

Article

GHG Emissions Reduction through Urban Planners' Improved Control over Earthworks: A Case Study in Finland

Eeva-Sofia Säynäjoki ¹, Pia Korba ^{1,*}, Elina Kalliala ^{2,3} and Aino-Kaisa Nuotio ³

¹ Department of the Built Environment, Aalto University School of Engineering, P.O. Box 14100, FI-00076 AALTO, Finland; eeva.saynajoki@kiinko.fi

² Department of Architecture, Aalto University School of Arts, Design and Architecture, P.O. Box 16500, FI-00076 AALTO, Finland; elina.kalliala@aalto.fi or elina.kalliala@ramboll.fi

³ Ramboll Finland, P.O. Box 25, FI-02601 Espoo, Finland; aino-kaisa.nuotio@ramboll.fi

* Correspondence: pia.korba@aalto.fi; Tel.: +358-40-7430624

Received: 20 June 2018; Accepted: 9 August 2018; Published: 11 August 2018



Abstract: Most climate change mitigation schemes in urban planning concentrate on reducing greenhouse gas (GHG) emissions in the distant future by altering the urban form and encouraging more sustainable behaviour. However, to reach climate change mitigation targets, a more immediate reduction in GHG emissions is also needed as well as a reduction in GHG emissions in other fields. This article evaluates the important role of earthworks in the prompt and substantial reduction required for GHG emissions. The research includes a single case study and three focus group interviews. The results of the case study reveal the magnitude of possible emission reductions through urban planners' control over earthworks, whereas the findings of the focus groups shed light on the relevance of the findings beyond the single case. Three urban planning solutions were implemented in the case area to reduce GHG emissions from earth construction, resulting in the saving of 2360 tonnes of CO₂ emissions. Notable savings were also achieved in other emission categories. Such a successful management of rock and soil material flows requires a strong vision from the urban planner, cooperation among many different actors, and smart decisions in multiple planning phases. Furthermore, numerical data is needed to confirm the environmental benefits if the coordination of earthworks is to be widely included in regional climate change mitigation strategies.

Keywords: environmental sustainability; climate change mitigation; greenhouse gas emissions; urban planning; earthworks; case study; focus groups

1. Introduction

Concerns for environmental sustainability, especially commitments to the mitigation of climate change, increasingly influence the priorities of urban development [1–4]. The prevailing logic of reducing the environmental load through urban planning is to alter the built environment in a way that—within the altered urban structure—the functions of society would cause a less serious environmental impact than before [5–8]. Densification, an improved infrastructure for public transport, and new energy-efficient buildings are supposed to be the core elements of sustainable urban development [9–12]. Short distances and convenient public transport services reduce the need for private vehicle use [13–15]. Smaller and more energy-efficient modern living and working spaces consume less heating energy that—within the compact urban form and centralised infrastructure—can be produced through combined heat and power or waste-to-energy generation [1,16–18]. In addition, urban planning solutions that improve the microclimate can directly reduce the need for energy consumption within the built environment. For example, large parks can cool down local urban

thermal environments [19] and thus reduce the need for cooling indoor spaces within the area. Recently, a practical application has been introduced for identifying the areas within a city that have the most potential for such benefits [20].

According to numerous regional and city-level climate change mitigation strategies, greenhouse gas (GHG) emission reduction targets are typically set to certain reference years, and the releases from ground transport and housing are modelled and followed on a yearly basis. If such yearly emissions in the reference year in the future actualise as low as targeted, society is seen to have reduced its emissions according to the mitigation strategy. However, emissions that are caused to get there, i.e., by the construction activities that are imperative for modifying the built environment, are not necessarily taken into account. Even if building new public transport infrastructure and new energy-efficient buildings—typically united with urban densification policies—can cut future GHG emissions by reducing private vehicles and improving the energy efficiency of space use, the manufacture and transport of materials, as well as construction work, cause a substantial amount of initial GHG emissions [21–23]. Therefore, the gains in transport and housing emissions contribute to climate change mitigation only after the demerits of the new construction are redeemed.

Urban planners are in a unique position to steer and regulate urban regeneration [9,24,25]. Given the massive material flows of new construction, it seems obvious that the environmental aims of urban planning should include the immediate development phase in addition to the future use phase of the built environment. Yet, the potential of urban planning to contribute to mitigation of climate change is seen to lie merely in the use phase—planners exclusively aim to reduce GHG emissions from future housing and daily journeys through urban design [12]. The logic may link to the long-time overall perspective of urban planning; if cumulative GHG emissions are considered within the time frame as long as the presumed lifespan of urban structures, the emissions caused in the construction phase may well appear insignificant [26–28]. However, if GHG emissions are still considered cumulatively but within the time frame of climate change mitigation targets and the prompt and substantial GHG emissions reduction required, the negative effect of the immediate emissions from construction becomes much more relevant.

Multiple studies have already stressed the rising importance of the construction phase in a building or a residential area's life cycle GHG emissions [21,29–31]. It can thus be a prominent part of future sustainability strategies to extend the lifespan and to optimise the use of the existing building stock through energy renovations and housing policies instead of replacing old buildings with new construction. In addition, where new construction is still necessary, more attention should be paid to reducing GHG emissions from the manufacture and transport of materials and energy-intensive worksite activities. A growing body of literature have analysed the climate change mitigation potential of wood construction, decreased embodied energy of cement, concrete and bricks, recycling of building materials, and use of local resources [32–38]. As an element of urban planning, the use of low carbon building materials can be facilitated, promoted, or even obliged in plan provisions and written plan regulations.

Besides aboveground structures, earthworks account for a considerable amount of GHG emissions due to massive rock and soil material flows that are typically driven to and from the construction site, causing heavy truck traffic. In Finland, the yearly consumption of natural mineral aggregates is approximately 100 million tonnes, and local depletion of materials gradually lengthens transport distances [39]. Furthermore, urban excavated soil and rock are more often seen as troublesome discard than a useful resource that could be consumed on-site or in other projects [40]. The literature on GHG savings from the on-site use of excavated soil and rock as construction materials is rather scarce, and there is a need for scientific evidence and further research to assess the environmental potential of reuse [40]. The few studies that have investigated the climate impact with reusing excavated materials at the construction site are, however, encouraging. Chittoori et al. [41] reported that the reuse of excavated soil within a pipeline construction project reduced the climate impact of material

management by 85%. Eras et al. [42] counted the reuse of 700,000 m³ of excavated materials in an industrial construction project as saving 4000 tonnes of CO₂ from transportation fuels.

The purpose of this study is to investigate whether reducing the negative environmental impact of earthworks could be part of sustainable urban planning and to assess the magnitude of such contribution to climate change mitigation. The respective research questions are:

- (i) Is it possible to reduce the negative environmental impact of earthworks through urban planning?
- (ii) Is the outcome of such an action comparable to the achievements of prevalent practices, especially in climate change mitigation?

The rest of the paper is structured as follows. Methodology is introduced in Section 2. Section 3 presents the results of the analysis. The findings are discussed in Section 4, and Section 5 concludes the paper.

2. Research Design

A single case study and three focus group interviews were conducted, first to assess the magnitude of emissions reduction that can be achieved through an urban planner's control over earthworks, and second to investigate the relevance of the findings beyond the single case. In the case study, an example of a situation where the circumstances were seen as favourable for a pioneering act of an urban planner to be taken to coordinate earthworks with appeal to climate change mitigation was examined, and the emissions savings achieved were modelled. In turn, the focus groups allowed urban planning and earth construction professionals from several cities and a few other organisations to discuss the case and the results and critically appraise the stature of the findings.

2.1. Case Study

The Kuninkaantammi case area is a 120-hectare-wide residential development for 5000 inhabitants that is located in the northwest corner of Helsinki, the capital of Finland. Before the development, two-thirds of the area was inbuilt woodland and one-third was industrial brownfield and scattered low-rise residential blocks, mainly built in the 1950s. The soil—bedrock and clay in this case study area—represents typical southern Finnish soil. The planning situation is also typical of larger Finnish cities.

The pre-construction work began in 2013, removal of current functions and civil engineering work in 2014, housing construction in 2015, and the development is planned to be finished by 2025. The total floor area for housing will be 230,000 m², and for business and services, it will be 120,000 m². The case study covers three planning solutions that were initially intended to reduce the transport of excavated materials.

Whereas most of the area rests on a rocky ridge and the soil is mostly suitable for construction, earthworks at three separate sites were identified to produce an extensive surplus of materials or to require a considerable amount of imported materials. First, it was a given alignment that a one-kilometre-long tunnel, passing under Central Park from Paloheinä to Kuninkaantammi, was to be excavated in the bedrock to accommodate an extension of a regional bus route. Approximately 250,000 tonnes of blasted stone were to be released and accommodated. Second, in the immediacy of this excavation site, a layer of soft clay, extending to a depth of a few metres, was to be removed from an area of 10,000 m² and replaced with more solid foundation material. Around 50,000 tonnes of clay were to be disposed of, plus approximately 300,000 tonnes of rock material required for earthworks. Third, a five-metre-deep and 26,000-m²-wide pond had been filled over time with assorted earth and biomasses. Given the smell of the decomposing material and the instability of the ground, the pond was to be refurbished. The pond contained approximately 200,000 tonnes of assorted materials, part of them being contaminated soil.

The first planning solution was to arrange the crushing of the blasted stone right outside of the tunnel and to coordinate the immediate earthworks—which required only slightly more rock materials

than those released from the excavation site—in a way that the crushed materials could be transported directly to the nearby building sites where they were used for necessary earth construction. The second planning solution was to pile the clay that was unsuitable for construction into a landscaping hill that provides a barrier between a recreational area and the main road and serves as an additional extension of the recreational area. Some of the blasted stone from the tunnel was used to build a supporting structure for the clay hill. The third planning solution was not to empty the entire pond but to leave in place as much material as possible by building a technical control system to collect the slowly releasing flow of adverse gases and liquids. The buildings that were originally planned for the pond area were relocated elsewhere, and the pond became a recreational area. An urban planner coordinated all three planning solutions with support from the city and especially their mass coordinator. The positions of the planning solutions in Kuninkaantammi are illustrated in Figure 1.



Figure 1. The three planning solutions in Kuninkaantammi.

The authorities representing the city of Helsinki were interviewed to define where the surplus earth materials would have been exported to—and where the required rock materials would have been imported from—if the logistics of the earthworks had not been optimised and the local use for the surpluses introduced. Besides greenhouse gases, consumption of fuel and energy and five other types of atmospheric emissions—nitrogen oxides (NO_x), sulphur dioxide (SO₂), volatile organic compounds (VOCs), particles, and carbon monoxide (CO)—were calculated for the actualised earthworks and correspondingly to the comparison. The analysis included the production and processing of materials, their placement in or removal from the earth structures, and transportation. Only the direct consumption of fuel and only the direct atmospheric emissions from the use of vehicles and machinery were considered, i.e., the manufacture and maintenance were not included in the analysis.

The Excel-based life cycle inventory analysis program MELI HEL (version 2.0) (VTT, Espoo, Finland) was used for the calculations. The MELI HEL model is an updated and tailored application of

the Finnish life cycle impact assessment procedure for earth constructions (MELI) that had already been developed in 1999 by VTT Technical Research Centre of Finland [43,44]. Besides the MELI methodology, VTT constructed a supporting database for the environmental burdens of earth construction materials and unit operations and the related traffic exhaust emissions and energy consumption. Given that the MELI HEL model uses the updated and tailored database, only the type, dimensions, and materials of each earth construction structure and transportation distances were required as case-specific input data. Transportation distances were divided into urban and country mileage.

2.2. Focus Groups

Three focus group interviews were conducted in the city of Helsinki during the case study—in August 2015, December 2015, and March 2016. Four Finnish cities and four other organisations—two regional councils, one consulting company, and one national association of infra contractors—were invited; the number of representatives was not limited. The first interview was held with eleven participants representing four cities and three other organisations, the second one with twelve participants from four cities and two other organisations, and the third one with fourteen participants representing all four cities and four other organisations. Eight of the participants attended all three focus groups, including at least one person from each of the four cities. Five participants attended two of the groups, and three participants attended only one group. The interviewees are experienced professionals in urban planning or earth construction and are actively involved in research projects concerning the contribution of urban planning to climate change mitigation. A researcher acted as a moderator for each focus group meeting. The conversations were recorded in writing. Each meeting lasted approximately one and a half hours, including an introduction and a discussion.

The intention of the first focus group was to ascertain the potential contribution of the research. The research plan and the suggested case area were introduced to the interviewees. In addition, a presentation was given about strategic coordination of earth material flows in the city of Helsinki. The second focus group was arranged at a time when most of the preliminary work for the case study was done and the detailed scope of the analysis could be defined. The three planning solutions proposed for consideration and the suggested life cycle inventory analysis program MELI HEL were introduced to the group for critical commentary. The third focus group primarily aimed to evaluate the stature of the results from the case study and to discuss their implications. The results were presented to the group, and the magnitude of the GHG reduction from earthworks was compared to the climate change mitigation potential of a more traditional objective for urban planning: retrenchment of private vehicle use. It was investigated whether the results have the potential to guide policies and practices and if the magnitude of the GHG reduction is enough to change the current status of earthworks in the environmental strategies of urban planning.

The written data collected in the focus groups was analysed thematically. Given the general intention of the focus group method, the use of counts is less important than a rich investigation of content and the complexities of meaning [45,46]. The group served as the fundamental unit of analysis, and single responses were primarily analysed as a part of interactive conversation. As the first data display, a set of codes was developed to represent the identified themes and subthemes and were manually applied to the written record (raw data) as summary markers for later phases of analysis. Given the nature of the focus group data and the fundamental unit of analysis, the codes were applied to relatively long clips of discussions. As the second display, the data was manually sorted under the theme codes and new, more specific coding was conducted. At this point, the data was reduced based on relevance to the research questions. As the third and final data display, the responses were arranged according to the final themes.

3. Results

The findings of the case study revealed the magnitude of possible emission reductions through urban planners' control over earthworks, whereas the findings of the focus groups shed light on the

relevance of the findings beyond the single case. The results of the case study are presented first, followed by the findings of the focus groups.

3.1. Case Study

The three planning solutions that were implemented in Kuninkaantammi and examined in this study reduced CO₂ emissions from earthworks by 2360 tonnes. Notable savings were also achieved in other emission categories. The results of the emissions modelling are first itemised separately for each planning solution in Sections 3.1.1–3.1.3. Finally, the total emissions reductions and their distribution between the three planning solutions are presented in Section 3.1.4.

3.1.1. Planning Solution 1: Local Use of the Blasted Stone

The blasted stone from the excavated one-kilometre-long tunnel was crushed right outside of the tunnel and used entirely locally, within an average distance of half a kilometre from the tunnel. A total of 143,000 m³ of crushed stone was needed for immediate earthworks, of which 122,000 m³ could be produced from the blasted stone, leading to a supplement import of 21,000 m³. The most realistic comparison was that the blasted stone would have been transported away from the case area and deposited in the sea to reclaim land within other urban development sites in Helsinki. The transportation distance would have been approximately 25 km. Without the coordination and the local use of the blasted stone, all the rock materials that were needed for the immediate earthworks would have been imported. The required amount of crushed stone would have been available at the distance of 20 km. The results of the emissions modelling are presented in Table 1.

Table 1. Emissions savings from the local use of the blasted stone.

	Solution	Comparison	Difference	
Blasted stone (t)	243,840	243,840	0	0%
Transportation distance (km)	0.5	25	24.5	98%
Imported crushed stone (t)	42,000	286,000	244,000	85%
Transportation distance (km)	20	20	0	0%
Fuel consumption (L)	261,364	624,922	363,558	58%
Energy consumption (kWh)	976,728	4,641,387	3,664,659	79%
CO ₂ (kg)	534,364	1,503,433	969,069	64%
NO _x (kg)	6928	14,136	7208	51%
SO ₂ (kg)	515	523	8	2%
VOC (kg)	1423	1781	358	20%
Particles (kg)	865	1016	151	15%
CO (kg)	3486	4207	721	17%

3.1.2. Planning Solution 2: Clay Hill

The 50,000 tonnes of removed soft clay, which was unsuitable for construction, were piled onto a landscaping hill at a distance of approximately 100 m. In addition, 17,000 m³ of the blasted stone from the tunnel was used to build a supporting structure for the clay hill; however, this has already been included in the previous calculation. The most realistic comparison was that the soft clay would have been transported away from the case area. Without stabilisation (an expensive and even more emission-intensive option), the closest admittance site for the clay would have been at a distance of approximately 40 km. The results of the emissions modelling are presented in Table 2.

Table 2. Emissions savings from the local use of the soft clay.

	Solution	Comparison	Difference	
Soft clay (t)	49,500	49,500	0	0%
Transportation distance (km)	0.1	40	39.9	100%
Fuel consumption (L)	10,461	88,476	78,015	88%
Energy consumption (kWh)	36,460	822,856	786,396	96%
CO ₂ (kg)	27,829	237,638	209,809	88%
NO _x (kg)	286	1872	1586	85%
SO ₂ (kg)	0	2	2	100%
VOC (kg)	37	94	57	61%
Particles (kg)	17	43	26	60%
CO (kg)	93	206	113	55%

3.1.3. Planning Solution 3: Refurbishment of the Pond

Instead of removing all of the approximately 200,000 tonnes of assorted earth and biomasses from the pond, only the top layer was replaced, which made the pond suitable for a recreational area but not for a construction site. The contaminated soils (20%) of the removed top layer were separated and transported for treatment at a distance of approximately 50 km, and the rest (80%) of the earth was restored into the pond. Three additional batches of rock materials were needed for the new structure, the transportation distances being 0.5 km, 20 km, and 25 km. The most realistic comparison was that the pond would have been entirely emptied (as initially suggested), all the removed assorted earth and biomasses would have been transported away from the case area, and replacement earth would have been imported for refilling the pond. The transportation distances would have been approximately 25 km for the 135,000 m³ of earth to be disposed and 20 km for the 156,000 m³ of earth to be imported. The results of the emissions modelling are presented in Table 3.

Table 3. Emissions savings from the minimal refurbishment of the pond.

	Solution		Comparison		Difference				
Material (1000 tonnes)	31.5	7.4	18.2	6.2	26.0	202.8	312.0	425.5	82%
Transportation distance (km)	0	50.0	0.5	20.0	25.0	25.0	20.0	-	-
Fuel consumption (L)			54,523			512,166		457,643	89%
Energy consumption (kWh)			452,825			4,616,621		4,163,796	90%
CO ₂ (kg)			138,351			1,322,123		1,183,772	90%
NO _x (kg)			1134			10,423		9289	89%
SO ₂ (kg)			0			9		9	100%
VOC (kg)			80			638		558	87%
Particles (kg)			37			281		244	87%
CO (kg)			178			1387		1209	87%

3.1.4. Total Impacts of the Three Planning Solutions

The total emissions savings from improved control over earthworks in the Kuninkaantammi case and their distribution between the three planning solutions are presented in Table 4.

Table 4. The distribution of the emissions savings between the three planning solutions.

	Total	(1) Blasted Stone	(2) Clay Hill	(3) Pond			
Fuel consumption (L)	899,216	363,558	40%	78,015	9%	457,643	51%
Energy consumption (kWh)	8,614,851	3,664,659	43%	786,396	9%	4,163,796	48%
CO ₂ (kg)	2,362,650	969,069	41%	209,809	9%	1,183,772	50%
NO _x (kg)	18,083	7208	40%	1586	9%	9289	51%
SO ₂ (kg)	19	8	42%	2	11%	9	47%
VOC (kg)	973	358	37%	57	6%	558	57%
Particles (kg)	421	151	36%	26	6%	244	58%
CO (kg)	2043	721	35%	113	6%	1209	59%

3.2. Focus Groups

In the focus group interviews, the participants clearly stated that the material flows of earth construction are not yet widely considered in the climate change mitigation efforts of urban planning. The thematic analysis of the focus groups suggests a two-folded reasoning for this. First, cities' climate change mitigation strategies seem to be dominated by other means of eco-efficiency and especially by urban density. Second, while urban planners have a number of issues to consider, the measures stated in the strategic guidelines are typically prioritised. As one of the interviewees put it: "The issue (emissions reduction through coordination of the earthworks) is indeed in its infancy" (FG3, city 2). However, the participants in the focus groups expressed a growing interest in cutting these emissions, and they widely agreed that environmental aspects other than urban density could and should be considered in urban planning. Consequently, the interviewees stated that the problem of GHG emissions from earthworks is increasing in importance and that a few cities are already taking a lead for others to follow. The interviewees also agreed that there is potential for both environmental and monetary benefits in the improved coordination of rock and soil material flows.

Throughout the focus groups, co-operation and availability of numeric information were seen as vital for strengthening the issue's momentum. The interviewees saw co-operation and knowledge sharing within a city, between cities, and between organisations as a major trigger. Other cities were eager to learn from early adopters. The participants highlighted the importance of interdepartmental cooperation and its problems. As one interviewee stated: "Knowledge sharing would be smoother if everyone working on this issue sat in the same building. We already have knowledge to share" (FG3, City 1).

Numeric information was said to be very important in clarifying the magnitude of the emissions reduction potential, and potentially to also reveal monetary benefits. As one interviewee stated: "Discussions about GHG emission reductions are often rather abstract, and thus these concrete results are really beneficial" (FG2, City 1). It was explained that because urban planners do not have sufficient data, they are unable to estimate whether putting effort and resources into controlling the earthworks has enough potential to reduce GHG emissions sufficiently to be worthwhile. Therefore, the results of the case study that were presented and discussed in the last focus group were met with enthusiasm. As one of the interviewees stated: "It is rather confusing, when everything is stated to be sustainable, but no numbers are ever presented. This research is good, because the results are numeric and elucidate the concept." (FG3, City 1). Another participant added: "Direct means to reduce GHG emissions through urban planning are rather rare" (FG3, Organisation 4). Finally, the interviewees expressed their hope that the case study results could be used to guide and convert policies and practices, to gain more resources for coordinating the earthworks, and possibly also to speed up administrative processes.

4. Discussion

This study examined the capability and motivation of urban planning to reduce the environmental impact of earthworks and the potential magnitude of such contribution to climate change mitigation. The main interest of the research was to investigate whether reducing the negative environmental impact of earthworks could be a respective part of sustainable urban planning. A single case study and three focus group interviews were conducted to answer the following research questions:

- (i) Is it possible to reduce the negative environmental impact of earthworks through urban planning?
- (ii) Is the outcome of such an action comparable to the achievements of prevalent practices, especially in climate change mitigation?

4.1. Case Kuninkaantammi: Certain and Immediate, Remarkable Emissions Reduction

The results of the case study show that an urban planner's control over earthworks can result in remarkable GHG emissions reduction, in addition to notable savings in other emission categories. The three planning solutions implemented in a residential area in Helsinki reduced the CO₂ emissions

from earthworks by 2360 tonnes. Compared to the results by Ottelin et al. [47], it saves about the same amount of CO₂ as 250 inhabitants abandoning their private cars for 10 years and using only public transportation. Compared to the prevalent practice of reducing private vehicle use through urban planning—where emissions savings come slowly and uncertainly (not least because of the rebound effect e.g., [48])—the environmental benefits of controlling earthworks are both certain and immediate.

It is rarely considered in the strategies of sustainable urban planning that the carbon intensity of both traffic fuels and energy production is constantly decreasing. A similar amount of energy consumption most likely causes more emissions in the immediate development phase than in the future use phase of the built environment. If the GHG emissions of new construction are seen as *carbon investments* that are supposed to be paid back and eventually become beneficial through savings in future traffic fuel and other energy use, there is a risk that some of the investments will fail due to the uncertainties of the future. At least within the time frame of the commitments to climate change mitigation and related emission reduction targets, more emissions may be caused than saved through such strategies [21–23]. The further in the future the return is expected, the higher are the uncertainties [49,50]. Therefore, the certain and immediate emissions savings, such as those of earthworks, could be more effective than the prevalent practices of building a better future.

According to Magnusson et al. [40], two previous studies [41,42] have reported the reuse of excavated rock and soil on-site to have saved approximately 4.8 and 12 kg CO₂ per tonne of material, respectively. The two on-site reuse solutions examined in this case study in Finland (*local use of the blasted stone and clay hill*) resulted in CO₂ savings of approximately 4.0 and 4.2 kg per tonne of excavated rock and soil, respectively. The third planning solution examined in this study (*refurbishment of the pond*), which mainly reduced the amount of the material to be excavated, saved approximately 5.8 kg CO₂ per tonne of material that would have otherwise been excavated and replaced with imported soil. Therefore, the results of this case study seem to be of the same scale as previous results and, by no means, exaggerative. Given that the life cycle perspective in all three studies is somewhat limited, the factual emission savings are likely to be even bigger.

4.2. Beyond the Kuninkaantammi Case: Implementing the Results into the Planning Process

According to the focus group interviews, the results of the case study can be used to guide and convert policies and practices. The material flows of earth construction are not yet widely considered in urban planning, but the issue seems to be gaining momentum. The interviewees strongly assumed that consideration of the material flows would lead to both environmental and monetary benefits, which was stated to be necessary for an effect on decision-making. In the current situation—where unbuilt bedrock areas with only a modest need for earthworks become scarcer, driving the trend to build on areas of clay, with a challenging topography and the need for quarrying—there is a growing need for controlling the GHG emissions from earthworks in varying cities.

The first planning solution implemented in the Kuninkaantammi case has already become increasingly more common in construction areas in Finland. In general, this type of solution requires early mapping of the utilisation possibilities, preplanning, and space for crushing and sorting the material. Even if crushing were not possible on-site, there are still several options for reuse on-site, such as stone walls, dam and river structures, road structures, supporting embankments, and pre-construction (e.g., land plots). This kind of local reuse is possible to consider in almost any project. However, if crushing were possible on-site, the options for reuse increase as the crushed material can be used in several layers in road structures [51]. The second planning solution has traditionally been used in highway building and other massive infrastructure projects, but it can also be customised for other types of development sites. Other recent examples are Ida Aalberg Park and Alakivi Park in Helsinki, where the reuse of 15,000 m³ and 34,000 m³ of stabilised clay from surplus soils resulted in significant monetary saving in both cases [51]. This type of solution requires early mapping of the utilisation possibilities, preplanning, and space for sorting the material. The third planning solution requires accurate information on the properties of the contaminated soil. Recent

examples in Finland include Perkkää park in Espoo and Jätkäsaari park in Helsinki, where the clay was stabilised in slopes and then reused on-site [52].

In addition to the three planning solutions in the Kuninkaantammi case, there are various other solutions that could be considered on a neighbourhood scale. Crushed stone is valuable for different uses, such as sub-base structures for roads and base layers for new buildings. In addition, due to its high filtration quality, crushed stone is also used for storm water collection and storage systems [51]. Surplus soils have traditionally been used in noise barriers and also in landscape walls, planting, and structural growing beds. Furthermore, the reuse of the biologically diverse topsoil can potentially decrease the need of newly produced commercial soil and increase the ecological value of the site. An overseas example of an innovative and extensive use of excavation soil is a huge land sculpture *Northumberlandia* (“*Lady of the North*”) in England. The reclining female figure, completed in 2012, is located near Cramlington, Northumberland. The 34-metre-high and 400-metre-long sculpture is made of 1.5 million tonnes of earth from the neighbouring Shotton Surface mine and set in a 19-hectare public park [53]. Besides on-site reuse solutions, reuse in other projects or at a facility may offer further possibilities; mass balance on a larger scale between multiple projects can potentially be even more beneficial but will demand even more extensive cooperation [40].

Technically, the three planning solutions examined in the Kuninkaantammi case study can be applied to typical urban planning projects. The common critical steps for all these solutions are: (1) minimisation of the need for excavation and demolition; (2) identifying the needs and availability of different materials; (3) locating the spots where materials are needed; (4) finding out where the surplus can be prefabricated; and (5) locating where to take any existing waste.

As Kuninkaantammi was a pilot case, earthworks received special attention in the urban planning process. An urban planner coordinated all three planning solutions, with support from the city organisation and especially from their mass coordinator. The design solutions were modified during the planning to balance the demand for surplus soils with their supply. This was possible due to the start of optimising at an early planning phase. Partly due to good and well-timed communication with the residents, there was no need to apply for permission for the temporary on-site crushing, and temporary stocking was possible on-site. To make the reduction of earthworks GHG emissions a widespread process, three factors need to be addressed: (1) identifying the earthworks as an important issue; (2) getting enough resources to coordinate them; and (3) incorporating the coordination of earthworks as an essential part of the urban planning process.

According to the focus groups, earth construction is not included in city-level climate change mitigation strategies. While the interviewees saw the reuse of surplus soils as an important and relevant issue in urban planning, especially in larger schemes, the resources given for specific action were stated to be prioritised based on strategic guidelines. The same tendency seems to be present in different international certification schemes and assessment tools that do not give any major role for controlling the earthworks in sustainable urban planning [54–56]. Therefore, the potential of earthworks in sustainable urban planning seems to be undervalued when the results of this study are reflected in strategies, guidelines, and certification requirements. According to the focus groups, multidisciplinary teams of experts could greatly aid urban planners to successfully coordinate earth construction. The same solutions and instructions might not always apply, and solutions might also need to be altered during the design phases when the initial data increases and gets updated. Local and plan-specific insights and solutions might be needed in addition to general guidelines and adequate expertise. Key parties sharing a common goal and commitment is essential for reaching the right timing and determining decisions through the process.

Additional diverse case studies are needed to further increase understanding of the GHG emissions reduction potential of earthworks. Given that current research is mainly focused on the waste flows of construction materials, there is a lack of knowledge on the overall management practices of excavated soil and rock [40]. Numerical evidence of the environmental and monetary benefits of

reuse and the potential role of urban planners in coordinating multidisciplinary action are the key areas of interest.

5. Conclusions

The results of this study challenge the prevailing logic of urban planning to reduce the environmental load mainly in the distant future by altering the built environment in a way that—within the altered urban structure—the functions of society would cause a less serious environmental impact than before. The findings widen our understanding of the capability of urban planning and the potential scope of climate change mitigation in cities. The case study shows that urban planning can achieve remarkable GHG emissions reduction through improved control over earthworks. Consequently, the environmental aims of urban planning should include not only the future use phase of the built environment, but also the immediate development phase. This way, the contribution of urban planning in the mitigation of climate change can be significantly greater. Unfortunately, the findings of the focus groups indicate that currently earth construction is not considered in GHG reduction strategies of urban planning and is not seen as an important factor in climate change mitigation schemes. Therefore, there seems to be an untapped potential for improved resource efficiency and additional GHG emissions reduction in urban planners' control over earthworks.

The results of the study suggest that reducing GHG emissions from earthworks demands a strong vision from the planner, cooperation with many different actors, and smart decisions in multiple planning phases. Collaboration seems to be important both within a city and between neighbouring cities. Urban planners must be given the mandate and support from other experts to design and coordinate planning solutions that decrease the rock and soil material flows to and from areas of urban development. Based on this research, potential can be seen in positioning urban planners' control over earthworks into cities' climate change mitigation strategies and considering different measures to reduce the GHG emission of earthworks in varying urban development projects. However, such policies entail increased awareness and strong numeric evidence of the environmental, and potentially monetary, benefits. From the urban planners' perspective, these findings can help stress the importance of the issue within their organisations and gather the required resources for action. This study both adds to the cumulative knowledge from case studies and evokes further academic discussion on the issue. It provides practical numerical data that clarifies the magnitude of the emissions reduction potential of earthwork control in urban planning. Furthermore, it underlines the importance of reaching beyond the current understanding of climate change mitigation in cities and the prevailing logic of sustainable urban planning.

Author Contributions: The first author, E.-S.S., and second author, P.K., are responsible for initiating and executing the research (collecting data and conducting analysis) and for writing the paper together with the third author, E.K. The fourth author, A.-K.N., contributed substantially to the interpretation of the data and reviewing the content of the work. All authors have read and approved the final manuscript.

Funding: The authors thank the cities of Helsinki, Espoo, Vantaa, and Lahti, the Helsinki-Uusimaa Regional Council and Infra Contractors Association in Finland for research funding. The views expressed by the authors do not necessarily reflect those of the funders.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, and interpretation of the data; in the writing of the manuscript; and in the decision to publish the results.

References

1. Dodman, D. Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *Environ. Urban.* **2009**, *21*, 185–201. [[CrossRef](#)]
2. Bulkeley, H. Cities and the Governing of Climate Change. *Annu. Rev. Environ. Resour.* **2010**, *35*, 229–253. [[CrossRef](#)]
3. Hoornweg, D.; Sugar, L.; Gomez, C.L.T. Cities and greenhouse gas emissions: Moving forward. *Environ. Urban.* **2011**, *23*, 207–227. [[CrossRef](#)]

4. Edenhofer, O.; Pichs-Madruga, R.; Sokona, Y.; Farahani, E.; Kadner, S.; Seyboth, K.; Adler, A.; Baum, I.; Brunner, S.; Eickemeier, P.; et al. (Eds.) *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
5. Myers, D.; Kitsuse, A. Constructing the future in planning: A survey of theories and tools. *J. Plan. Educ. Res.* **2000**, *19*, 221–231. [[CrossRef](#)]
6. Shane, A.M.; Graedel, T.E. Urban environmental sustainability metrics: A provisional set. *J. Environ. Plan. Manag.* **2000**, *43*, 643–663. [[CrossRef](#)]
7. Gunnarsson-Östling, U.; Höjer, M. Scenario Planning for Sustainability in Stockholm, Sweden: Environmental Justice Considerations. *Int. J. Urban Reg. Res.* **2011**, *35*, 1048–1067. [[CrossRef](#)]
8. Bourdic, L.; Salat, S. Building energy models and assessment systems at the district and city scales: A review. *Build. Res. Inf.* **2012**, *40*, 518–526. [[CrossRef](#)]
9. Kenworthy, J.R. The eco-city: Ten key transport and planning dimensions for sustainable city development. *Environ. Urban.* **2006**, *18*, 67–85. [[CrossRef](#)]
10. Eaton, R.L.; Hammond, G.P.; Laurie, J. Footprints on the landscape: An environmental appraisal of urban and rural living in the developed world. *Landsc. Urban Plan.* **2007**, *83*, 13–28. [[CrossRef](#)]
11. Glaeser, E.L.; Kahn, M.E. The greenness of cities: Carbon dioxide emissions and urban development. *J. Urban. Econ.* **2010**, *67*, 404–418. [[CrossRef](#)]
12. Säynäjoki, E.S.; Heinonen, J.; Junnila, S. The Power of Urban Planning on Environmental Sustainability: A Focus Group Study in Finland. *Sustainability* **2014**, *6*, 6622–6643. [[CrossRef](#)]
13. Holden, E.; Norland, I.T. Three Challenges for the Compact City as a Sustainable Urban Form: Household Consumption of Energy and Transport in Eight Residential Areas in the Greater Oslo Region. *Urban Stud.* **2005**, *42*, 2145–2166. [[CrossRef](#)]
14. Grazi, F.; van den Bergh, J.C.J.M.; van Ommeren, J.N. An empirical analysis of urban form, transport, and global warming. *Energy J.* **2008**, *29*, 97–122. [[CrossRef](#)]
15. Kennedy, C.; Steinberger, J.; Gasson, B.; Hansen, Y.; Hillman, T.; Havránek, M.; Pataki, D.; Phdungsilp, A.; Ramaswami, A.; Mendez, G.V. Greenhouse gas emissions from global cities. *Environ. Sci. Technol.* **2009**, *43*, 7297–7302. [[CrossRef](#)] [[PubMed](#)]
16. Norman, J.; MacLean, H.L.; Kennedy, C.A. Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions. *J. Urban. Plan. Dev.* **2006**, *132*, 10–21. [[CrossRef](#)]
17. Rickwood, P. Residential operational energy use. *Urban Policy Res.* **2009**, *27*, 137–155. [[CrossRef](#)]
18. Satterthwaite, D. How urban societies can adapt to resource shortage and climate change. *Philos. Trans. R. Soc. A* **2011**, *369*, 1762–1783. [[CrossRef](#)] [[PubMed](#)]
19. Yan, H.; Wu, F.; Dong, L. Influence of a large urban park on the local urban thermal environment. *Sci. Total Environ.* **2018**, *622–623*, 882–891. [[CrossRef](#)] [[PubMed](#)]
20. Kazak, J.K. The use of a decision support system for sustainable urbanization and thermal comfort in adaptation to climate change actions—The case of the Wrocław larger urban zone (Poland). *Sustainability* **2018**, *10*, 1083. [[CrossRef](#)]
21. Säynäjoki, A.; Heinonen, J.; Junnila, S. A scenario analysis of the life cycle greenhouse gas emissions of a new residential area. *Environ. Res. Lett.* **2012**, *7*, 034037. [[CrossRef](#)]
22. Chester, M.; Horvath, A. High-speed rail with emerging automobiles and aircraft can reduce environmental impacts in California’s future. *Environ. Res. Lett.* **2012**, *7*, 034012. [[CrossRef](#)]
23. Chester, M.; Pincetl, S.; Elizabeth, Z.; Eisenstein, W.; Matute, J. Infrastructure and automobile shifts: Positioning transit to reduce life-cycle environmental impacts for urban sustainability goals. *Environ. Res. Lett.* **2013**, *8*, 015041. [[CrossRef](#)]
24. Bulkeley, H.; Betsill, M. Rethinking Sustainable Cities: Multilevel Governance and the Urban Politics of Climate Change. *Environ. Politics* **2005**, *14*, 42–63. [[CrossRef](#)]
25. Bithas, K.P.; Christofakis, M. Environmentally sustainable cities: Critical review and operational conditions. *Sustain. Dev.* **2006**, *14*, 177–189. [[CrossRef](#)]
26. Winther, B.N.; Hestnes, A.G. Solar versus green: The analysis of a Norwegian row house. *Sol. Energy* **1999**, *66*, 387–393. [[CrossRef](#)]
27. Junnila, S.; Horvath, A.; Guggemos, A.A. Life-cycle assessment of office buildings in Europe and the United States. *J. Infrastruct. Syst.* **2006**, *12*, 10–17. [[CrossRef](#)]

28. Ortiz, O.; Castells, F.; Sonnemann, G. Sustainability in the construction industry: A review of recent developments based on LCA. *Constr. Build. Mater.* **2009**, *23*, 28–39. [[CrossRef](#)]
29. Thormark, C. A low energy building in a life cycle—Its embodied energy, energy need for operation and recycling potential. *Build. Environ.* **2002**, *37*, 429–435. [[CrossRef](#)]
30. Blengini, G.A.; Di Carlo, T. Energy-saving policies and low-energy residential buildings: An LCA case study to support decision makers in Piedmont (Italy). *Int. J. Life Cycle Assess.* **2010**, *15*, 652–665. [[CrossRef](#)]
31. Gustavsson, L.; Joelsson, A. Life cycle primary energy analysis of residential buildings. *Energy Build.* **2010**, *42*, 210–220. [[CrossRef](#)]
32. Thormark, C. Environmental analysis of a building with reused building materials. *Int. J. Low Energy Sustain. Build.* **2000**, *1*, 1403–2147.
33. Hammond, G.P.; Jones, C.I. Embodied energy and carbon in construction materials. *Proc. Inst. Civ. Eng. Energy* **2008**, *161*, 87–98. [[CrossRef](#)]
34. Sathre, R.; Gustavsson, L. Using wood products to mitigate climate change: External costs and structural change. *Appl. Energy* **2009**, *86*, 251–257. [[CrossRef](#)]
35. Habert, G.; Roussel, N. Study of two concrete mix-design strategies to reach carbon mitigation objectives. *Cem. Concr. Compos.* **2009**, *31*, 397–402. [[CrossRef](#)]
36. Seyfang, G. Community action for sustainable housing: Building a low-carbon future. *Energy Policy* **2010**, *38*, 7624–7633. [[CrossRef](#)]
37. Imbabi, M.S.; Carrigan, C.; McKenna, S. Trends and developments in green cement and concrete technology. *IJSBE* **2012**, *1*, 194–216. [[CrossRef](#)]
38. Cabeza, L.F.; Barreneche, C.; Miró, L.; Morera, J.M.; Bartolí, E.; Fernández, A.I. Low carbon and low embodied energy materials in buildings: A review. *Renew. Sustain. Energy Rev.* **2013**, *23*, 536–542. [[CrossRef](#)]
39. Lonka, H.; Loukola-Ruskeeniemi, K.; Ehrukainen, E.; Gustafsson, J.; Honkanen, M.; Härmä, P.; Jauhiainen, P.; Kuula, P.; Nenonen, K.; Pellinen, T.; et al. *Kiviaines- ja Luonnonkiviteollisuuden Kehitysnäkymät*; Ministry of Employment and Economy: Helsinki, Finland, 2015; p. 75, ISSN 1797-3554.
40. Magnusson, S.; Lundberg, K.; Svedberg, B.; Knutsson, S. Sustainable management of excavated soil and rock in urban areas—A literature review. *J. Clean. Prod.* **2015**, *93*, 18–25. [[CrossRef](#)]
41. Chittoori, B.; Puppala, A.J.; Reddy, R.; Marshall, M. Sustainable reutilization of excavated trench material. *GeoCongress* **2012**, 4280–4289. [[CrossRef](#)]
42. Eras, C.J.J.; Gutierrez, A.S.; Capote, D.H.; Hens, L.; Vandecasteele, C. Improving the environmental performance of an earthwork project using cleaner production strategies. *J. Clean. Prod.* **2013**, *47*, 368–376. [[CrossRef](#)]
43. Eskola, P.; Mroueh, U.M.; Juvankoski, M.; Ruotoistenmäki, A. *Life Cycle Analysis of Road and Earth Construction*; VTT Research Notes; VTT: Espoo, Finland, 1999; p. 127.
44. Mroueh, U.M.; Eskola, P.; Laine-Ylijoki, J. Life-cycle impacts of the use of industrial by-products in road and earth construction. *Waste Manag.* **2001**, *21*, 271–277. [[CrossRef](#)]
45. Massey, O.T. A proposed model for the analysis and interpretation of focus groups in evaluation research. *Eval. Program. Plan.* **2011**, *34*, 21–28. [[CrossRef](#)] [[PubMed](#)]
46. Guest, G.; MacQueen, K.M.; Namey, E.E. *Applied Thematic Analysis*; Sage Publications: Los Angeles, CA, USA, 2012; ISBN 9781412971676.
47. Ottelin, J.; Heinonen, J.; Junnila, S. Rebound effect for reduced car ownership and driving. In *Nordic Experiences of Sustainable Planning: Policy and Practice*; Kristjánsdóttir, S., Ed.; Urban Planning and Environment; Routledge: Abingdon, UK; New York, NY, USA, 2017; pp. 263–283, ISBN 978-1-3155-9852-9.
48. Ottelin, J. Rebound Effects Projected Onto Carbon Footprints: Implications for Climate Change Mitigation in the Built Environment. Ph.D. Thesis, Aalto University, Helsinki, Finland, 2016.
49. Schwietzke, S.; Griffin, W.M.; Matthews, H.S. Relevance of emissions timing in biofuel greenhouse gases and climate impacts. *Environ. Sci. Technol.* **2011**, *45*, 8197–8203. [[CrossRef](#)] [[PubMed](#)]
50. Dutil, Y.; Rouse, D.; Quesada, G. Sustainable buildings: An ever evolving target. *Sustainability* **2011**, *3*, 443–464. [[CrossRef](#)]
51. Nuotio, A.-K. Sustainable Usage of Surplus Construction Soil and by-Products in Green Area Construction Works. Master's Thesis, Aalto University, Espoo and Helsinki, Finland, 2013; p. 125.

52. Final Report on the Pilot Applications and Quality Control of the Absoils Project. Ramboll Finland oy. 2015. Available online: http://projektit.ramboll.fi/life/absoils/matsku/absoils_final_report_on_pilots_and_quality_control.pdf (accessed on 19 June 2018).
53. Atlas Obscura. Northumberlandia: Lady of the North. 2017. Available online: <http://www.atlasobscura.com/places/northumberlandia-lady-of-the-north> (accessed on 15 August 2017).
54. U.S. Green Building Council, Land Use Law Center (Pace Law School). Technical Guidance Manual for Sustainable Neighborhoods: How to Use the LEED for Neighborhood Development Rating System to Evaluate and Amend Local Plans, Codes, and Policies. Available online: <https://www.smartgrowthamerica.org/app/legacy/documents/Technical-Guid.-Man.-for-Sust.-Neighborhoods-2012.pdf> (accessed on 19 June 2018).
55. BREEAM Communities. Technical Manual SD202-01.:2012 Issue: 0.1 Issue Date: 21/02/2013. Available online: <https://www.breeam.com/discover/technical-standards/communities/> (accessed on 19 June 2018).
56. Japan Sustainable Building Consortium (JSBC); Institute for Building Environment and Energy Conservation (IBEC). CASBEE for Urban Development (2014 Edition). Technical Manual. 2014. Available online: <http://www.ibec.or.jp/CASBEE/english/downloadE.htm> (accessed on 18 July 2017).



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).