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Lessons learnt from the design and construction strategies of two Norwegian low emission construction sites

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Abstract. Over the last couple of years, research related to fossil free and emission free construction sites has developed rapidly in Norway, with an ambition to contribute towards global, national and regional emission reduction targets. Major public players are already demanding fossil free construction sites through public procurement, whilst requirements for emission free construction sites are on the way. Even though the Norwegian construction industry is a forerunner, there is a lack of knowledge or common understanding among different stakeholders on the definition, scope and strategies needed for fossil free and emission free construction sites. The aim of this paper is to present the main challenges and opportunities from the construction phase of two Norwegian zero emission construction sites, namely Campus Evenstad in Hedmark and Lia nursery school in Oslo. Construction activities considered include transportation and installation of building materials, construction machinery, temporary works, energy use, waste management and person transport. This paper presents and discusses the lessons learnt from the design, ambition levels, inputs from stakeholders, emission reduction solutions of these two construction sites, and evaluates methods considered to address conceptual and practical issues. In conclusion, this paper suggests lessons learnt for reducing GHG emissions from Norwegian zero emission construction sites.

1. Introduction

The Norwegian construction industry is responsible for approximately 1.2% of national GHG emissions, which corresponds to around 660,000 tCO_{2eq} [1]. The significance of construction phase emissions becomes clear when one considers that these emissions occur over a short period of time during the early stages of a building's life cycle [2]. In comparison, use phase emissions occur over the lifetime of the building, typically over a 60-year period. Emissions from the construction site may be high enough to question whether new construction hinders ambitions in reaching GHG mitigation goals, no matter how energy efficient buildings are during operation [3].

Over the last couple of years, research relating to fossil free and emission free construction sites has developed rapidly in Norway [4-9], with an ambition to contribute towards international (e.g. the Paris agreement), national (for example, 40% emission reduction by 2030 and becoming a low-emission society in 2050) and regional (e.g. 95% direct emission reduction before 2030 in Oslo) emission reduction targets.

There has been a stronger focus on emission reduction, for example through the revised national transport plan, technical regulations [10] and environmental criteria from DIFI [11]. There has also been an increase in demand from public and private actors to prioritise emission reduction measures in their projects. The market has developed rapidly since Omsorgsbygg (Oslo municipality's enterprise for social service buildings) started the market dialogue with Bellona (environmental NGO) on emission free construction sites. Omsorgsbygg has since developed requirements for emission reductions on their construction sites. The authorities contribute with

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national support in the form of innovation projects with targets for emission reductions, including that from construction sites.

The authors have identified a need for increased knowledge on fossil free and emission free construction sites among different actors in the construction industry, including the identification and implementation of design and construction strategies for fossil free and emission free construction sites, and to set industry standards for fossil free and emission free construction sites. There is also a need for more knowledge and expertise among contractors and suppliers on emission free alternative solutions and technologies.

The aim of this study is to present the valuable lessons learnt from two Norwegian construction sites which have implemented solutions aiming to achieve emission free or fossil free construction. The paper will discuss emission free and fossil free construction site definitions, how the case studies implemented measures to achieve these ambitions and what measures may be further considered.

2. Definition

The terms 'fossil free' and 'emission free' are often used interchangeably when discussing emissions from a building site. However, these two terms are dependent on first defining which construction activities take place on a building site. In both cases, construction activities include transport of materials, transport and operation of construction machinery, transport of construction workers, energy use, internal transport, storage, temporary works, additional materials for installation of building materials and components, transport of waste, waste treatment and disposal, as depicted in the system boundary of construction activities in Figure 1. These are good examples of construction site activities identified by harmonising EN 15804 [12], EN 15978 [13] and NS 3720 [14]. To follow, is a definition of fossil free and emission free construction sites by harmonising existing Norwegian definitions [4, 15, 16].

Firstly, a fossil free construction site is a construction site that does not use any fossil fuels in any of its on-site construction activities. Fossil fuels (i.e. diesel or propane) are often replaced with bioenergy and biofuels (i.e. HVO or wood pellets) or alternative renewable energy resources such as electricity or hydrogen.

On the other hand, an emission free construction site is a construction site that does not have any direct or indirect greenhouse gas (GHG) emissions from its construction activities. However, achieving no GHG emissions from the construction process is difficult to obtain especially when indirect, upstream emissions are included in the system boundary. Therefore, the Norwegian construction industry has adopted a stepwise approach that works towards the ambition of an emission free construction site. This stepwise approach starts with the fossil free construction site. Next, ambitions can be raised to an 'on-site emission free' construction site which covers no direct GHG emissions from construction activities taking place on-site (e.g. from internal transport, operation of construction machinery and on-site energy use). The next step involves adding emission free transport to and from the construction site, whilst the final step covers the whole system boundary depicted in Figure 1. The authors acknowledge a parallel initiative which investigates the 'waste free' construction site, however this initiative is outside the scope of this article. The authors have also noted that the Norwegian construction industry has adopted the term 'clean construction' to cover both fossil and emission free construction sites.

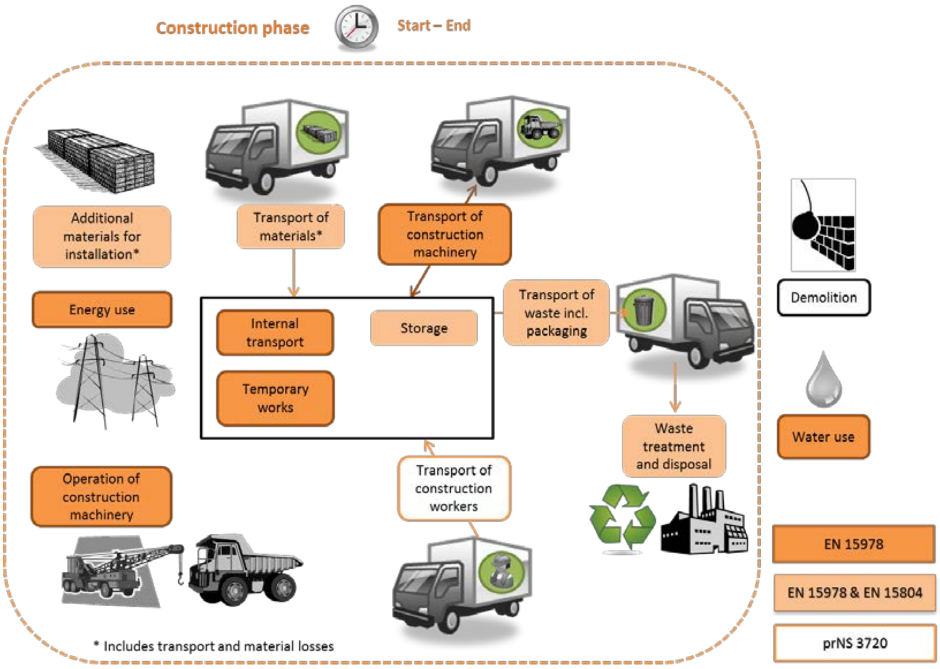


Figure 1. System boundary for construction activities [2, 12-14].

When the terms fossil free or emission free are used, it is important to clearly define the system boundary for both what is included and what is not included in the assessment. This should include, among other things, construction site activities, construction method (e.g. on-site or off-site), type of emissions considered (e.g. direct and / or indirect GHG emissions), emission factors used, as well as a clear description of construction solutions, implementation model and choice of technologies used.

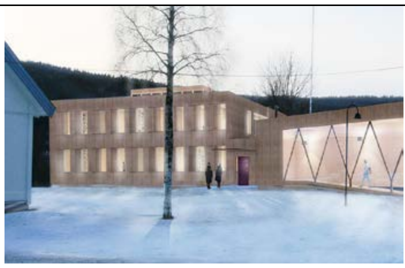
An advantage to implementing emission free construction solutions includes not only zero GHG emissions, but also reduces other types of harmful environmental emissions such as nitrogen oxides (NOx), sulphur oxides (Sox), particulate matter (PM_5, PM_{10}) and noise (dB), which affect both local air quality and human health. Some examples of emission free alternatives include electric, battery-powered, or hydrogen-powered construction machinery, electricity or district heating for temporary heating and drying, use of zero emission vehicle transport to, from, and at building sites (for transport of machinery, materials, waste and personnel).

3. Case studies

The construction sites chosen for this study consist of two Norwegian building projects, namely Campus Evenstad in Hedmark and Lia nursery school in Oslo. Campus Evenstad consists of an administration and educational school building, and has the highest ZEB ambition level out of the ZEB pilot projects (ZEB-COM, which compensates for all emissions relating to operational energy use "O", embodied emissions from materials "M" and emissions relating to the construction phase "C" with local renewable energy generation) [17-19]. Lia nursery school is described as the first fossil free construction site and Norway's most environmentally friendly nursery, with a very ambitious level of BREEAM Very Good [2].

Both case studies document the same construction activities, namely: transport of building materials, transport and operation of construction machinery, energy use, temporary works, transport of waste, waste treatment and disposal and person transport. Any demolition works belonging to the previous life cycle of the existing building, and any cleaning services or water use during the construction period are not accounted for in both case studies. A summary of key information on the two case studies is given in Table 1. An overview of the success factors and challenges of the two case studies is given in sections 4 and 5.

Table 1: Key information on the two case studies

<table>
<tr><td></td><td>
Campus Evenstad, Ola Roald Arkitekter</td><td>
Lia nursery school</td></tr>
<tr><td>Type of building</td><td>Administration and educational building</td><td>Nursery school</td></tr>
<tr><td>Location</td><td>Høgskolen i Innlandet, Postboks 400, 2418 Elverum, Hedmark, Norway</td><td>Harald Sohlbergs vei 19, Oslo, Norway</td></tr>
<tr><td>Heated floor area (m^2)</td><td>1141</td><td>1600</td></tr>
<tr><td>Main construction materials</td><td>Solid wood construction, wood fibre insulation, and an untreated timber cladding</td><td>Prefabricated timber elements with timber interior and exterior cladding, hollow concrete slab flooring for the first-floor construction, and light weight concrete roof elements</td></tr>
<tr><td>Energy system</td><td>Combined heat and power (CHP) unit, powered by the gasification of wood chips</td><td>Water-based ground source heat pump and photovoltaic panels on the roof</td></tr>
<tr><td>Project owner</td><td>Statsbygg</td><td>Omsorgsbygg Oslo</td></tr>
<tr><td>Construction period</td><td>15th December 2015 -
22nd December 2016 (374 days)</td><td>10^{th} April 2016 -
27^{th} November 2017 (166 days)</td></tr>
<tr><td>Ambition</td><td>ZEB-COM</td><td>Plus energy building (produces more energy than it uses), BREEAM-NOR Very Good; fossil free construction site</td></tr>
<tr><td>GHG emission results from construction phase (for life cycle modules A4 and A5, in accordance with EN 15978)</td><td colspan="2">
<table>
<tr><th rowspan="2">Construction site activities</th><th colspan="2">Campus Evenstad</th><th rowspan="2">Lia nursery school ($kgCO_{2eq}/m^2/yr$)</th></tr>
<tr><th>Design phase ($kgCO_{2eq}/m^2/yr$)</th><th>As-built phase ($kgCO_{2eq}/m^2/yr$)</th></tr>
<tr><td>Transport of building materials</td><td>0,44</td><td>0,30</td><td>0,55</td></tr>
<tr><td>Installation of building materials</td><td>0,00</td><td>0,20</td><td>N/A</td></tr>
<tr><td>Construction machinery</td><td>0,21</td><td>0,96</td><td>0,4</td></tr>
<tr><td>Energy use</td><td>0,13</td><td>0,34</td><td>0,04</td></tr>
<tr><td>Person transport</td><td>0,26</td><td>0,21</td><td>0,11</td></tr>
<tr><td>Temporary work</td><td>0,00</td><td>0,02</td><td>0,01</td></tr>
<tr><td>Waste</td><td>0,00</td><td>0,01</td><td>0,08</td></tr>
<tr><td>Uncertainity</td><td>0,09</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Sum ($kgCO_{2eq}/ m^2/yr$)</td><td>1,14</td><td>2,03</td><td>1,19</td></tr>
</table>
</td></tr>
<tr><td>References</td><td>[2, 17, 19]</td><td>[4, 7]</td></tr>
</table>

4. Lessons learnt from the two case studies

4.1. Procurement process

In Lia nursery school, Omsorgsbygg's ambition was to implement one of the first fossil-free construction sites. In order to realise this ambition, a set of requirements were set during the early procurement process. This included three focus areas, with corresponding requirements, targeting the following areas: construction machinery, heating and drying, and transport to, from and within the construction site. The goal was to use electrified machinery, where possible, as well as to use renewable solutions for heating and drying, if available. The procurement process also included quality and environmental criteria (weighted by 60%), whilst the weighting for price criteria was set to 40% [4]. First-hand experiences from Lia nursery school has enabled Omsorgsbygg to raise the quality and environmental criteria in future procurement processes to up to 75% (e.g. Tåsen nursing home project [4]). Furthermore, Omsorgsbygg used lessons learnt from Lia barnehage to set the reduction of GHG emissions and local emissions from the construction site as award criterion in future procurement competitions (e.g. Tåsen nursing home project).

4.2. Early planning

It was also observed that more time and resources were used in the early project phases for the planning of both Campus Evenstad and Lia nursery school compared to other typical projects. In Lia nursery school, there was a close cooperation between actors, where the ambition definition, concepts, challenges and opportunities were discussed at an early stage in the project. Several clarification meetings were carried out to collect input, learn from previous experiences, examine accessibility of machineries and equipment in the market and discuss measures that could enable to achieve the goal of a fossil free construction site. A draft plan was created in the early phase where the various actors were given the opportunity to give input to get a more efficient and productive workflow. Lia nursery school is situated adjacent to a school area which also sets construction limitations related to the safety of school children and heavy transport restrictions to and from the building site. All these factors contributed to the project being completed one month before schedule. In summary, the project achieved a shorter construction phase as well as better transport logistics and safer construction site.

In Campus Evenstad, early planning of the construction site was performed to consider emission reduction measures. GHG emission calculations were performed to evaluate the potential source of emissions based on experience-based estimates provided by the contractor through a series of partner workshops. The early design phase emission results enabled stakeholders to plan for the reduction of GHG emissions during the construction phase. The as built phase GHG emission results showed a 33% decrease in emissions from person transport and a 25% decrease in emissions from the transport of building materials [17]. Campus Evenstad is situated in a rural area. Therefore, the contractor enabled onsite living for construction workers to help reduce emissions from person transport. Similarly, the contractor selected locally produced building materials to help reduce embodied emissions from distances travelled. The results from some construction activities showed an increase in emissions. This is due to limited previous GHG emission calculation experience and a lack of emission data. One such example of this is the emission calculations for construction machineries, whereby on-site diesel consumption was underestimated due to unknown weather conditions, and a delayed construction start which meant casting concrete foundations during a Norwegian winter. On the other hand, measures for reducing GHG emissions from transport include increasing the technological level of vehicle transport (i.e. EURO class 6).

4.3. Choice of construction system

In Lia nursery school, the use of prefabricated construction solutions and locally produced elements is considered as one solution which reduced the number of transports of both materials and personnel to site. Choosing off-site construction has also reduced the use of construction machinery and the handling of waste as well as a total reduction of the construction period. This is demonstrated by the fact that it only took 13 days from when the foundation was finished until the roof was mounted. Nevertheless, the scope of the project did not include the task of finding out and calculating how much material choices contribute to total GHG emissions. Quantification of the emission saving potential due to the choice of construction method is an important factor in ascertaining this consideration.

On the other hand, the design of the administration and educational building at Campus Evenstad focuses on material choices and energy systems to reduce GHG emissions relating to operational energy use and embodied material emissions. As a result, a lot of attention was given to choosing a solid wood construction system with wood fibre insulation and timber cladding to harness the biogenic carbon properties of wood.

4.4. Energy sources

In Lia nursery school electricity has been sufficiently provided and supplied directly from the electricity grid throughout the construction process. Electric machineries such as small electric excavators and wheel loaders have been used for specific activities. It was difficult to get fossil-free alternatives in place in the early phase of the project. There was a desire to use electric construction machines, but electric machineries were not available during the construction period of this project. As an alternative biodiesel was used instead fuelling the large construction machineries. The other challenge was that the construction machines were delivered to the construction site with a tank full of diesel even if they were planned to use biodiesel. This would have been solved if all parties involved in the project being familiar with the goals and potential solutions.

In Campus Evenstad, electricity imported from the grid was replaced with onsite electricity generated from the CHP unit during the last four months of construction, which enabled to reduce emissions by 0.13 $kgCO_{2eq}/m^2/yr$. If the CHP system had been implemented before the construction phase started, then the grid-based electricity could have been replaced by electricity and heat generated by the CHP system, leading to even lower embodied construction emissions. Further reduction of emissions from energy use could be achieved by reducing the need for heating and drying, by keeping the building dry. For example, a temporary roof cover or tent may have been in-stalled to hinder rain from soaking down the construction. A cover would also enable for building materials being properly stored in dry places. Similarly, the seasons can be exploited to reduce onsite energy demands further. For example, installing concrete foundations during the summer months reduces the need for thawing the ground and can improve curing times. Energy consumption from lighting may be reduced by using energy-saving lightbulbs and motion sensors for security against break ins or theft outside of working hours, which means lighting is only required for 8 instead of 24 hours a day, leading to a 66% saving [2]. Another energy saving measure may be improved construction of the onsite construction cabins to include; thicker wall and roof insulation, heat recovery, thermostats, and air-to-air or water-to-air heat pumps.

4.5. *Transport and logistics*

The construction logistics was well planned in the early design phase of Lia nursery school. External factors such as an urban setting with a lack of space and storage area and the fact that the construction site was located next to a school contributed to the need for extra precise planning of deliveries and logistics to, from and within the construction site. Prefabricated elements were chosen for floors, walls and ceilings, in combination with choice of local suppliers of concrete to reduce waste and to enable consequent lower transport need leading to a shorter construction period. However, the use of prefabricated elements also may increase the construction logistics. The GHG emission calculation results show that the transport of materials (including the prefabricated elements) to the construction site is the main GHG emission contributor. It would have been interesting to perform a sensitivity analysis in order to evaluate the impact from the choice of construction method. In addition, other solutions such as use of public transport and car-pooling of workers were considered to reduce the impact from transport.

4.6. *Waste*

In both Lia nursery school and campus Evenstad, ambitious waste minimization targets were set by establishing goals on the reduction of the amount of waste generate (in kg) per square meter of the building. The waste plan was used to collect the total amount and type of onsite construction waste generated during the construction period and consider waste reduction solutions.

4.7. *GHG emission*

GHG calculation was not performed in the early planning phase of Lia nursery school project. Emission reduction measures considered and implemented were rather based on assumptions that they lead to lower emissions. Performing LCA in the early design phase would have helped to further evaluate, plan and compare GHG emission reduction measures. The LCA study performed during the construction phase however has provided experience and knowledge about how to analyze and document GHG emissions from the construction phase, defining the system boundaries, data sources, and selecting the correct calculation methodology. The only possible sensitivity analysis performed in the LCA study enables the possibility to evaluate emission reduction measures, namely the use of different fuel sources in the construction machinery. However, it was difficult to perform a complete sensitivity analysis to evaluate the emission reduction results from other measures due to lack of data.

In the Campus Evenstad project, the estimated results from early design phase were used to evaluate, plan and reduce emissions during the construction phase. The calculations in Campus Evenstad also showed discrepancies between estimated emissions and actual emissions calculation results. E.g. there was an 80% increase in emissions from construction machinery, 67% increase from energy use, 33% decrease from person transport and a 25% decrease from transport of building materials.

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5. Discussions
The findings from the two case studies show that the following aspects are of high importance in succeeding with achieving fossil free or emission free construction sites. Good planning in the early phase, consideration of external factors, cooperation between all involved stakeholders, clear definitions of requirements and set goals and finally openly sharing knowledge, experience, implementation- and documentation methods.

Both case studies show the great importance and necessity of early planning and cooperation between different actors. Decisions through collaboration made in the early phase impose on several aspects in the implementation phase. External factors such as availability of machineries, sustainable fuel, electricity, available infrastructure during the construction period and choices of construction methods such as prefabricated elements also influence the results and level of ambitions. Close cooperation can enable to use previous knowledge, resources and expertise wisely. This will eventually increase the competence amongst involved actors and result in more specific requirements and award criteria. Setting environmental requirements or targets in the procurement process is a very important factor which enables to consider new and innovative solutions from the builders. The main barriers are considered to be the lack of knowledge and experience amongst stakeholders, high costs, lack of access to fossil-free or emission-free solutions and use of new technologies. Both cases clearly show examples of traditional solutions based on linear thinking, without consideration of new technologies aiming for optimization and circularity.

The need for clear definition and description of system boundary for both fossil and emission-free construction sites to create a common understanding of what is included in the term fossil-free and emission-free is identified. Requirements should also be transparent, measurable and comparable. E.g. even if both case projects are considered as low-emission projects, they have set different ambitions and emission reduction solutions. There is also a need for increased expertise among owners and builders about their expectations when they are setting the requirements and possibilities for fossil-free or emission-free alternatives.

Quantitative evaluation methods should be used in the early design phase of the project to highlight real emission savings. Utilization of LCA methodology will enable to evaluate the environmental performance of emission reduction measures. Further study is required to collect case studies of different building typologies to gain experience in evaluating and minimizing the potential environmental impacts from different types of construction sites nationally and internationally. In the LCA calculation, it would be useful to evaluate how or in what degree the emission reduction measures from the construction phase enable to meet local or regional goals and its contribution to Norway's pledged reductions. Performing cradle-to-grave LCA, including various environmental indicators, will enable to avoid the problem shifting from one life cycle phase to another or from one environmental indicator to another. Furthermore, the economic and social pillars of sustainability should be integrated using life cycle cost (LCC) and social life cycle assessment (SLCA) to evaluate the sustainability of the building in general and the construction site specifically.

Experience from emission reduction measures, evaluation and documentation methods in Campus Evenstad and Lia Nursery school can be used as a reference for other projects. There are also new guidance documents [4, 5, 15] and good examples [6] which can be used as reference. Further work on collecting of case studies and testing the guidance in actual pilot project would be useful.

6. Conclusions
This study has presented the lesson learnt from the two Norwegian construction sites. The results from the two case studies clearly show that the goal of achieving a fossil and/or emission free construction site is possible. It requires giving close attention to the early planning phase, a thorough and open collaboration between involved stakeholders where knowledge and previous experience is shared. There is also a great need for clearly defined ambitions, requirements, system boundaries and quantitative evaluations methods in order to document the actual emission reductions. This will help to compare building sites not only against reference projects but also between projects and to further develop methodologies to achieve both national and global emission reduction goals.

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