Selbukassa - A Case Study for Aiming at Low Emission Buildings through Extensive Reuse of Materials

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Abstract. Recent reports from UN International Resource Panel call for double decoupling – decoupling of material use and related environmental impacts from economic growth. The construction and use of buildings constitute a significant portion of energy use, GHG emissions and extraction of materials in Europe. One of the central strategies addressing double decoupling in the construction industry is reuse and recycling of building materials and components that would limit raw material extraction and embodied emissions related to new products. A recent IPCC report states the urgency of limiting GHG emissions already by 2030 to remain below the 1.5-degree target. Given this timeframe, reducing emissions in the early stages of a buildings lifetime appears worth considering, meaning prioritizing embodied over operational emissions. The case study used for this article is an ongoing building project "Selbukassa" ("the Selbu box") situated in Svartlamon – an experimental neighbourhood for urban ecology in Trondheim, Norway. It is a bottom-up, self-build project with a strong focus on reuse of materials. The 300 m² building will house 4 families and is built reusing an old log house, as well as CLT-elements from a former pavilion used for exhibiting an art piece by the local artist Killi Olsen. Other salvaged materials and components include windows, doors, roof slate and most of the internal and external finishes. Due to the experimental status of the area and to allow for reuse of building components with lower energy performance, the fulfilment of energy requirements in the building code TEK 17 was not required by the local building authorities. The article examines the embodied and operational emissions of Selbukassa, and compares it with a reference building with no reused components and complying with energy requirements in the building code TEK17. Simien v.6.009 is used for energy simulations of the two cases, and LCA tool One Click LCA Norge for NS 3720:2018 with data sourced from Norwegian and other European EPDs is used for estimating embodied emissions. The article investigates the possible savings in emissions linked to reuse of materials, as well as the trade-offs between reused components with worse energy performance and the consequential higher energy demand. The article contributes to the discussion about the various implications of reuse of materials and more generally on how the built environment could respond more optimally to a combined emission and resource use reduction challenge.

1. Introduction

Problem statement

The latest UN IPCC report states that we have just until 2030 to limit devastating global warming and remain below the 1.5-degree target. [1] We are also facing a fast-growing global resource use with planetary boundaries pushed beyond their limits. The extraction and processing of materials, fuels and food make up about half of total global greenhouse gas emissions and more than 90 percent of biodiversity loss and water stress. [2] UNEP (United Nations Environment Programme) has therefore introduced the concept of ‘double decoupling’ – decoupling of material use and related environmental impacts from economic growth [3]. IRP (International Resource Panel) has recently recommended that high-income nations aim for an absolute decoupling of material use and related environmental impacts from economic growth. [4] Absolute decoupling is achieved when the related environmental pressure (e.g. resource use or emissions) either remains stable or decreases while economic activity increases. [5]. Ekins et al. state that there is no guarantee that reducing emissions will reduce material extractions and related impacts, and may even increase them. Therefore reductions in GHG emissions have to be combined with targeting reduced extractions (incl. increased resource productivity through all stages of production, and reduced resource use in consumption). [6]

In Europe, the construction and use of buildings is responsible for 42% of our final energy consumption, 35% of greenhouse gas emissions, and more than 50% of all extracted materials. European commission porposes to strengthen and complement existing policies for promoting energy efficiency and renewable energy use in buildings with policies for resource efficiency. [7]

However, most of the current sustainable building concepts (passivehouse, plushouse, nearly zero energy buildings) still focus on energy use with no or little attention paid to embodied emissions or reduction in material extraction. The Norwegian Zero Emission Building definition [8] includes emission accounting for both operational energy and embodied emissions from materials over the lifetime of a building, but it does not explicitly address resource efficiency.

The share of embodied emissions over the lifetime of residential buildings can vary between 11% and 33% in conventional buildings, with an increasing share in low energy buildings (26% – 57%) and nearly zero energy buildings (74% – 100%). [9] The largest fraction of embodied emissions occurs during construction period, with smaller fraction linked to future maintenance and replacement of elements. Some studies have shown significant emissions linked to technical systems (heating, ventilation, PV), especially if replacements were included, ranging from 18% – 46%. [10]

Already previously it has been stated that it is possible that carbon savings made at the start of a buildings lifecycle could be more valuable than predicted savings in the future [11]. Especially considering the short timeframe for emission reduction until 2030, the fraction of embodied emissions becomes more prominent for both conventional and low energy buildings. Furthermore, expected decarbonisation of the grid will lead to lower operational emissions linked to energy use and decreasing prospects for offsetting embodied emission particularly linked to higher insulation levels or technical components such as PV with energy production.

Birgisdottir et al have developed a set of strategies for reducing embodied emissions – substitution of materials (substitution with bio-based or recycled/reused materials), reduction of resource use (light-weight, more durable or recycled/reused materials), reduction of construction and end-of-life stage impacts (construction-related strategies, waste management, seasonal timing etc.)[12] All these strategies are relevant for the case study used in this article, since it addresses substitition of new materials with reused materials, while reducing resource use/ extraction and using ‘waste’ from other buildings. Reuse and recycling of materials has been a focus in a number of building projects – ‘Återvunna huset’ (recycled-house) in Sweden in 1998 [13], ‘Gjenbrukshus’ (reuse-house) in Norway in 2003 [14], more recently in the work of architecture studio Lendager Group in Denmark [15] to name a few, and analysed in several reports in the Nordic countries and Europe [16]. Recently with an increased interest in the ‘circular economy’ concept, the building industry is slowly following the trend, but procedures and necessary networks to make reuse more widespread are not yet established.

The case – Selbukassa in Svartlamon

Svartlamon is an experimental neighbourhood for urban ecology in Trondheim, Norway. The area is experimenting with participatory processes, bottom-up approach and DIY practices in building and maintenance of buildings. Experimental building is an important aspect – in 2004 the then highest CLT building in the world, several off-grid micro houses, and recently an internationally acclaimed self-build rowhousing project based on a student master work known as 'Eksperimentboliger' were all built in Svartlamon.

The latest addition to these experiments is "Selbukassa" (the "Selbu box"), a building of ca. 300 m² that shall provide housing for four families and wishes to showcase an alternative to the conventional housing market and building industry. As a self-build project, the future tenants are responsible for planning and construction of the house.

The project aims at low environmental impact by making use of salvaged building materials to a large extend. The main part is a log house built in the 1920s from the village of Selbustrand near Trondheim that the owner gave away for free. The house was dismantled and transported to Trondheim by the self-builders. It is the basis of the design of the new building and has been rebuilt and extended vertically by adding a third floor, and horizontally by an extension. The extension is built using reused CLT-elements from a former pavilion for the art piece "Salamander night" by the artist Killi Olsen from 2007. Other important building components such as windows, doors, roofing, internal surface materials are primarily reclaimed materials, for example through local peer-to-peer marketplaces. To reduce the use of new materials and due to the limited skills of the builders/tenants, only moderate additional insulation is planned. On the other hand, the project falls within the Norwegian building category of block of flats and has to comply with the strict fire and structural requirements, and to a lesser extend sound requirements of this building category.

Figure 1 The log building from 1920s in original state (left), log building without external cladding (center), the artists pavilion in CLT from 2007 (right).

Research questions

This work sets out to assess the environmental impact of the Selbukassa project as a case study to reuse and upgrade old log houses along with extensive reuse of other building materials and components.
The main question is if the embodied emissions savings linked to extensive reuse of materials and components with worse energy performance can compensate for higher operational energy use and related operational emissions when compared to state-of-the-art components.

In a larger context the article aims to investigate how the built environment can respond more optimally to a combined emission and resource reduction challenge both in short term (the 2030 timeframe) and over the whole lifecycle of buildings.

2. Method

Embodied and operational emissions over the entire building life are calculated for Selbukassa and a reference case of a standard new building with all-new materials and components that fulfil the current energy efficiency requirements in building code TEK17. Simien v.6.009 is used for energy simulations of the two cases. LCA tool One Click LCA Norge, customised to Norwegian requirements, is used for estimating embodied emissions. Emission calculations are based on NS 3720:2018 with data sourced primarily from Norwegian EPDs complemented with other European EPDs. Several scenarios are studied – different emission factors for energy as required by NS 3720, and different accounting periods of 60 (entire building lifetime) and 10 years (emissions accumulated until 2030).

Embodied and operational emissions are calculated over the entire building life cycle according to NS 3720:2018. Modules included in the calculation are: Product stage A1 – A3, Construction stage A4 (transport) and A5 (limited to on-site waste management), Use stage B4 and B5 (replacement and refurbishment) and B6 (energy consumption in operation), End of life stage C1- C4. Other modules were not included in the calculations due to the limited scope of the article. [17] Product service lifetimes are adopted from One Click LCA Norge, and within the ranges given in Byggforskserien 700.320 [18].

As indicator of environmental impact, Global Warming Potential (GWP) in CO$_2$-equivalents are used. The functional unit is 1 m^2 useable area BRA over an estimated service life time for the building of 60 years. The useable area BRA for the Selbukassa project is 311 m^2.

The cases

Case 1 – “Selbukassa”. Resource saving and extensive reuse of materials and building components is given priority over energy performance. To allow for reuse of building components, the fulfilment of energy requirements in the building code TEK17 was not required by the local building authorities. Construction principles are adapted to allow for self-building. Thus timber framing and insulation levels in the external wall was reduced in dimension/ thickness. The site, however, required substantial foundation works. The gallery had to fulfill strict requirements of fire resistance and emergency escape, and will therefore be built in a steel-concrete composite structure.

Case 2 – “TEK17”. The reference is a building with the same inner dimensions, calculated floor area (useable BRA), and window area. The building is made according to state-of-the-art construction with insulated timber framing for the main building. The use of non-reused logs or CLT was not considered for the external walls of the new building, since timber framing represents a more material efficient and optimal solution when reuse is not the goal. Insulation levels of external walls, roofs, and energy performance of windows is increased, balanced ventilation is installed to comply with the energy efficiency requirements in TEK17.

Embodied emissions

The embodied emissions include the main building elements of the building envelope and the major internal building elements as slabs and inner walls, as well as technical systems like ventilation and heat pump. Elements not included are internal stairs, flashings, fixed interior, appliances and sanitary objects. Due to high uncertainties, surfaces coverings (paints, varnish, but also tiles) of external and internal surfaces are not included for both cases.

In agreement with NS 3720, emissions of reused elements are assigned to the previous life of the component, i.e. not considered in the emission accounting. In case of the “Selbukassa”, windows, internal and external doors, roofing tiles, as well as internal siding and flooring is omitted from the emission calculation. It is assumed that these will be salvaged similar to the Eksperimentboliger-project, and later replaced with reused elements. Replacement of reused materials and building components is assumed with similar reused materials.

Operational emissions

Normative values according to NS 3031 were used in the simulations. The energy supply system for the Selbukassa case is based on the wishes discussed with the self-builders. Balanced ventilation is unlikely, but a central extract from bathrooms and kitchens will be installed. A exhaust-air-heat pump is discussed and taken into account in the simulations and contributes to the waterborne floor heating. The TEK17 case represents state of the art balanced ventilation with heat recovery of 80 %, and waterborne floor heating. The heating is covered by an air-to-water heat pump.

In accordance with NS 3720, two emissions factors are considered for electricity – Scenario 1: Norwegian electricity only, and Scenario 2: EU28+NO, a mix of Norwegian and 28 EU countries. In both cases, emissions decrease linearly from 2020 (27 g CO2e/kWh for scenario 1, and 277 g CO2e/kWh for scenario 2, both calculated from NS 3720) to 2050 (13 g CO2e/kWh for scenario 1, and 29 g CO2e/kWh for scenario 2), and remain at that level. In this paper, calculated annual emission factors from 2020 to 2080 are used, not average emission factors over the entire lifetime.[17]

3. Results

Figure 2 presents the embodied emissions associated with phases A1-5, B4-5, and C1-3 for both cases split for the building element categories. The largest portion of emissions are linked to technical systems (41 resp. 43%), foundations (23 resp 17%), and in case of the TEK17 building to external walls (16%). While most buildings elements have largest emission in the product phase, technical installation continue to have high emissions in phase B4 replacement due to estimated service life of 25 years, i.e. double replacement during 60 years of building lifetime. Of those, most emissions are in fact linked to the electrical systems. However, the higher emissions of installations in the TEK17 case result from the more advanced ventilation system and heat pump. The higher emissions for external walls are linked to higher insulation level and emissions related to new windows. Other building elements like foundations, structure and internal floors have similar emissions since these are built with little or no reused materials in both cases.

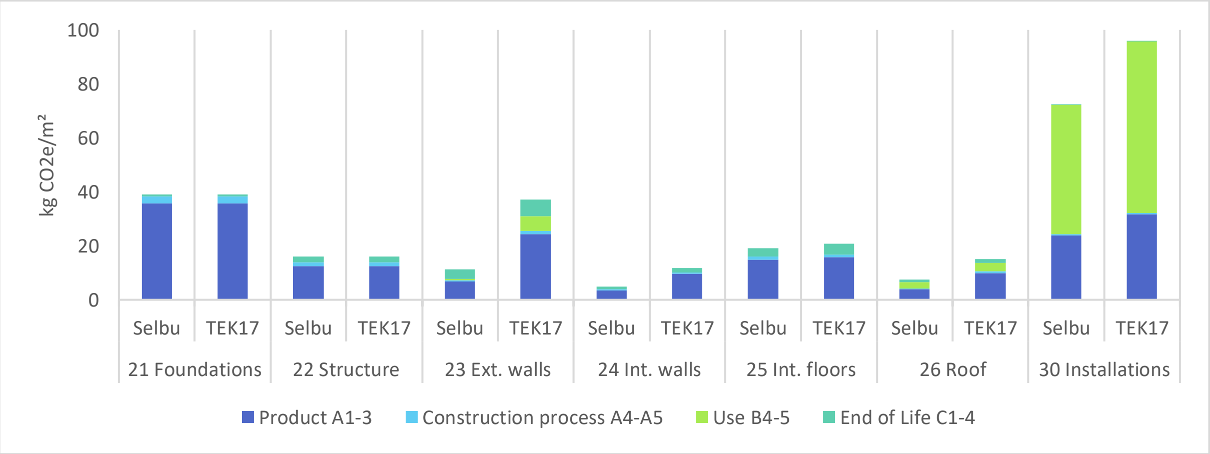
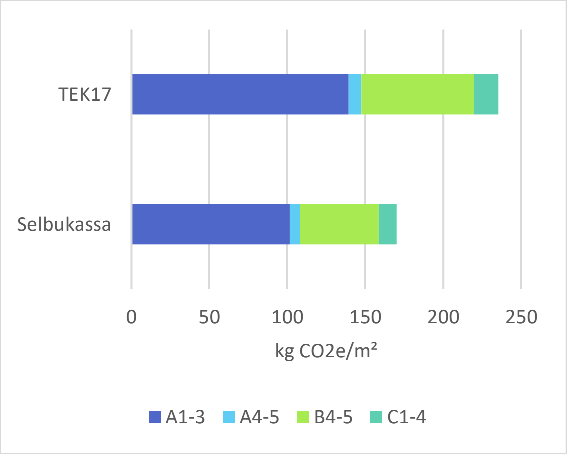


Figure 2: Embodied emissions split up for building elements

Figure 3 shows the total embodied emissions of both cases. As expected, the Selbukassa case has lower embodied emissions. Case Selbukassa has ca. 170 kg CO2e/m² (ca. 2,8 kg CO2e/m² per year for 60 years building lifetime), while case TEK17 has almost 40 % higher emissions of ca. 235 kg CO2e/m² (ca. 3,9 kg CO2e/m² per year). Although the total embodied emissions are different, the ratio of phases is similar in both cases – materials and transport (phases A1-5) account for 62 %, and replacements and end-of-life (phases B4-5, C1-4) for 38 % of total embodied emissions, which is in the range also found in other literature.

Figure 4 presents embodied emissions in relation to the two scenarios of emissions linked to energy use. In both cases and or both scenarios, embodied emissions are lower than operational emissions. In case of the scenario EU28+NO, emissions of energy use are over 5 times higher than embodied emissions of case “Selbukassa” and ca. 3 times higher than for case TEK17.



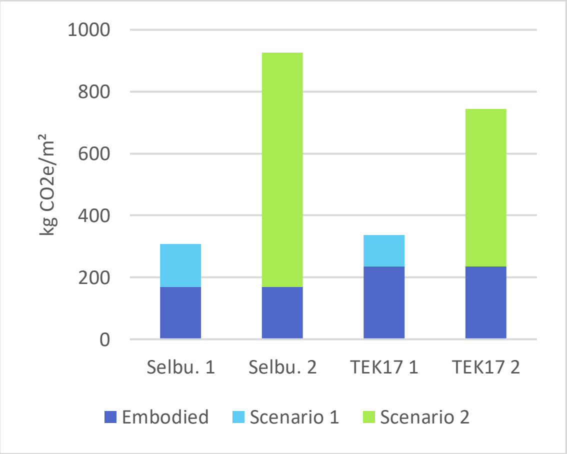


Figure 3 (left): Embodied emissions for both cases

Figure 4 (right): Total emissions for both cases for both energy scenarios

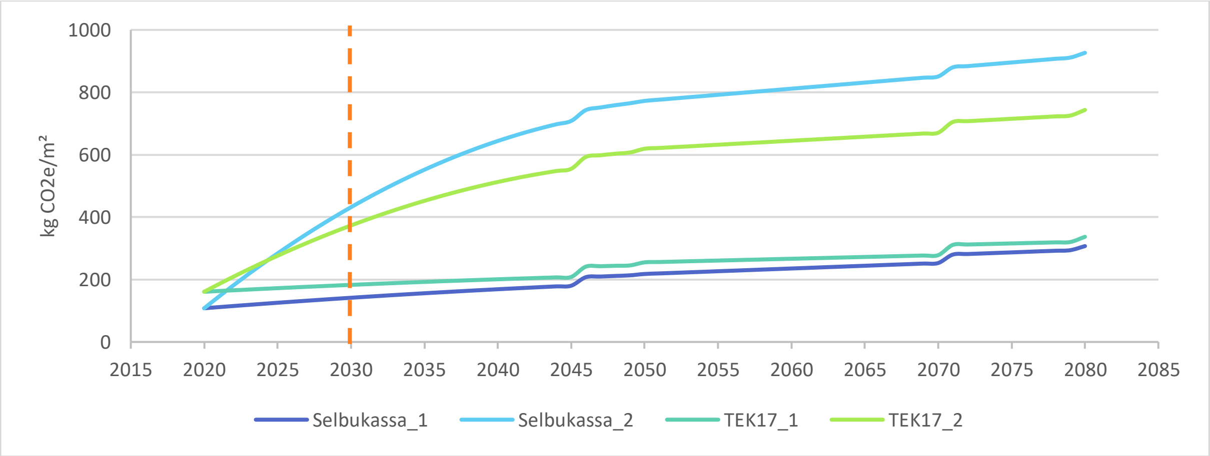


Figure 5: Cumulative emissions for both cases and both scenarios (1. Local Norwegian, 2. EU28 + Norway mix)

Figure 5 shows cumulative emissions projected over the building lifetime based on annual emission factors for electricity. Starting point is 2020 with emissions linked to phases A and B. In case of scenario 1 with the Norwegian emission factor, increase is very low, and although both cases converge, case "Selbukassa" remains below case TEK17 due to lower initial emissions. In case of scenario 2, "Selbukassa" surpasses "TEK17" after ca. 5 years, and after 60 years, total emissions are ca. 25 % higher than case TEK17. The impact of replacements is visible at 25, 30 and 50-year marks. At the critical 2030-mark, case "Selbukassa" has either ca. 22 % lower cumulative emissions than TEK17 in scenario 1, or 17 % higher emissions in scenario 2.

Embodied emissions and raw material use for both cases is shown in Figure 6. The highest use of material measured in weight is associated with the foundations, particularly the masses under the foundations and the concrete of the foundations. However, highest emissions are linked to technical installations with the lowest raw material use of all investigated building elements. No clear correlation between material use and emissions is evident.

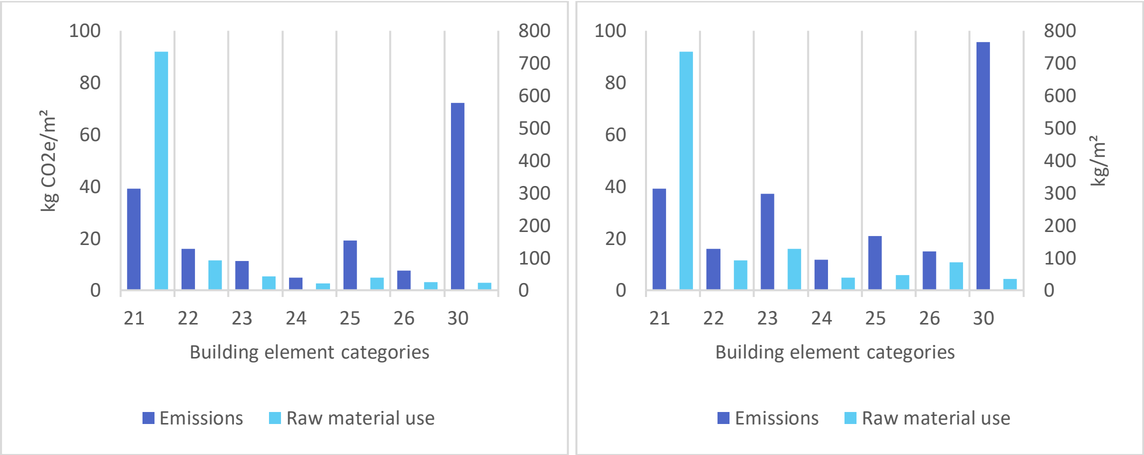


Figure 6: Embodied emissions and raw material use for case "Selbukassa" (left) and case "TEK17" (right)

4. Discussion

Over the lifetime of both Selbukassa and TEK17 cases the operational emissions are higher than embodied emissions with both scenarios for electricity emission factors (NO and EU28+NO). Since Selbukassa has lower or higher emissions than TEK17 building depending on the electricity factor used, no clear result can be obtained about the trade-offs between reused components, reduced new material use and energy efficiency.

Reuse is seen as advantageous in the context of reduced resource use, but the actual emission savings vary among different materials. The reused elements in Selbukassa like the old log building, windows and cladding might represent a large fraction of the materials used, but do not represent a large fraction of saved GHG emissions. To maximize benefits of reuse, reuse has to be carefully planned from early stages of design and it has to be project specific, prioritizing reuse of building components and materials with otherwise high environmental impact, and considering the effects of worse energy performance. A more detailed study on a single component level (e.g. windows) is necessary to optimize the reuse of components linked to energy performance of the building.

Assuming that emission reduction within 2030 is more urgent than in long-term perspective, this should be considered in the choice of indicators, e.g. using GWP20 with a shorter time horizon instead of GWP100, or introducing a relative weighting prioritizing early emission reductions. Furthermore, the principles for emission accumulation over time and sensitivity towards electricity factors and grid decarbonization should be investigated further to develop more adaptive strategies for emission reduction over the whole lifespan of the building.

Further research is necessary to develop a framework for addressing the ‘absolute decoupling’ targets in the building sector.

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References

[1] IPCC, *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* 2018, IPCC: World Meteorological Organization, Geneva, Switzerland, 32 pp. p. 32.

[2] IRP, *Global Resources Outlook 2019: Natural Resources for the Future We Want.* , in *A Report of the International Resource Panel. United Nations Environment Programme.* 2019: Nairobi, Kenya.

[3] UNEP, *Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel.* . 2011.

[4] IRP, *Assessing global resource use: A systems approach to resource efficiency and pollution reduction*, in *A Report by the International Resource Panel. United Nations Environment Programme*. 2017, IRP: Nairobi, Kenya. p. 100.

[5] Agency, E.E., *Progress on resource efficiency and decoupling in the EU-27*, in *EEA Technical report*. 2014, European Environment Agency: Luxembourg. p. 56.

[6] Ekins, P., B. Meyer, and F. Schmidt-Bleek, *Reducing Resource Consumption - A Proposal for Global Resource and Environmental Policy, GWS Discussion Paper, No. 2009/5*. 2009, The Open Access Publication Server of the ZBW – Leibniz Information Centre for Economics.

[7] European Commission, C.f.t.C.t.t.E.P., the Council, the European Economic and Social Committee and the Committee of the Regions *Roadmap to a Resource Efficient Europe, COM/2011/0571 final.* 2011.

[8] Selamawit Mamo Fufa, R.D.S., Kari Sørnes, and I.A. Marianne Inman, *A Norwegian ZEB Definition Guideline*, in *ZEB Project report no 29* 2016 The Research Centre on Zero Emission Buildings (ZEB).

[9] Chastas, P., T. Theodosiou, and D. Bikas, *Embodied energy in residential buildings-towards the nearly zero energy building: A literature review.* Building and Environment, 2016. **105**: p. 267-282.

[10] Birgisdottir, H., A. Moncaster, A.H. Wiberg, C. Chae, K. Yokoyama, M. Balouktsi, S. Seo, T. Oka, T. Lützkendorf, and T. Malmqvist, *IEA EBC annex 57 'evaluation of embodied energy and CO2eq for building construction'.* Energy and Buildings, 2017. **154**: p. 72-80.

[11] Torhildur Kristjansdottir, H.F., Eivind Selvig, Birgit Risholt, Berit Time, Laurent Georges, Tor Helge Dokka, Julien Bourelle, Rolf Bohne and Zdena Cervenka, *A Norwegian ZEB-definition embodied emission*, in *ZEB Project report 17*. 2014, The Research Centre on Zero Emission Buildings (ZEB).

[12] Malmqvist, T., M. Nehasilova, A. Moncaster, H. Birgisdottir, F. Nygaard Rasmussen, A. Houlihan Wiberg, and J. Potting, *Design and construction strategies for reducing embodied impacts from buildings – Case study analysis.* Energy and Buildings, 2018. **166**: p. 35-47.

[13] Thormark, C., *Environmental analysis of a building with reused building materials.* International Journal of Low Energy & Sustainable Building, 2000. **Vol. 1**.

[14] Pettersen, N., *Pilotprosjekt. Gjenbrukshus i Trondheim. En bro fra destruksjon til konstruksjon.* . 2005, Trondheim kommune.

[15] Astbury, J. *Lendager Group uses recycled materials to build 20 townhouses in Copenhagen.* 2019 [cited 2019 14.05.2019]; Available from: https://www.dezeen.com/2019/04/16/upcycle-studios-townhouses-lendager-group-copenhagen-recycled-materials/.

[16] AS, A.V., *Utredning av barrierer og muligheter for ombruk av byggematerialer og tekniske installasjoner i bygg*, A.S. Nordby, Editor. 2018.

[17] Norway, S., *NS 3720:2018 Methods for greenhouse gas calculations for buildings (in English)*. 2019.

[18] SINTEF Byggforsk, *700.320 Intervaller for vedlikehold og utskifting av bygningsdeler.* Byggforskserien. 2017, Oslo: SINTEF.