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A low carbon, circular economy approach to concrete procurement

City of Zurich (Switzerland)

Image: Pixabay / Pexels

Background

The City of Zurich is the largest city in Switzerland, with 430,000 inhabitants and a public procurement budget of over €1.8 billion. It spends around €370 million (420 million CHF) per year on new public buildings, and around 15-25% (€55-90 million per year) of this cost is related to structural work, including the building's concrete structure and shell.

Construction and demolition waste is one of the largest waste streams in the EU (accounting for between 25-30% of all waste generated). Concrete, bricks, gypsum, wood, glass, metals and other common construction materials can all be recycled, saving space in landfills, and reducing the amount of virgin materials excavated for building activities. The EU Circular Economy Action Plan highlights the importance of recovering valuable resources in the construction and demolition sector, and an EU-wide mandatory target for recycling 70% of construction and demolition waste in Member States by 2020 has been set. However, recovery varies greatly across the Union, from less than 10% to over 90%, and much work is still needed on the ground to adequately identify, separate, and recover valuable materials[1].

Recycled materials can replace a portion of one of concrete's main ingredients – aggregate (typically composed of gravel, crushed rocks and sand). The inclusion of recycled aggregates help close some of the material loops related to concrete, making it more circular, and for over 15 years, the City of Zurich has strived to use as much recycled concrete aggregate as possible in its public building projects.

However, recycling concrete alone will not overcome its other major environmental impact – CO_2 emissions. These emissions are largely embodied in the production of concrete's other main ingredient – cement (a binding material, typically made by heating limestone with clay or shale, and grinding the result into a fine powder, called clinker). Although cement only makes up around one-eighth of concrete's mass, it is responsible for more than 70% of concrete's GHG emissions due to the energy intensity of clinker production, which results in around 680kg CO_2 emissions per tonne of cement, or 250 kg CO_2 emissions per tonne of concrete.

It is possible to reduce the GHG emissions of concrete by replacing a portion of clinker in cement with a lower emission ingredient. For example, one type of cement (called CEM III/B[2]) replaces 66-80% of clinker with slag-sand (a by-product of iron production), which reduces the CO_2 emissions per cubic meter of concrete by up to 25-30%. As such, Zurich has also required the use of reduced CO_2 cement when procuring new buildings since 2013.

1 http://ec.europa.eu/environment/waste/construction_demolition.htm

2 Different types of cement (CEM) are classified using Roman numerals from I to V, which indicates the content of Portland cement and slag and fly ash. This is followed by the letter A, B, or C, which indicates decreasing clinker content.

Overall, the City of Zurich's holistic approach to concrete procurement proves that by scaling-up sustainability requirements to a citywide approach, while also addressing 'soft' barriers such as the aesthetic concerns, the city has supported a systemic change in the its construction market. Not only are many suppliers now willing and able to produce recycled, low carbon concrete in order to compete for public contracts, but many architects now also prefer these more sustainable options due to their aesthetic properties alone.

Development of approach

> "Recycled concrete is now used whenever technically feasible in public building projects, including exposed concrete elements and watertight basement systems. In some buildings, as much as 98% of concrete used now comes from recycled sources."

Around 20 years ago, reducing the amounts of gravel being extracted and used in construction was being discussed widely by the public, in political spheres and by the building industry. As a consequence, several studies were conducted, which aimed to further develop the process of recycling demolition waste. Up until that point, recycled concrete had only been used for lower strength construction work, but the aim was to increase its quality, in order to also use it in the construction of buildings.

In 2002, Zurich's first public building built with recycled concrete – the "Im Birch" school – was completed. This initial experiment was conducted in close cooperation with a local concrete producer, and included quality testing. The final building contained 80% recycled concrete and cost €78 million (€11 million of which was structural work).

Due to the success of this pilot, in 2005 it became mandatory that all public buildings should be built with recycled concrete in line with SN EN 206:2013 and SIA 2030 standards. This means that concrete products must contain at least 25% recycled aggregates in total mass).

Zurich specified that recycled concrete should reach RC-C quality as a minimum, that is, concrete which contains 50% virgin aggregate and 50% recycled concrete aggregate (particles from concrete, concrete products, mortar and concrete bricks). Where technically possible, however, RC-M concrete is preferred. That is, concrete which contains 75% virgin aggregate and 25% mixed demolition aggregate (particles from fired clay bricks and roofing tiles, calcium silicate bricks and non-floating aerated concrete).

While RC-M contains a lower rate of recycled aggregate than RC-C, Zurich has chosen to focus on this, in order to incentivise the recovery of this otherwise more difficult to recover mixed demolition waste, which makes up around 60% of Switzerland's 10 million tonnes of mineral construction waste produced per year.[3]

In addition to their focus on the environmental impact of material flows, Zurich has a goal to become a '2000 Watt Society'. This is based on the calculation that each person, globally, requires 17,500 kilowatt-hours of energy per year, which corresponds to a continuous requirement of 2,000 watts (with watts indicating how many joules of energy are required per second). Zurich aims to reduce average primary energy consumption to 2,000 watts per person (with a maximum 50 watts from fossil energy), and 1 tonne of CO_2 emissions per person by 2050. Compared with 2005 levels, this means three-times less energy and nine-times less greenhouse gas (GHG) emissions per person per year. This ambition is the result of a public vote in 2008, and is now enshrined in the City's Constitution.

Many of the City's policies are now anchored in the '2000 Watt Society' initiative, including the 7-Step Plan for Energy Resource and Efficient Building Construction and Management. The 7-Step Plan was first developed in 2008 by the Department of Building and Planning of the City of Zurich to promote sustainable development of the built urban environment over its entire lifecycle. The plan specifies that environmentally friendly and energy efficient construction should be a decision-making criteria in procurement, with buildings required to meet the Swiss Minergie-P ECO Standard, which guarantees very low energy consumption and maximum possible use of renewable energies.

As a consequence of Zurich's overall target to become a '2000 Watt Society', the Building Surveyor's Office was looking for ways to reduce the energy and carbon footprint of recycled concrete, which - while having a very positive

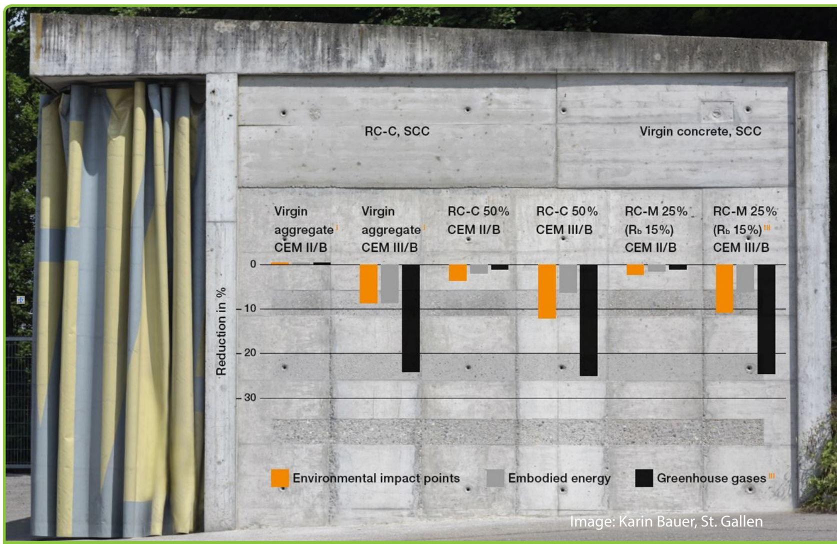
3 www.stadt-zuerich.ch/hbd/de/index/hochbau/bauen-fuer-2000-watt/grundlagen-studienergebnisse/2017-08-nb-Beton-Konkret.html

impact on closed-loop material cycles, mining in gravel quarries, land preservation and disposal of construction waste in landfills - did not show necessary improvements in energy and CO_2 efficiency. Based on experiences with construction work where CEM III/B was used for technical reasons other than energy and CO_2 efficiency, a study was launched to analyze the cement production and its emissions. The results showed that the use of CEM III/B reduced CO_2 emissions by 25-30% compared to conventional concrete.

In 2013, Zurich introduced the additional requirement that all concrete used in building construction works procured by the city meet the CEM III/B cement standard.

To address the concerns of architects and other stakeholders regarding the aesthetic quality of recycled, CEM III/B concrete, Zurich built '[a mock-up wall](#)', which allows for a direct comparison of the effects of various aggregate types (virgin gravel, recycled aggregate comprising concrete demolition waste or mixed demolition waste) and cement types (CEMII/B or CEM III/B) on the finished product. The 'mock-up wall' also shows the effect of treatments on different types of concrete, including sandblasting, polishing, colour-washing, or graffiti-proofing.

By building the 'mock-up wall', Zurich proved that in addition to environmental benefits, the impact of recycled aggregates on the concretes end-characteristics are limited, while the use of CEM III/B gives concrete a slightly lighter colour, which is actually considered as an additional aesthetic advantage by many architects.



Mock-up Wall: Key sustainability parameters of concrete types: reduction of recycled concrete types and CEM III/B in comparison to conventional concrete made with virgin aggregate and CEM II/B.

Approach Results/Outcomes

Recycled concrete is now used whenever technically feasible in public building projects, including exposed concrete elements and watertight basement systems. In some buildings, as much as 98% of concrete used now comes from recycled sources. Between 2005 and 2018, an average 18,400 m^3 of concrete per year is used in public building projects, of which 90% (or 17,000m^3) is made from recycled aggregate. A sample of the buildings built over this period demonstrate the stretching ambition of Zurich's approach:

- **The Werdwies housing complex**. Completed in 2006 with a 75% share of recycled concrete (including watertight basement and ceilings made from recycled concrete, and load-bearing walls from RC-M from 100% mixed mineral demolition waste). Total building cost: €74 million.
- **The Leutschenbach school**. Completed in 2009 with a 95% share of recycled concrete. Total building cost: €66 million (including €18 million in structural works).
- **The Triemli city hospital**. Completed in 2015 with a 95% share of recycled concrete (in accordance with SN EN 933-11). Total building cost: €262 million (including €60 million in structural works)
- **The Kronenwiese housing complex**. Completed in 2017 with a 95% share of recycled concrete with CEM III/B, with some walls also being made with RC-M. Total building cost: €45 million (including €10 million in structural works)
- **The Kunsthaus (Art Museum)**. Completion expected in 2022.Built with a share of 98% recycled concrete (produced in situ) with CEM III/B. Total cost of around €182 million (€31 million of structural works).
- **The [Hornbach housing complex](#)**. Completion expected in 2023. Built with a share of 95% recycled concrete and CEM III/B, including 50% RC-M (walls and ceilings). Total cost of around €70 million (including structural works of €14 million).

In addition to buildings, up to 30% of material used in new road foundations (sub-base layer) in Zurich now comes from recycled concrete, while the road base can contain up to 60% reclaimed asphalt (or up to 80% on pavements and places with low traffic volumes). The City is also trying to increase this proportion of recycled asphalt, and current tests using a new mixture of reclaimed asphalt look promising, and may eliminate previous differences in road quality while increasing the amount of reclaimed asphalt that can be used.

Kerbstones are also collected and reused. A reused kerbstone saves 0.2kg of CO_2 per kerbstone compared to a Swiss-origin kerbstone and 1.4kg of CO_2 compared to a kerbstone imported from China. Added together, the CO_2 reduction potential of reusing kerbstones is considerable, and also avoids the environmental and social impacts of mining.

Around 17,000m^3 of virgin materials (and landfill space) has been saved by Zurich's approach to recycling concrete in buildings alone. In addition, the use of CEM III/B has improved the lifetime energy consumption of concrete by approximately 5%. On the one hand, dismantling and processing of demolition waste requires less embodied energy than mining virgin gravel in quarries. On the other hand, recycled concrete requires more cement, and depending on the circumstances, must be transported further. For this reason, the use of recycled concrete only makes sense from an energy perspective when it is available from within a 25 km radius of the construction site – which is the case throughout the greater Zurich area using CEM III/B also reduces greenhouse gas emissions per cubic meter by around 25%.

In terms of cost, recycled concrete is around the same price or slightly cheaper than virgin concrete. Costs which are saved on the reduced requirement for virgin sand and gravel are balanced against slightly higher costs related to the higher consumption of energy required during the cracking and production process of recycled concrete.

In Zurich's experience, supply follows demand, and since requiring recycled concrete in its public buildings, more and more suppliers have invested in production capabilities to meet these demands, and from one supplier, there are now eight to ten suppliers in the Zurich area offering recycled concrete.

Lessons learned

Zurich's approach to concrete procurement over the last 15 years proves it is possible to build with recycled, CO_2 reduced concrete in a way which is safe, inexpensive, and which has no drawbacks from an aesthetic point of view.

Recycled concrete costs approximately €178/m^3, which is around the same price as concrete made from virgin material. Likewise, choosing CEM III/B instead of conventional cement in concrete formulations is a simple and cost-neutral way of reducing CO_2 emissions without compromising quality.

Many of the barriers to using recycled, reduced CO_2 concrete are human but by addressing quality concerns, it is possible to overcome these. The 'mock-up wall' was an effective, convincing way to overcome architects' concerns and even convince them of the aesthetic value of concrete with reduced environmental impacts.

Through this process, the City found it very helpful to work closely with at least one concrete producer from the beginning, in order to understand the practicalities of recycling concrete in public building projects.

Sorting construction materials at the demolition site is a prerequisite to successful concrete recycling. This is already mandatory in Switzerland and several other EU countries.

Based on its 15 years of experience, the City of Zurich believes that all cities today should be looking at ways to use demolition waste more efficiently and in an environmentally friendly manner, and recommend that by starting small any city can build experience and prove quality and applicability, before scaling their approach up.

Contact person:
Sonja Gehrig, City of Zurich, Sonja.gehrig@zuerich.ch

For related information, please see the European GPP criteria for Office Building Design, Construction and Management, the Technical Background Report and the Procurement Practice Guidance Document.