.-5.6.2015, San Francisco.

Forsman, J., Kreft-Burman, K., Lindroos, N., Hämäläinen, H., Niutanen, V. & Lehtonen, K. 2013. Experiences of utilizing mass stabilised low-quality soils for infrastructure construction in the capital region of Finland – case ABSOILS project. The XXVIII International Baltic Road Conference, Vilna, Liettua, 26.-28.8.2013.

Forsman, J., Korhonen, O., Havukainen, J. & Kreft-Burman, K. 2012. Mass stabilisation in construction of soft subsoils and in environmental geotechnics at city of Helsinki. Rostock 12th Baltic Sea Geotechnical Conference, 31.5. – 2.6.2012.

Niemelin, T. and Kreft-Burman, K. 2015. EU-Life ABSOILS. LCA and LCC verification report. Ramboll. Unpublished.

Ministry of the Environment, 2004. Instruction for dredging and depositing dredged materials. Environmental Guide no 117.

Finnsementti, 2012. Environmental report.

Confederation of Finnish Construction Industries RT and Infra Contractors Association in Finland, 2014. Kestävä kiviaineshuolto (in Finnish "Sustainable supply chain of aggregate"). Powerpoint presentation. Read 13th August 2014.