Emission reduction through preconstruction and utilization of alternative materials in infrastructure projects

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Abstract.

Construction have a significant impact on the amount of emitted green-house gas (GHG) and a potential to cut emissions is quite substantial. In this article, possibilities provided by preconstruction activities and utilization of alternative materials are discussed. Preconstruction means actions to be taken in advance when soils in the construction area are too soft. These actions may be e.g. deep mixing, replacement or preloading. Considering that constructed subgrades, ground improvement and some other earth works required for the infrastructure project can be very energy-intensive, emissions can be reduced substantially only if preconstruction options, areal mass balance and potentiality of alternative materials are identified early enough. Examined case studies also focus on possibilities to reduce emissions related to certain materials e.g. deep mixing binding agents. In deep mixing, blend of cement and quick lime is the most traditional binder component. Therefore, reducing the amount of cement + lime and selecting the cement type have a great impact on CO₂ emissions. Cement amount can be reduced by alternative materials such as fly ash, blast furnace slag or gypsum. Possibilities to reduce CO₂ emissions were studied in various infrastructure projects and reflected to climate strategies. The studies were focused on areas and operations where changes were possible such as transportation, construction materials or subgrade construction methods. This article describes the case studies related to construction of various infrastructure projects and identified possibilities to reduce emissions.
1. Introduction

In Finland, the use of natural resources in building and construction works per capita is 2–3 times greater than the average in EU countries. The resource-wise use of rock and land masses has been recognized as one of the methods with the greatest potential for reducing CO$_2$ emissions. For example, construction works in Helsinki produce over 800 000 m$^3$ of unspoiled surplus landmass annually, which was previously not utilized in the city.

As part of the European Union, Finland is committed to the Paris Agreement on climate change, Finland is committed to reduce greenhouse gas emissions with 40 % by the year 2030 compared to the level in 1990. Currently Finland has reduced its emissions to more than 21 per cent below the 1990s level and it will reach the EU’s climate targets for 2020 ahead of schedule. [1]

Finland has new ambitious government programme [1] which aims to transform Finland into a socially, economically and ecologically sustainable society by 2030 and strengthen Finland’s role as a leader in the circular economy. The Government’s decisions will put Finland on a path towards achieving carbon neutrality by 2035. One of the objectives is to reduce the carbon footprint of construction and housing by building a carbon neutral society and improving the quality of construction. This is achieved by e.g. implementing the low-carbon construction roadmap and develop a legislative framework based on the carbon footprint of buildings throughout their lifecycle and enhance the efficiency of the circular economy and the recycling of materials in the construction sector. In infra construction sector one of the most important factor reducing impact of the construction is efficient land mass coordination (presented in chapter 2).

The Finnish energy and climate road map for the year 2050, targets to decrease the emissions by 80-95 % compared to the 1990 level, is set [2].

The cities of Helsinki, Espoo, Tampere and Turku have their own climate strategies aiming to reduce their CO$_2$ emissions by a set year. The goal of the climate strategies is a common vision and appreciation of operating policies to reduce impacts on the climate. The aim is to ensure that greenhouse gas emission cuts become a consistent element in the objectives executed by various city agencies for their own operations. The cities are seeking set greenhouse gas reductions per capita without compromising economic growth and wellbeing. The strategies present and underline action to be taken in order to achieve the presented climate mitigation goal.

Although climate work can be done on a local level without exact emission calculations and based on the experience and indicators, succeeding in the international climate policy, requires emission calculation data. Without homogenous and commensurable emission calculation data, the international commitments are difficult to make, and the fulfilment of previous agreements are hard to monitor in practice.

Emissions from build environment (buildings and infrastructure) are expected to form the single largest category of consumption-based emissions for C40 cities between 2017 and 2050, being responsible for 21% of consumption emissions [3]. C40 refers to a network of the world’s megacities committed to mitigate climate change [4]. Emissions of infrastructure construction are especially linked to material transportation and CO$_2$ emission intensive materials, such as cement and steel. Case studies made in Helsinki, Turku and Tampere in Finland, showed that CO$_2$ emission reduction in infra construction projects are possible, when the preconstruction methods, areal mass balance and alternative materials generated in the vicinity of the site, are identified and optimised early enough.

The objective of this article is to analyse the emission reduction potential in preconstruction activities and utilization of alternative materials in infra construction projects and to give understanding on the magnitude of the emission reduction possibilities. Furthermore, this study aims to provide information about practices differing from conservative construction projects in order to achieve technically successful and climate friendly project. In addition, the calculated cost reductions are also presented although they have not been the focus of the studies. Emission reduction possibilities in preconstruction practices are discussed and reflected to current practices in different city operations.
2. Development programs for land mass coordination

2.1. Development programs

In the early 2010s, the City of Helsinki was facing a need for a significant change in strategy regarding what to do with the surplus land masses generated from the fast-growing land development areas. One contributing factor was that the major landfilling areas for surplus land masses were closing.

To tackle this matter the metropolitan area cities Espoo and Helsinki launched “Principles developed for utilization of excavated soil, rock and demolition materials”. The city of Vantaa has similar framework in the making and is expected to be finished in 2020. The principles apply to core processes run such as land acquisition and management, general land use planning, zoning, preconstruction, design and construction of infrastructure and buildings. These principles shall be followed in projects and activities performed in cooperation with building contractors and other parties. Furthermore, practices of data management, communications and interaction are also considered in the principles.

The principles provide tools to control, specify and unify tasks to be performed by different divisions in the City administration. They define the tasks of soil mass coordination and utilization of excavated soil, rock and demolition materials in earthwork. Management of surplus materials shall become a part of routine activities controlled by ERP (Enterprise Resource Planning) system. The core of the coordination of soil and rock material management is to identify mass flows needed and generated in short and long-term perspective. A primary task is to guide soil flows directly from a source of origin to utilization, or from one construction site to another. Another task is to guide the soil flows to a temporary storage or via refining treatment to utilization. Furthermore, the coordination shall be responsible for forecasting the soil flows, design (e.g. preconstruction design) and construction monitoring and control, and maintaining relevant data on soil masses quantity and quality.

2.2. Preconstruction

In the development programs the preconstruction is one of the important key points to execute effective land mass coordination. The term preconstruction means actions that are carried out when an area to be constructed is geotechnically too soft or difficult to construct and the area must be for example solidified or mass in the area must be exchanged. Preconstruction methods reduce or avoid settlements and/or improve stability of the construction site.

Preconstruction includes inter alia: soil excavation, rock blasting and fill placement, subgrade reinforcement and load reduction, improvement of areal stability, treatment of polluted soil, sediment dredging and land reclamation, demolition of existing structures and relocation of pipelines. Commonly used preconstruction methods are mass exchange, preloading with berms or vertical drainage, deep compaction and deep stabilization. Also, light weight structures, counter embankments and geo-reinforcements are widely used. Suitability of the preconstruction method depends on the characteristics of the construction area, such as soil conditions, environmental considerations needed for the construction activities and the available time frame.

Preconstruction is mentioned several times in principles and in the development actions plans. For example, city of Helsinki has action plans regarding preconstruction [5]:

- to secure allocation of city funds for preconstruction (action number 3)
- to perform system analyses of areal preconstruction needs (action number 7)
- perform soil sampling and testing on sites significant for soil mass economy to support related soil mass calculations and to inspect preconstruction solutions (action number 9)
- clarify preconstruction solutions for area development which promote mass balance optimization and reduce CO\textsubscript{2} emissions. Analyse possibilities to utilize no-dig methods in preconstruction as a part of creating and improving construction preconditions. (action number 11)
As the infra construction is very energy intensive, preconstruction provides possibilities for significant emission reductions when the preconstruction alternatives, the areal mass balance and the alternative materials generated in the vicinity has been mapped early enough in advance.

2.3. Deep mixing binders
If deep stabilization is used as a preconstruction method, CO\textsubscript{2} emissions can be decreased by replacing the most emission intensive binders (cements and quick lime) with industrial based alternatives such as fly ash generated by coal combustion-or biobased materials, blast furnace slag or gypsum. For example, CO\textsubscript{2} emissions from the production of Portland cement (CEM I) in Finland are 30% higher than from Portland Composite cement (CEM II).

Use of alternative binders usually does not require more effort than usual stabilisation studies, that are anyway case-specific. However, it should be considered that use of certain still non-commercial waste-based binders may require additional studies and e.g. environmental permits.

There are already several recycle material derivates binders on the market and available to use instead of cement+lime origin from virgin natural materials. Also, use of recycled materials should not be based on individual sources, since the energy production is under a transition period and restriction in coal consumption, which is an important source of fly ash, could be expected.

3. Methodology
The method used to calculate the emissions in the case examples, is MS Office Excel-based program developed by Ramboll Finland Oy. The purpose of the program is to calculate CO\textsubscript{2} equivalent emissions in infrastructure projects. Alternatives calculated in each case, are technically comparable with each other.

The calculation method follows the standard EN 15804 Sustainability of construction works, standard stage A, including all parts of the product (A1-A3 product stage) and the construction activities (A4-A5 construction process stage). These calculations do not include the standard stages B (use stage) and C (end of life stage).

The used CO\textsubscript{2} calculation tool produces input-output (IOA) analysis, where a region (the area to be constructed) is the object of the study. Although it is not an environmental impact assessment (EIA) neither a strategic environmental assessment (SEA), which are used for specific project purposes, the results of these CO\textsubscript{2} calculations can (and should) have impact on the decision-making process as the calculations are intended to show where and how the carbon emission reductions can be made without compromising the technical requirements, and simultaneously save the construction costs.

4. Case studies
The studied cases are real studies made by Ramboll Finland Oy and city of Helsinki including infrastructure projects, climate strategies and development programs for land mass coordination. The climate strategies were used as a reference material and not studied as a separate case study.

In general, climate targets of the cities do not cover preconstruction as a route, where emission reductions are possible to achieve. What it comes to construction related issues in climate targets, they are focused on energy efficient buildings and densifying the land use. From the studied cases, only city of Helsinki has considered preconstruction also in its climate strategy.

The infrastructure projects are in the cities of Helsinki, Turku and Tampere. Case in Helsinki is a CO\textsubscript{2} calculation for the future city district, Karhunkaataja area. In the case in Turku, CO\textsubscript{2} calculations were made for three different streets in a new Skanssi city district area to be constructed. In the case of Tampere three cases that were constructed earlier, were calculated to show their CO\textsubscript{2} savings potential for future decision-making purposes. In this paper, main findings from the case calculations are presented.

Three cities of the capital area, Espoo, Vantaa and Helsinki, have or will have a development program for land mass coordination, which aim to cut costs and emissions through logistically optimized soil transportation and utilizing surplus soil in construction projects. Of those the city of Helsinki has had its
own development program since 2012 (full data available from 2014) and thus results of the programme are available and included in this study.

4.1. Helsinki, Land mass development program 2014-2019
Since the beginning of the development program [6], the City of Helsinki has managed to save the in 2014–2019 approximately 47 M€, 6.9 million liters of fuel and 17.1 thousand ton of CO₂ emissions in total. The savings were enabled particularly by soil mass coordination between construction sites, temporary storage and treatment of soil material and design and implementation of utilization. The cumulative growth has increased through the years since the program was implemented (Figure 1.) Furthermore, by 2017, the reuse of land masses in construction projects had grown by over 1 million metric tons [6].

![Figure 1](image.png)

**Figure 1.** Cumulative sum of saved CO₂ emissions (kg eq.), liters of fuel used and saved costs (euros, €) during the land mass development program 2014-2019 in city of Helsinki [6].

4.2. Helsinki, preconstruction of Karhunkaataja area
In Helsinki, a new residential area of 11 000 citizens, called Karhunkaataja area (26 ha), will be built and it is estimated that the construction of the area starts during 2020. Karhunkaataja is located on northeast of Helsinki. Development of the area is essentially connected to the upcoming new tram route Raide-Jokeri. Currently the area is mostly unconstructed, topographically variable (+14.0 – +38.0) and soil conditions vary from clay and silt to bare bedrock areas and till (Figure 2). Planned residential areas are located on all ground conditions [7].
Urbanization plans of Karhunkaataja are aiming to economically viable construction with phased construction. In the studied area the city plan allows to use surplus soil masses and rock material in order to increase ecological aspects of the construction. Thus, several different preconstruction alternatives were studied in the Karhunkaataja area as presented in Table 1 [7].

Regional development and the preload embankment are significant factors for the areal mass balance, CO$_2$ emissions and construction resource efficiency. There are several options of preconstruction methods that can be applied on different parts and phases of a construction project. Alternative 1 (ALT) focuses on utilization of the blasted rock inside the project area. In ALT2 the blasted material cannot be utilized inside the project area and aggregates for the construction must be bought form the markets. The ALT2 is divided to different options by the utilization on virgin and recycled aggregates. ALT 3 is so-called 0-case. The ALT 3 and its variations are conservative, and often emission intensive ground improvement methods (such as mass stabilization and lightweight structures) [7].

The results show that alternative 2b generates the lowest total CO$_2$ emissions with a total of 866 000 kg CO$_2$ eq., when total emissions of other methods vary between 1 098 000 – 5 309 000 kg CO$_2$ eq. In alternative 2b, crushed concrete aggregate is brought from nearby distance and used instead of virgin aggregate, giving 21-84 % less CO$_2$ emissions when compared to other alternatives. In alternatives 3, the share of materials and/or transportations play an important role in total CO$_2$ emissions. Both alternatives ALT3c and ALT3a generate high material emissions with total 3 425 000 – 5 309 000 kg CO$_2$ eq. for ALT3c1-2 and 3 262 000 kg CO$_2$ eq. for ALT3a. In ALT3c the transportation related emissions are the highest being 36–92 % higher than with other methods, as the lightweight materials are transported from about 130 kms distance [7].
Table 1. Preconstruction alternatives in Karhunkaataja case [7].

| Alternative | Preconstruction method and explanation |
|-------------|----------------------------------------|
| ALT 1       | Blasted rock is processed (crushed) and will be used for the preload embankments in Karhunkaataja project area. |
| ALT 2       | Blasted rock cannot be utilised and in project area. The material needed (20 000 m$^3$) in the projects is bought from the markets. ALT 2a virgin crushed aggregate (transport distance of 25 km) and ALT2b recycled crushed concrete aggregate (transport distance of 10 km) |
| ALT3        | Preloading is compared to some “faster” preconstruction method  
  - ALT 3a - mass stabilisation, cement 60 kg/m$^3$, transportation distance of the binder is 220 km  
  - ALT 3b - mass replacement with crushed aggregate or blasted rock. Excavated soils from mass replacement are transported to 40 km to landfill.  
  - ALT 3c1 - lightweight structure with lightweight aggregate ALT 3c2 - lightweight structure with foamed glass |

Figure 3. Calculated CO$_2$ emissions (kg eq.) for different preconstruction methods for the Karhunkaataja case [7].

4.3. Tampere, street projects
Tampere calculations were made for cases already constructed some years ago. Arvo Ylppö -street was constructed in 2016–2017, it is 1200 m long with 14 400 m$^2$ asphalted pavement. Three different scenarios were made for which the CO$_2$ calculations were done. The case alternatives are presented in table 2 [7].

According to Arvo Ylppö -street case calculations, alternative 3A produced 11–16 % less emissions than the other two alternatives (Figure 3).
Table 2. Preconstruction principles in Arvo Ylpön katu street case [7].

| Alternative | Preconstruction method and explanation |
|-------------|----------------------------------------|
| ALT 1       | Actual construction                     |
| ALT 2       | Assumption that crushed concrete is not utilised in this construction site and kerbs will not be recycled |
| ALT3A       | Assumption that crushed asphalt is utilised in fillings and concrete blocks are replaced with natural stones from Finland |

Figure 4. Calculated CO\textsubscript{2} emissions (kg eq.) for different preconstruction methods for the Arvo Ylpön katu street case [7].

4.4. Results of the infrastructure projects

The achieved CO\textsubscript{2} and cost savings of the studied cases are presented in Table 3, 4 and 5. It should be noted that these results include also the pavement structures although they are not part of preconstruction activities. For comparison purposes, Skanssinkatu, Vallikatu, Kauhakorvenkatu and Arvo Ylpön katu are similar cases [7].

The results show that CO\textsubscript{2} and cost savings are connected to each other in such a way, that when the infrastructure project is optimized to avoid needless CO\textsubscript{2} emissions, it benefits the project also financially. For example, the cost savings (€) per road meter vary from 2 up to 133 €/road meter.
Table 3. Emission savings potential between different alternatives in the studied cases [7].

| Case                        | Highest emission (kg CO₂ eq) | Lowest emission (kg CO₂ eq) | Emission savings potential (kg CO₂ eq) |
|-----------------------------|------------------------------|-----------------------------|----------------------------------------|
| Skanssinkatu, Turku         | 242,866                      | 219,106                     | 23,760                                 |
| Vallikatu, Turku            | 4,277,769                    | 1,652,238                   | 2,625,531                              |
| Perhekatu, Turku (transportations) | 41,913                      | 29,855                      | 12,058                                 |
| Kauhakorvenkatu, Tampere   | 450,099                      | 382,634                     | 67,465                                 |
| Arvo Ylpön katu, Tampere   | 366,537                      | 326,475                     | 40,062                                 |
| Karhunkaataja, Helsinki     | 5,309,348                    | 866,292                     | 4,443,056                              |
| Myrskynkatu and Härmälänojanpuisto, Tampere | 159,486              | 48,578                      | 110,908                                |

Table 4. Emissions per m² and per road meter in the studied cases [7].

| Case                        | Emissions per m², highest (CO₂ eq/m²) | Emissions per m², lowest (CO₂ eq/m²) | Per road meter, highest (CO₂ eq/m) | Per road meter, lowest (CO₂ eq/m) |
|-----------------------------|--------------------------------------|--------------------------------------|-----------------------------------|----------------------------------|
| Skanssinkatu, Turku         | 101                                  | 91.3                                 | 810                               | 730                              |
| Vallikatu, Turku            | 156                                  | 60.1                                 | 3,565                             | 1,377                            |
| Perhekatu, Turku (transportations) | 5.44                          | 3.88                                 | 107                               | 77                               |
| Kauhakorvenkatu, Tampere   | 42.9                                 | 36.4                                 | 500                               | 425                              |
| Arvo Ylpön katu, Tampere   | 25.5                                 | 22.7                                 | 305                               | 272                              |
| Karhunkaataja, Helsinki     | 114                                  | 18.7                                 | -                                 | -                                |
| Myrskynkatu and Härmälänojanpuisto, Tampere | 51.8                          | 15.8                                 | -                                 | -                                |

Table 5. Cost savings per m² and per road meter in the studied cases [7].

| Case                        | Cost savings per asphalted m² (€) | Cost savings per road meter (€) |
|-----------------------------|-----------------------------------|---------------------------------|
| Skanssinkatu, Turku         | 17                                | 133                             |
| Vallikatu, Turku            | n/a                               | n/a                             |
| Perhekatu, Turku (transportations) | 2                               | 2                               |
| Kauhakorvenkatu, Tampere   | 10                                | 122                             |
| Arvo Ylpön katu, Tampere   | 8                                 | 96                              |
5. Conclusions
Finland is aiming to cut CO$_2$ emissions 80–95 % by the year 2050 in comparison to the level in 1990 (71.6 Mtons) [2]. In order to achieve this sustainability goal, the next Government Programme will introduce a new taxation framework and environmental policies to promote the circular economy. At the municipal level, climate strategies targeting a carbon neutral economy are already being implemented in several cities. In addition, the implementation and success of these policies will depend on the commitment and compliance from all city operating sectors.

Helsinki Metropolitan Area has been experiencing a fast expansion during the last decades. Land use planning, settlement structures and used construction practices are very important from the point of view of greenhouse gas emissions due to its long-lasting effects. Therefore, climate strategies should mitigate the carbon footprint of all city operations and encourage for active and innovative approaches in all business practices.

This study shows that there are emission reduction potentials yet unexplored and not considered in the climate targets of cities. As the case examples show, it is possible to optimize the construction project to save generating CO$_2$ emissions when the mass balance, transportation distances and used materials are studied well in advance. For best results, these should be already considered at the general planning stage – where and how the generating masses can be best utilized. Land use development programme is a good example of carefully planned set of practices, which resulted in a positive outcome.

The practices involved in the land mass development program of Helsinki show a notable effect on the total amount of CO$_2$ (eq.) emissions emitted and fuel consumed, which allowed the city to achieve significant savings in costs. Thus, it can be stated that resource wise practises are both climate friendly helping to tackle the climate impacts and help to balance the economy related to construction operations. A successful land mass development programme requires careful planning and co-operation with different city operation authorities, operators and decision makers.

Land mass development programmes are essentially connected to climate strategies. Transport has been stated to be the third largest source of emission in the Helsinki Metropolitan Area being responsible for approx. 20 % of total emissions [2]. Land mass development programme is fundamentally about optimizing logistics of the land mass transportation and thus directly decreases emissions caused by traffic. Key actions for the successful results were i.e. setting up temporary land mass operation sites, coordination of land masses already in the master plan creation phase, using land mass pilot projects as learning tools and utilization of land masses in street and park planning. Also, several CO$_2$ calculations were promoted during the programme, which gave important input and information about the outcome of the implemented land mass utilization projects.

The results of this study show a decrease of 72–84 % in CO$_2$ emission when using preconstruction methods in construction in comparison to other construction methods. Preloading and vertical ditches should be used in preconstruction when possible in relation to time constraints. Time-consuming preconstruction methods generate less CO$_2$ emissions as the methods are based on natural physical phenomenon instead of using intensive work-effort and material transportations. The most difficult construction areas, such as soft and wet clay soils, could be designed as parks or other recreational areas, that do not require heavy preconstruction methods. When new area is constructed, it also should be pointed out an area, where the needed materials could be stored and processed so that all stages of material logistics can be optimized. Also, by increasing the levelling in the area, additional excavations and generation of surplus soil can be avoided. Higher level for example in parks, enables the utilisation of surplus soils in the area.

Climate strategies together with legislative framework should take into consideration the ongoing development of circular economy and enable flexible use of alternative materials and practices.
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