A concrete answer for circular construction: three prototypes reusing saw-cut elements

SYNOPSIS

Existing concrete buildings should be retained for as long as possible to reduce the environmental burden of demolition and new construction. However, when urban pressure makes demolition unavoidable, salvaging and reusing concrete elements elsewhere in new structures, rather than reducing them to rubble, efficiently prolongs the use of existing resources at their highest structural value. Concrete reuse is not a new approach: pioneer cases have demonstrated its potential, but broader adoption has still not been seen across the wider industry.

Three prototypes recently built by Ecole Polytechnique Fédérale de Lausanne researchers and students in Switzerland demonstrate the feasibility and potential of reusing elements saw-cut from cast *in situ* concrete structures. The prototypes deal with different scales of elements, from small blocks to large slab elements and 3D assemblies. Lifecycle assessments confirm that reusing concrete elements drastically reduces the upfront global warming potential of new construction, providing a new lower-bound benchmark for sustainable, circular construction.

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Circular strategies for concrete

Concrete is the most used construction material worldwide[1] thanks to its numerous qualities, including its availability, low cost, versatility, workability, strength, durability and fire resistance. Its manufacturing process, however, combined with widespread and growing use, results in significant environmental impacts related to global warming, raw material depletion and the destruction of natural ecosystems[2,3].

Concrete also comprises 30% of the industry's waste stream in Europe[4]. Buildings are being demolished after an increasingly shorter service life[5], driven by the obsolescence of the spaces they create rather than by the structural material's degradation[6]. Decommissioned concrete structures are today commonly crushed into aggregates, depriving them of their initial geometry and structural capacity. These concrete aggregates are then used as backfill or as partial replacement for natural aggregates in so-called recycled concrete mixes. While this strategy reduces natural gravel extraction, recycled concrete mixes require quantities

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↗FIGURE 1: **Concrete elements extracted by sawing before demolition of building, stored next to commonly produced concrete rubble**

of cement at least equivalent to conventional mixes, leading to a comparable level of global warming potential (GWP)[7].

Before recycling, circular strategies consist of, in priority order, refusing, reducing, repairing and reusing[8]. Applied to construction, to prevent the production of both concrete waste and new concrete structures, this translates into reviewing our needs for new buildings and exploring solutions for renovation, strengthening and transformation of existing structures. When maintaining the structure in place is deemed impossible, another circular solution is the reuse of concrete elements after minimal transformation, such as extracting elements by sawing from buildings planned for demolition **(Figure 1)**, and then reassembling these into new loadbearing structures.

Reuse of structural concrete

Reuse aims to extend the service life of the reclaimed elements beyond that of the original structure by using their pre-existing geometry and structural capacities. After assessing the existing reinforced concrete structure to evaluate the reusability of its elements[9], relatively large elements – parts of walls, slabs or complete frames – are extracted by sawing and lifting, transported, stored if required, and finally reassembled into a new structure, using connection techniques analogous to those used in prefabrication.

In central and northern Europe, there are dozens of executed projects where precast reinforced concrete panels have been reclaimed from one building and reused in another[10]. In the cases where it was verified, a clear reduction of the upfront GWP was demonstrated. Some even show a financial advantage, particularly when elements are reused without heavy reconditioning or when the owners of the new buildings are also the owners of the decommissioned buildings[11].

For example, in 1986 in Middelburg in the Netherlands, contractors carefully dismantled the top seven floors of an 11-storey prefabricated building using sawing and lifting equipment[12] The salvaged wall and slab panels were used to build new three- and four-storey apartment blocks. Similarly, in 1997 in Linköping, Sweden, 1850t of large concrete wall elements, floor beams and foundations from two source buildings were reused in a new 26-flat building 64km away[13]. No technical problems were reported, and an environmental analysis showed that reusing the elements saved 60% of GWP compared with an identical building with the same structural requirements, constructed using new concrete. A government subsidy offset the 10–15% higher costs compared with conventional practice. However, the contractors felt that these extra costs were transient, as they were primarily due to the pioneering nature of the operation[14].

Regardless of these promising stories, reuse of concrete struggles for widespread adoption as it still raises questions associated with economic, logistical, technical and environmental considerations. To alleviate these concerns and showcase the potential of reusing elements saw-cut from cast *in situ* structures[15], three distinct prototypes were recently built by teams at Ecole Polytechnique Fédérale de Lausanne (EPFL):

- an arch footbridge made of 25 small blocks
- a loadbearing office floor made of four large slab elements
- a community pavilion made of six slab and column 3D assemblies.

In all three cases, a process-based lifecycle assessment (LCA) was carried out to quantify the upfront GWP of the prototypes and compare these numbers with equivalent structures made of new concrete. System boundaries begin with the donor building demolition (C1–C4) and end after the new construction (A1–A5)[16]. The GWP impact factors are taken from the Swiss national database and, when needed, completed with on-site measurements.

Re:Crete footbridge – reclaiming compressive strength of concrete

The prototype named Re:Crete **(Figure 2)** is a post-tensioned segmental arch, spanning 10m with a 1.2m rise and 1.2m width, which was built with 25 reclaimed concrete blocks[17]. Designed as a footbridge, for a 1.5kN/m^2 live load, the arch makes optimal use of the high compressive strength of concrete while the contribution of the steel reinforcement bars present in the reclaimed blocks is ignored. Two post-tensioning cables ensure that the blocks always remain in compression, even when subjected to asymmetric live loads.

Using circular diamond saws, the reclaimed blocks were directly cut at the final dimensions, 120cm × 40cm, in the 20cm thick cast *in situ* reinforced concrete basement walls of a building that was undergoing transformation. Once extracted, two holes were drilled in each block for the post-tensioning cables. The blocks were then transported to the prototyping hall and

↙FIGURE 2: **Re:Crete footbridge: completed arch**

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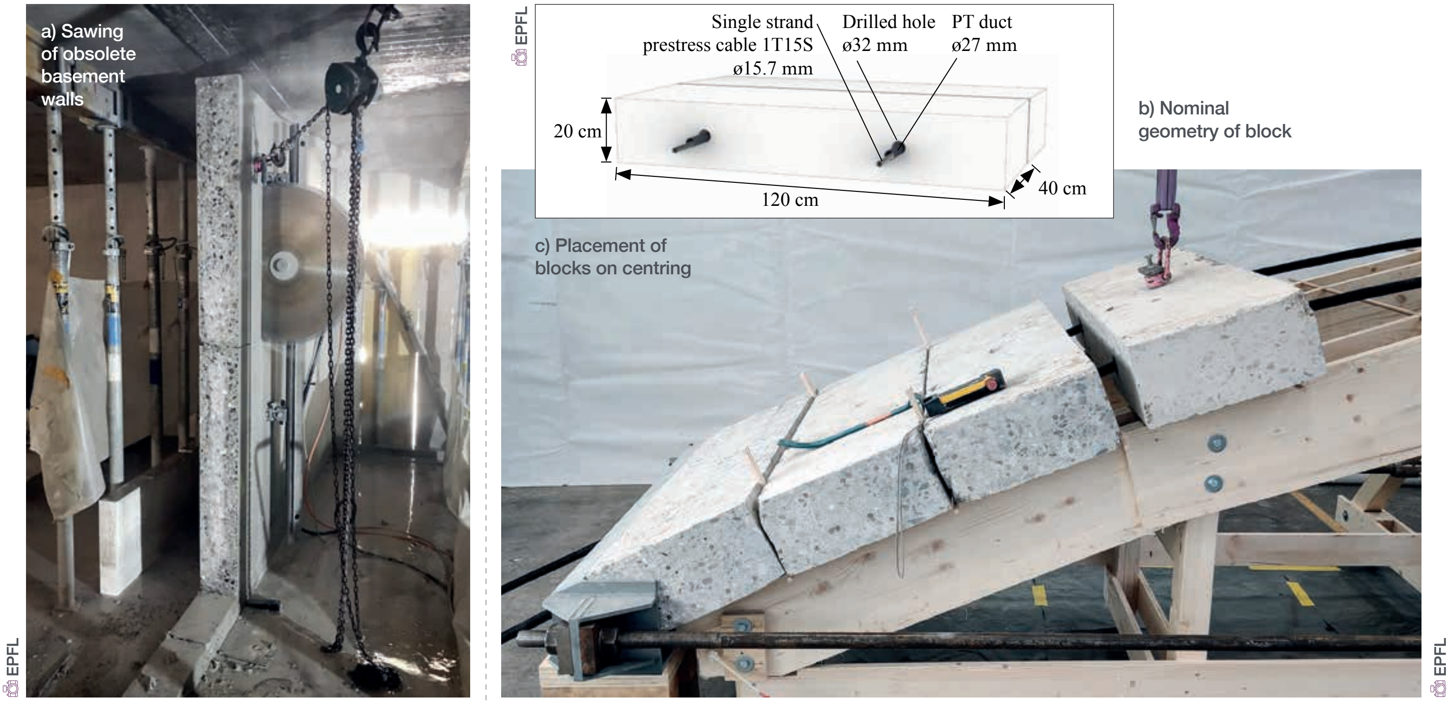

a) Sawing of obsolete basement walls

b) Nominal geometry of block

c) Placement of blocks on centring

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↗FIGURE 3: **Re:Crete footbridge: extraction and assembly**

placed on a timber centring **(Figure 3)**.

Before post-tensioning and subsequent lowering of the centring, joints were filled with mortar to ensure complete contact between the blocks and to compensate for sawing tolerances. Finally, to enhance the durability of the structure, the ducts of the post-tensioning cables were injected with mortar, and the joints were waterproofed using epoxy-glued plastic strips covered with an anti-slip layer.

A railing was installed, also made from reclaimed materials: metal tubes from obsolete festival tents and steel wire meshes from shop furniture. The footbridge now spans a river in Switzerland **(Figure 4)**.

A comparative LCA of the Re:Crete arch showed that its production generates a GWP 63% smaller than a similar arch made from monolithic recycled cast *in situ* concrete, 74% smaller than an arch made from steel beams, and almost the same as an arch made from glued laminated (glulam) timber beams[17]. The largest share of GWP for the prototype is due to the production of the timber centring and the transportation of the blocks. Nevertheless, the blocks could be transported over 600km before the emissions attributed to the Re:Crete prototype exceed those of a new concrete monolithic arch.

FLO:RE building floor – reclaiming bending capacity of reinforced concrete slabs

As building floors typically account for the most upfront GWP of buildings, the FLO:RE prototype **(Figure 5)** demonstrates the feasibility of constructing an extremely low-carbon loadbearing floor structure using only reclaimed elements[18]. This prototype further validates recent theoretical and analytical work on reusing saw-cut reinforced concrete elements to build low-carbon slabs[19].

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↗FIGURE 4: **Re:Crete footbridge, with railings and waterproofing strips, used by pedestrian to cross a river in Switzerland**

FLO:RE consists of a 30m^2 portion of an office floor slab built by combining four 2.5m × 3m, saw-cut, reinforced concrete slab elements with three reused, 5m long, wide-flange H steel girders for the main span (190mm high for the two side ones and 230mm high for the central one). It is designed to comply with all code requirements for new construction with a superimposed permanent load of 2kN/m^2 for the screed and flooring and an office building live load of 3kN/m^2, as well as fictitious lateral loads for wind and earthquake.

While the Re:Crete arch prototype only made use of the compressive strength of the blocks, this new prototype takes advantage of the contribution of the existing steel reinforcement in the reclaimed reinforced concrete elements, reusing them in bending.

The reinforced concrete elements were saw-cut from a 15cm thick flat roof slab of an office building built in the 1960s, while the steel profiles were reclaimed from an industrial hall from the 1970s **(Figure 6)**. Both donor buildings were in Switzerland near the prototyping hall. Although each building's structure was still in good condition, they were scheduled for demolition to make way for new developments on the sites.

Structural capacities of the elements were estimated with data from standards on existing structures and geometric measurements, including steel reinforcement bar spacing and diameters measured in an opening in the concrete. Because of the tight planning of the demolition site operations, the material properties of the concrete and steel (rebars and beams) were only tested later, in the prototyping hall[18]. In normal conditions, a complete assessment of the elements, using destructive and non-destructive testing methods, would have been carried out before deconstruction[9].

Once salvaged, the reused steel profiles were cut to the required 5m length, and the surplus was used to build the prototype's vertical supports. With the change of static system


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↙FIGURE 5: FLO:RE building floor: completed prototype


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↖FIGURE 6: FLO:RE building floor: extraction of concrete elements and steel beams


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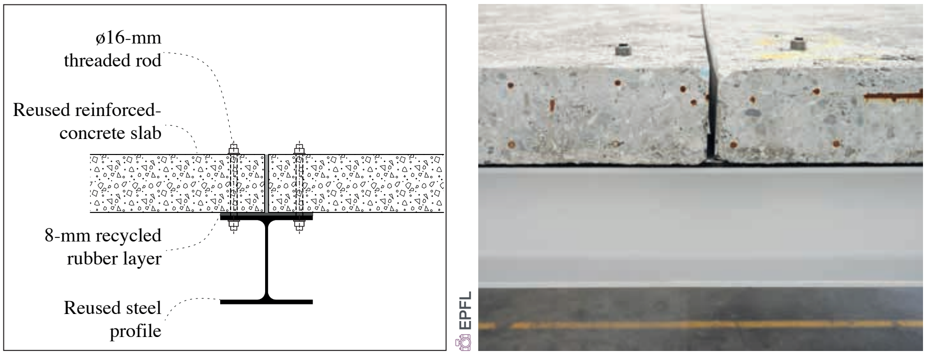
←FIGURE 7: FLO:RE building floor: placement of reclaimed reinforced concrete slab elements over steel beam



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↑FIGURE 8: FLO:RE building floor: connection detail between reinforced concrete slab elements and steel beams

from a continuous slab in the donor system to a simply supported slab in the new system, the bending moment at mid-span became critical for the reinforced concrete elements and their length was hence fixed to 3m – approximately three-quarters of the span of the donor slab. The reinforced concrete elements were installed on the reused steel beams **(Figure 7)**.

The connection between reused steel and concrete elements is designed to transfer the lateral loads to the vertical bracing system through friction, and no composite action is considered. The load transfer is ensured with bolted preloaded threaded rods in each corner of the slab elements **(Figure 8)**. Thanks to these dry connections, the floor structure was fast to assemble and is also dismountable and thus fully circular.

In a full-scale building, the number of connections might need to be adapted to ensure the vertical tying of the structure. Moreover, fire protection measures should be planned for the steel elements, such as fireproof paint or plasterboard enclosing.

The LCA of the construction process of the FLO:RE prototype shows that it has an ultra-low GWP compared with an equivalent 22cm thick reinforced concrete slab: 80% reductions when built 140km from the donor buildings; 92% if built within a radius of 20km around the donors; and 94% if built on the same site as the donors, i.e. no transportation. This corresponds to 15, 6 and 5kgCO$_2$e/m^2, respectively.

rebuiLT pavilion – reclaiming cast *in situ* reinforced concrete connections

The rebuiLT pavilion **(Figure 9)** is an experimental construction project designed and managed by EPFL students with the academic, legal and technical support of researchers and construction professionals[20]. Designed as a one-storey, 95m^2, multipurpose community space, the pavilion combines reused and biobased materials as well as low-tech construction methods and systems.

The main loadbearing structure is made of six reinforced concrete assemblies extracted from the structure of a 1970s industrial donor building located 4km away and scheduled for demolition **(Figure 10)**. Each assembly is self-standing and comprises one mushroom column and portions of the top and bottom slabs. Saw-cut reinforced concrete slab elements are interleaved between the assemblies to complete the ground-floor slab **(Figure 11)**.

Over the reinforced concrete structure, the roof structure was built by combining reclaimed massive timber and glulam timber, completed with biobased insulation and reclaimed tiles **(Figure 12)**. The space between the roof and the top of the reinforced concrete slabs is used for light storage, with a live load of 2kN/m^2. The vertical envelope is made with post-tensioned straw bales **(Fig. 12)** coated with clay mixes and salvaged windows from other nearby buildings, while the floor system is completed with biobased insulation and second-hand flooring.

The rebuiLT project showed how reusing large saw-cut assemblies requires the co-design and close coordination of the donor building's deconstruction and the receiver project's construction. The final shape and volume of the pavilion are highly dependent on the geometry of the donor building structure. For the pavilion, this meant mushroom columns provided a fixed height between slabs. The dimensions of the top slabs also depended on the available capacity of the existing structure and their new use as cantilevers.

The shoring, sawing, lifting and transportation of the saw-cut assemblies, each weighing 20t, required specific attention **(Fig. 11)**. To ease and speed up the construction process, the self-standing assemblies were not connected. After extraction from the donor building, the assemblies and flat slabs were therefore installed in one day, creating the main volume of the rebuiLT pavilion **(Fig. 9)**. A first rough LCA of the complete construction of the pavilion demonstrates that it has a GWP at least half as small as an equivalent pavilion made of cast *in situ* reinforced concrete and similar to a complete biobased solution with a timber structure.

Learnings and outlook

The construction of these three prototypes demonstrates the technical and logistical feasibility of reusing reinforced concrete elements for structural applications. Moreover, they confirm the drastic reduction in GWP compared with conventional concrete construction while simultaneously diverting large volumes from waste streams and reducing natural resource extraction needs. The diversity of element scales in the proposed solutions confirms that reuse should not hinder the creative exploration of design teams. However, the starting point of the design should already involve considerations about the potential donor building(s) and the related scale of the reclaimed saw-cut elements.

Today, concrete sawing is still too often seen as an exceptional technique, which contributes to additional project costs. Nevertheless, when the donor and receiving buildings have the same owner, costs can be optimised, leading to expenses comparable to conventional concrete construction[11]. Moreover, when concrete reuse gains a broader acceptance in the industry, extraction methods will be rationalised, leading to a further reduction in costs over time. In the case of the rebuiLT pavilion, three other projects were supplied with reinforced concrete elements sawn from the same donor building. In total, 137 reinforced concrete elements had to be extracted, which allowed the optimisation of

➔FIGURE 9: rebuiLT pavilion: reclaimed reinforced concrete elements in their final position

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↘FIGURE 10: rebuiLT pavilion: deconstruction of donor building

a) Interior view

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b) Sawing of reinforced concrete slab

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↘ FIGURE 11: rebuiLT pavilion: lifting of slab–column assemblies

a) On deconstruction site

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b) On construction site

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a) Construction of straw-bale walls

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b) Installation of reclaimed roof tiles

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FIGURE 12: rebuiLT pavilion: construction

the donor structure sawing pattern, limiting both the time and costs of the deconstruction.

In the hypothesis of mainstream application of concrete reuse in Switzerland, it could offset about one-sixth of concrete production at current rates of demolition and construction. While not insignificant, this ratio highlights the pressing need for complementary circular economy strategies – refuse, reduce, repair – to limit the demand for new concrete. Nevertheless, for as long as demolition remains common practice, the generation of concrete waste will persist. In response to the climate emergency, it is crucial to reconsider the end of life of building structures, to divert these locally available concrete elements from the waste streams and to use them at their full potential. As was shown by the three prototypes, the techniques and know-how for reuse of concrete elements exist, its environmental benefits are undeniable, and its costs are predictable.

Lifecycle analysis

Readers wishing to explore the LCA of each prototype in more detail are encouraged to refer to the following open-access publications:

Re:Crete – Devènes *et al.* (2022)[17]
FLO:RE – Bertola *et al.* (In press)[18] & Küpfer *et al.* (2024)[19]
rebuiLT – No LCA currently available

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