Recycled concrete: Environmentally beneficial over virgin concrete?

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Abstract Concrete often makes up for the major part of a building, based on mass. And it is environmentally intense, using gravel taken from landscape, and energy intensive cement. Swiss construction standards therefore start to ask for the use of recycled concrete. Is this environmentally useful in an overall ecobalance? In a series of LCA studies for materials and constructions [1], pro's and con's of using recycled or virgin gravel were identified. Interestingly, both energy- and emission-wise, the studies found little differences for virgin or recycled construction concrete, as long as the lower quality of recycled aggregate needs even a small increase in cement. Lean concrete with recycled content proved environmentally beneficial. The analysis showed the importance of using demolished construction waste, either loosely or in recycled concrete.

1 Introduction

Gravel and cement are environmentally relevant. They constitute the major part of concrete which in turn make up for major part of constructions all together. In densely populated Switzerland, gravel is becoming a scarce resource, as residential and industrial areas, roads and natural habitats as well as preserving ground water quality all limit the accessibility of gravel. Cement production is highly energy intensive, making it a large source of emissions, mainly to air. And finally downstream, the amount of concrete waste is also increasing, which leads to transports and large disposal volumes.

Energy and emissions are also key aspects of the Swiss approach to environmental issues in construction: energy considerations are at the heart of the "Minergy" standards [2], defining both energy consumption standards and pertinent construction standards for currently twelve building types. In addition, emission

related aspects can be found, e.g., in the Minergy-Eco standard [3], where the use of concrete based on recycled aggregate (recycled concrete) is advised.
The Swiss cement and gravel industries therefore have for long incorporated environmental issues in their industrial positions and development. At Holcim, a major producer of construction material, the question arose whether using concrete waste as resource for (recycled) concrete is actually environmentally beneficial. It therefore commissioned a life cycle assessment study on that issue, of which key results are presented in this paper.
For better readability, we use the term *"virgin concrete"* for concrete in which all aggregate is virgin, and *"recycled concrete"* for concrete which contains, possibly next to virgin aggregate, recycled aggregate stemming from demolition waste. *"Aggregate"* is the overall term for gravel and broken stone or concrete.

2 Project frame, scope(s) and goals of the LCA studies on concretes and recycled concretes

The project ran from 2008 - 2010. The project team included representatives from Holcim Switzerland as commissioner, the Rapperswil Institut für Bau und Umwelt who performed the calculations and analyses, and from E2 as project consultant. The critical review was led by Rolf Frischknecht (ESU-services, CH).

Goals of the study were to
1) Identify ecological optimization potentials of aggregate production
2) Develop scenarios for ecologically optimal production of aggregate and concrete for construction projects
3) Communicate environmental impacts of virgin and recycled concrete to the various stakeholders.

In the course of the project, the various levels of analysis turned to be almost separate LCA studies, so that the final report contains four assessment levels:
1) The analysis of aggregate (gravel, stone, recycled concrete)
2) The analysis of concrete, i.e. aggregate plus cement
3) The analysis of a fictitious building project
4) The analysis of a regional construction scenario.

For each level, a process scope and allocations had to be defined, which are mentioned in each chapter. Additional scope and allocation definitions can be found in the study's respective chapters [4].

For the impact assessment, six impact categories - three input and three output oriented - were assessed. Next to well-known categories, gravel is considered a scarce resource in Switzerland [5] and analysed as impact category:

Tab.1: Impact categories used

Impact category	Unit of measure
Gravel use	kg
Ecosystem damage potential through land use ("land use")	m² of built-up area equivalents * years of use
Cumulative energy demand ("energy use")	MJeq
Climate change	kg CO2eq
Acidification	kg SO2eq
Respiratory effects	kg particles of < 10 µm

Outside the ISO standards' and the review's scope, the Swiss Ecopoints impact assessment method [5] was applied for obtaining a weighted result.
The project was based on the technical know-how of the parties involved, on the experience on life cycle assessment of the IBU and of E2, on the life cycle inventory data of ecoinvent [6, 7] as well as internal data from various Holcim sites, and on the LCA software Umberto. The study was performed according to the ISO standards 14040 and 14044 [8].

3 Analyses of aggregate and of concrete

3.1 Definitions

In the first and second level of analysis, 1 ton of aggregate and 1 m3 of concrete were chosen as functional units, respectively. For virgin aggregate, the full production cycle of gravel or stone pits was covered. For recycled concrete, it was assumed that old buildings would be demolished anyhow (and not with the aim of getting to the concrete), so that the scope starts with the demolished building.

3.2 LCA of aggregate

Virgin aggregates from gravel pits and from a stone quarry were analysed. For recycled aggregate, *mixed demolition waste* (a low quality mix) and (rather pure) *demolished concrete waste* were considered, which can both be processed in either fixed or mobile facilities. Calculations, sensitivity analyses - e.g. on the allocation of processing emissions to waste and reuseable granulate - showed that aggregate from mixed demolition waste shows less environmental impacts in the energy-related categories (energy, climate, acids, respiratory) than both recycled concrete waste and virgin gravel and stone. For land related impacts (land use, gravel use), aggregates from mixed waste and from concrete waste are superior to virgin gravel or stone.
For stationary waste processing, *transports of construction waste* to the processing site account for large parts of the total reprocessing impacts, while for mobile processing, the *fuel use* of processing is mostly key.
Data quality for these processes is limited, however: Specific pit data showed large value spans for virgin granulate, and data availability for construction waste processing is still limited. To what extent recycled and virgin granulate actually differ might be assessed more in detail. For the further analysis in these studies, the ecoinvent standard data were used for aggregate production.

3.3 LCA of concretes I: high quality construction concrete

High quality construction concrete will be exposed to e.g. wind, heat and frost, and still maintain its strength for tens of years. The cement type chosen for the analysis is the widest used quality cement in the Swiss market. Recycled aggregate has less standardized forms than virgin aggregate and may contain material which negatively influence the concrete's quality. We therefore assumed that an average concrete producer will currently use slightly more cement for processing recycled aggregate. As Tab. 2 indicates, recycled aggregate also has a lower specific weight than virgin material.

Tab.2: Composition of construction concrete

	Concrete w/ virgin aggregate only (C30/37)	Concrete C30/37 with 25 % recycled aggregate
Aggregate	1999 kg virgin gravel	1397 kg virgin gravel 465 kg recycled concrete
Cement	303 kg (CEM II/A-LL)	320 kg (CEM II/A-LL)

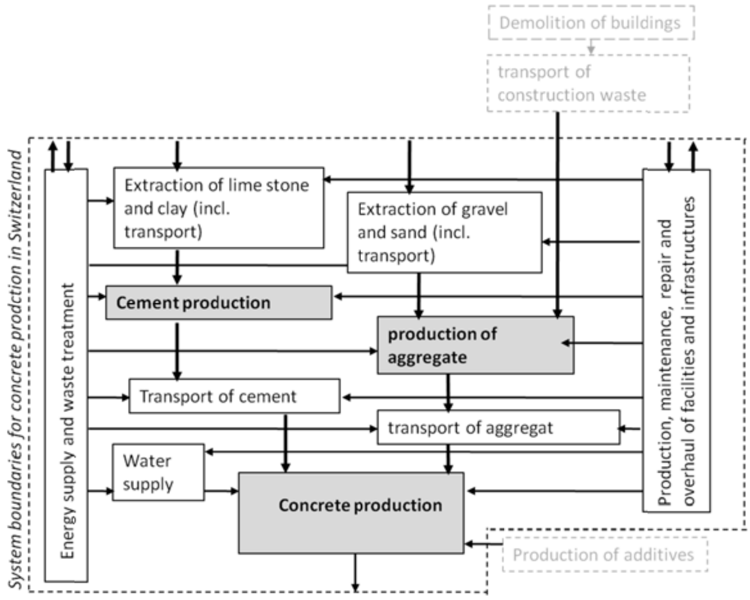

Fig.1: **Scope of the life cycle analysis of concretes. It includes all production processes, starting either at pit or with the demolished old building, transports, and all supporting investment, energy and waste related processes; additives are not analysed)**

The resource use and emission analysis (LCI) yields very little differences between the concretes. Recycled concrete is only lower for - obviously - gravel use, while the energy related impacts even turn out slightly higher with virgin concrete - due to the increased cement content. A similar result was obtained with impact assessment, where virgin concrete is ecologically beneficial for gravel use and land use, but not superior with regard to energy use and emission based impacts (fig. 2):

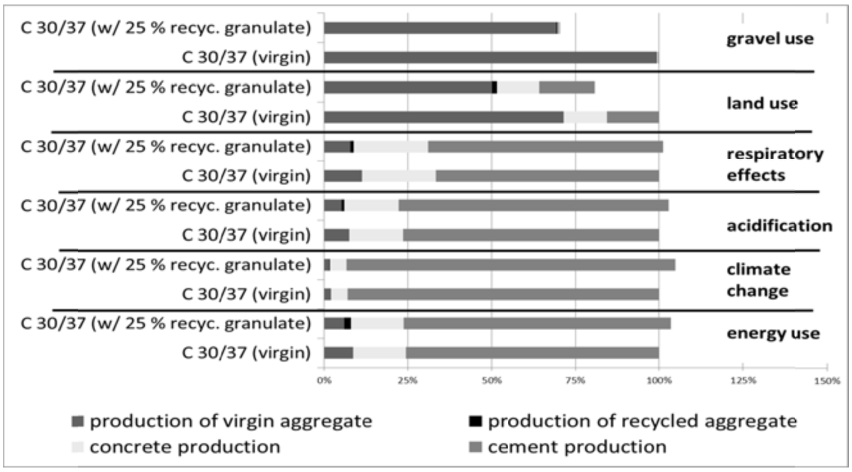

Fig.2: Impact assessment of construction concrete (virgin concrete vs. concrete with 25 % recycled granulate content)

Sensitivity analyses were performed on various aspects, by adapting the recycled concrete scenario and comparing the results to the virgin concrete. *Changed cement content* showed the most important sensitivity (see fig. 3); this again indicates the importance of cement in the assessment of concrete. Of smaller sensitivity was a *change of cement quality* (CEM I instead of CEM II increases the environmental burden due to the higher clinker content).

An *increase of recycled aggregate content* from 25 to 50 % showed virtually no relevance in all energy and emission related impacts, but of course reduces land use and gravel use.

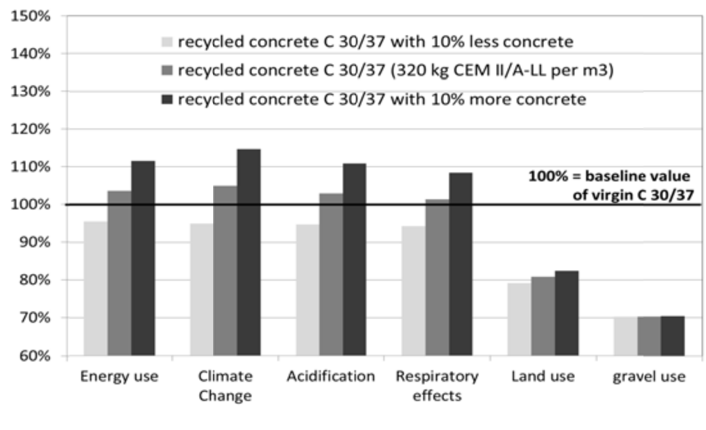

Fig.3: Sensitivity analysis for concrete: Varying the cement content. The 100 % line represents the impacts of virgin concrete, the columns show the sensitivities calculated for de- or increased cement in recycled concrete.

Replacing virgin gravel with broken (virgin) stone increases energy use by some 10 %, but all other impacts change little, due to the Swiss electricity mix used for breaking stones. *Increasing aggregate's transport distances* by 20 km increases energy use, acidification and respiratory effects by some 5 - 10 %.

3.4 LCA of concretes II: low quality concrete

Lean concrete is used for applications with lower quality needs, or where no quality is defined at all, e.g. installation walls for the construction period, or elements that have to resist little or no physical and chemical stress. A key assumption in the study was that lean concrete will - independently of the aggregate types - be produced with the same amount of cement, as is shown in tab.3:

Tab.3: Composition of analysed lean concretes

Components	Lean concrete (virgin)	Lean concrete (15 % recycled aggregate)	Lean concrete (100 % recycled aggr.)
Virgin gravel	1895 kg	1605 kg	-
Recycled concrete	-	242 kg	1587 kg
Cement (CEM II/A-LL)	200 kg	200 kg	200 kg

Analysing the environmental impacts of the three lean concrete types shows that if the use of recycled aggregate does not entail an increase in cement use, all environmental indicators are reduced through the use of recycled gravel: up to a few per cent for energy related impacts, and up to 70 or even 95 % for land use and gravel use (see fig. 4).

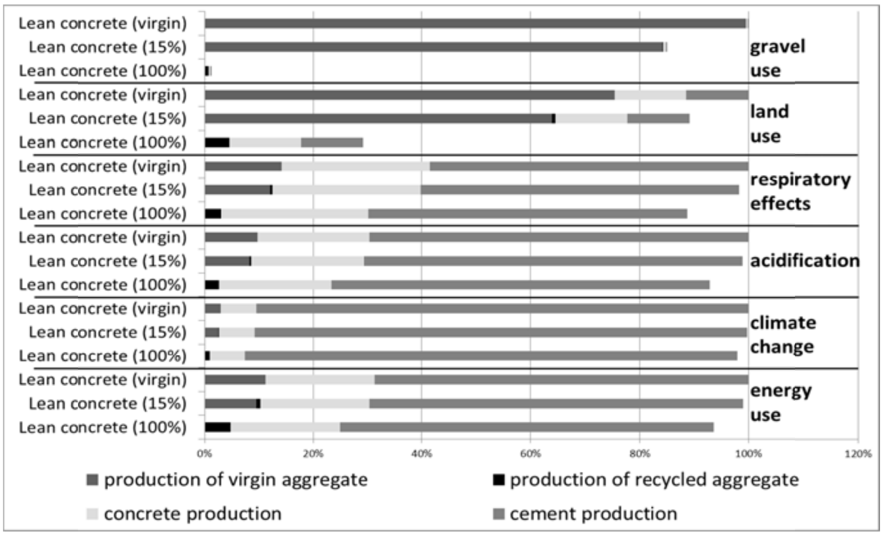

Fig.4: Impact assessment of lean concrete: lean concrete with virgin aggregate, with 15 % recycled granulate, and with 100 % recycled granulate)

The sensitivity analyses for lean concrete lead to similar conclusions as for construction concrete. Overall, the results for concrete were similar to those of earlier studies by Künniger et al. [9] and Jeske et al. [10].

4 Analysis of a fictitious building project

This analysis shows the environmental effects of replacing virgin gravel with recycled concrete in a construction project. The analysis is based on a real project in the greater Zurich area, where an old building was torn down and a new and larger house was built. The functional unit of this project is twofold: (1) the supply of concrete for the new house, and (2) the treatment of the waste of the demolished old house. This includes the treatment of the torn down material (not the tearing down itself, though), the gravel pit and further treatment, all transportation processes of aggregate, from pits, to and from the construction site, to waste treatment and deposits, etc. The construction processes - both tearing down the old and building the new house - are not included, as we assume that they do not depend on the choice of aggregate for concrete.

Tab.4: Key characteristics of the two building project scenarios

Functions	Scenario 1 (virgin gravel /	Scenario 2 (25 % recycled

	waste to deposit)	aggregate / waste to reuse)
Concrete for new building	10'000 m3 C30/37 (construction concrete)	10'000 m3 C30/37, containing 25 % recycled aggregate
Treatment of concrete waste	5'000 m3 concrete waste (cleaned), to waste deposit	5'000 m3 concrete waste (cleaned), to recycling into granulate

Transport distances were defined as in a possible Zurich construction site, i.e. distances to gravel pits, concrete production sites, inert material deposits, etc..
The impact assessment shows *scenario 2 to be environmentally beneficial* in all impact categories analysed (see fig. 5):

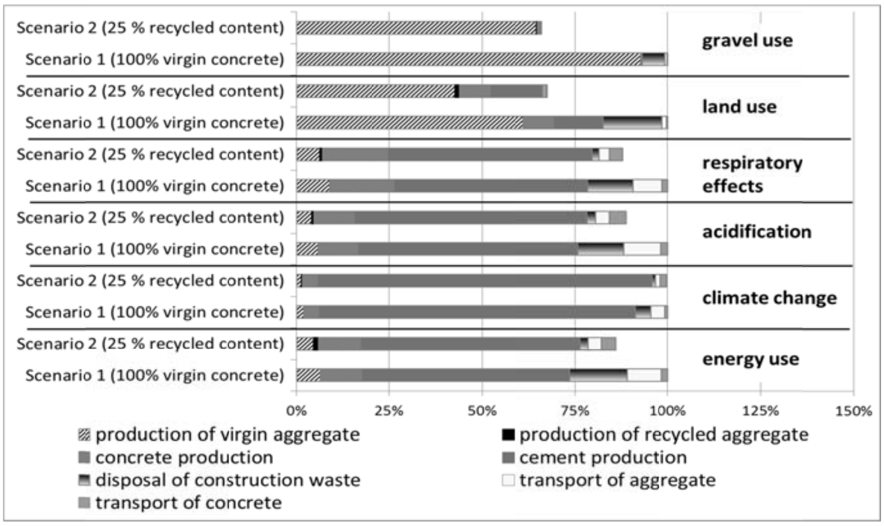

Fig.5: Impact assessment of a fictitious building project: Sc.1 uses virgin concrete and demolished concrete is disposed of as waste, Sc.2 uses concrete with 25 % recycled content and demolished concrete is recycled into granulate.

It is noteworthy that the waste treatment of scenario 1 (where waste goes to a deposit and not to recycling) makes up for large portions of the differences between scenarios 1 and 2: the benefit of recycling concrete waste stems to a large extent from the fact that the waste need not to be disposed of (fig. 5). As we changed the waste treatment in ccenario 1 from "to deposit" into "to recycling", there remained virtually no difference to scenario 2 anymore.

5 Analysis of a regional construction scenario

The most encompassing analysis was made on a regional scale. Here, demolished concrete is assumed to be used in some way in any case: Either demolished concrete is crushed and used as loose gravel (scenario A), or it is used in recycled concrete (scenario B). In both scenarios, the demolished concrete replaces gravel - either in loose application or as input to concrete production (see fig. 6). The region was modelled based on Swiss construction data and could represent the greater Zurich area's construction activity during one year.

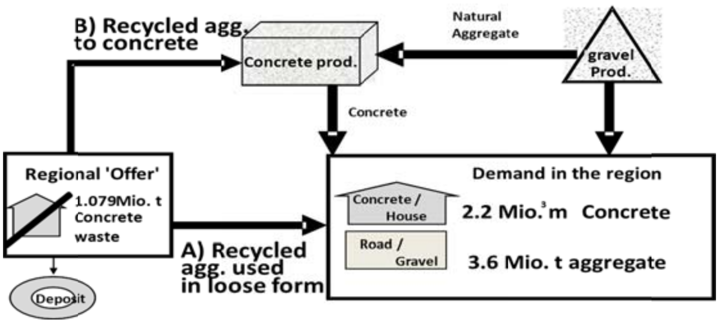

Fig.6: Material flows for the regional construction scenario. Demolished concrete is used either (A) in loose form (replacing some gravel of the 3.6 m t of aggregate) or (B) for recycled concrete (replacing gravel in the 2.2 m m3 of concrete).

Calculating the impacts yielded as overall result that it doesn't change the environmental effects by much whether demolition waste is used loosely (replacing loose gravel) or as input to concrete (again replacing gravel). Using demolition waste for concrete (scenario B) increases cement use (based on earlier assumptions) and reduces virgin gravel use. Therefore scenario B produces higher energy use and airborne impacts, but lowers gravel and land use - the differences are small, however (fig. 7):

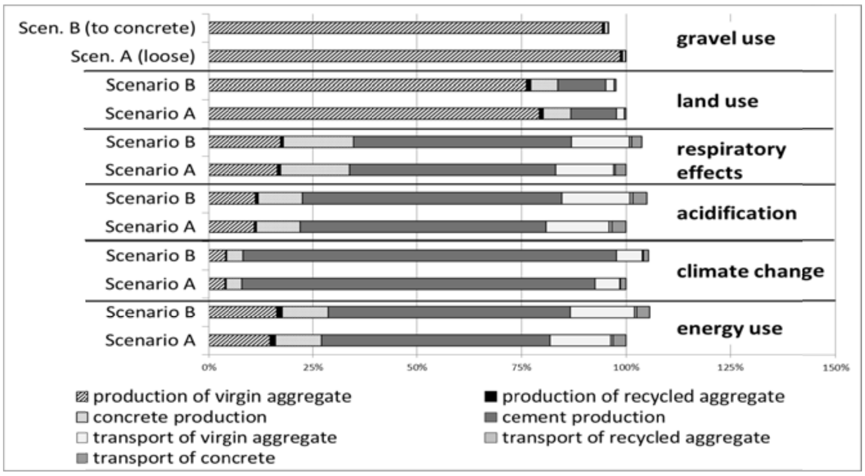

Fig.7: Impact assessment for the regional construction scenarios: Recycled aggregate is used either in loose form (A) or in recycled concrete (B)

The analysis of the regional scenarios with the weighting method of [5] also showed very little difference (less than 2 %) between the two scenarios. In the ecopoints assessment, the fact of not having to treat and deposit construction waste, the cement consumption are relevant as well, next to the gravel use.

6 Conclusions

1) Comparing concrete based on virgin versus recycled aggregate with the LCA approach yields valuable insights. Scope variations in this study are very important - as in almost all LCA study. But here, the scope issues differ from the usual, as the scope variation went from simple aggregate comparison to high level regional construction activity comparison.
2) Comparing high quality concrete using either virgin gravel or recycled concrete yielded similar environmental impacts, if - as assumed - recycled concrete needs a few percent more cement. In other words, high quality gravel with recycled aggregate seems not to be environmentally superior.
3) Recycled lean concrete (used for lower quality applications) does not need more cement than virgin lean concrete and is environmentally beneficial compared to virgin lean concrete.

4) In a system analysis - e.g. for a regional construction scenario -, recycled concrete is environmentally beneficial if alternatively, the concrete waste (which is at the base of recycling) is not re-used but disposed of.
5) Re-using concrete demolition waste is environmentally beneficial compared to disposing it.
6) If, however, concrete waste is used for construction purposes anyhow (e.g. due to legislation and/or waste deposit cost), the use of concrete waste in either loose form or in recycled concrete does not matter from an environmental point of view. In that case, the transport distances for the (waste) concrete to be recycled and the new production concrete should be considered when choosing how to use the waste concrete.
7) Cement is environmentally dominating the emission based impacts of concrete. The cement type and quantity used in concrete therefore makes a relevant difference. Developments to reduce clinker content and using alternative fuels in cement production will also improve the environmental profile of concrete.

7 References

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