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# Panorama of approaches to reuse concrete pieces: identification and critical comparison

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# Panorama of approaches to reuse concrete pieces: identification and critical comparison

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**Abstract** Practices that reuse concrete pieces in new building or infrastructure projects are currently diversifying as concrete reuse gains more and more relevance for sustainability. The present research provides a yet missing identification of the main approaches to these practices and introduces a new set of criteria to compare them. Five types of sourced concrete pieces are identified, three resulting from careful deconstruction and two from demolition. The study shows that approaches allowing the best re-utilization rate of the structural capacities of the concrete pieces are less compatible with current demolition practices, in contrast to approaches reusing debris. The reuse of wall and slab panels, beams, and columns is a promising approach as it implies a low to medium level of constraints on the new design while recovering the capabilities of discarded reinforced concrete equivalently. A few dozen built precedents have already applied this approach to precast components, but applications reusing cast-in-place concrete are lacking, despite considerable $CO_2$ emissions reduction.

## 1. Introduction

The piecewise reuse of concrete is a construction technique where pieces of existing concrete structures are extracted from buildings or infrastructure undergoing transformation or demolition and, after possible light alteration only, are reused in new projects. When demolition or heavy transformation is unavoidable, reusing concrete pieces drastically reduces waste production and substitutes the need for new materials in new construction, primarily new cement.

As concrete constitutes a significant waste flow in many countries – e.g., 6.5 million tons in Switzerland annually [1] – piecewise reuse is gaining interest as a sustainable, circular end-of-use strategy [2]. However, it is still often confused today with another end-of-use strategy: the recycling of aggregates into new concrete mixes, then called "recycled" concrete mixes. Reusing concrete pieces differs from concrete recycling because the latter crushes old concrete and reprocesses it into new concrete mixes while requiring as much cement as new conventional concrete mixes [3]. This difference is major since concrete embodied $CO_2$ originates mainly from cement production.

Recent research identified over 50 structural projects built with reused concrete pieces [2]. This research provided a new perspective on concrete reuse but also pointed out that techniques for reusing concrete pieces are increasingly diversifying and that a new range of practices is emerging. However, no panorama of the growing approach variety is available at the moment. Moreover, the implications of reuse approaches on the design project, the resource (re-)use, and their degree of technical readiness have not been compared yet. Therefore, this paper identifies, compares and illustrates with precedents five approaches where different types of concrete pieces are reused. The work also introduces a new set of comparison criteria to conduct the comparison.

## 2. Scope

This study focuses on the reuse of pieces extracted from precast (PC) and cast-in-place (CIP) reinforced concrete structures into new structural projects. The analysis excludes concrete recycling and adaptive reuse – i.e., the in situ reuse of a structural system that does not imply the division, movement, and reassembly of its pieces – both different from piecewise reuse. The study focuses on the valorization of existing concrete that would otherwise end up in landfills or recycling plants. It thus also excludes projects explicitly designed for disassembly or reuse that involve casting new concrete. The study focuses on the main approaches and recognizes the existence of hybrid approaches or cases that fall in-between canonical approaches or criteria.

## 3. Methodology

### *3.1. Overview*

The first step of this research is identifying approaches to concrete piecewise reuse. This identification is conducted by iteratively comparing and clustering a set of precedents, using the geometry of the reused pieces as a primary analysis parameter. The precedent set first relies on the database created by Küpfer and al. in 2023 [2] that gathers 77 examples documented until May 2022 and is then extended with more recently documented precedents via literature review. The second step is the critical comparison of the approaches. An original first set of assessment criteria is introduced to characterize and compare the approaches. The criteria are developed based on an initial comparative analysis of the precedents and de-/re-construction site visits.

### *3.2. Comparison criteria*

The criterion set involves seven aspects, summarized in Table 1and described in the following list.

***1 – Extraction method*** differentiates between the two main concrete-piece extraction methods considered in the study. *(a) Deconstruction* allows highly-controlled dismantling processes and the extraction of pieces with precisely defined dimensions. Tools are primarily circular saws, in addition to hydro-jetting or, eventually, piece lifting when connections are loose. Circular sawing is generally used in densely built environments or for transformation works. *(b) Demolition* corresponds to conventional demolition processes, usually with a hydraulic crusher. The dimensions of the extracted pieces are difficult to predict, and the separation between them is typically irregular. This method is the most widespread to turn down concrete structures but forces the downcycling of structural components (such as slabs or columns) as debris.

***2 – Reclaimed structural capacities*** indicate which main capacities of the concrete pieces the new systems rely on. Two main cases are considered in this study. *(a) Compressive strength only*, when the tensile strength provided by steel reinforcement bars in the donor structure is unused in the new system. In this case, either the new systems work only under compression, or additional material (i.e., prestressing or rebar embedding) provides any required bending resistance. *(b) Compressive and tensile strengths,* when the compressive strength of the concrete and the tensilestrength of the steel reinforcement bars are both used in the new system. New systems that reuse the existing bending resistance of reclaimed concrete pieces exist. If their resistance does not suffice to take the new-system moment, strengthening can be added [4].

***3 – Influence of the donor construction method*** informs whether the donor-structure construction method (i.e., PC or CIP) is *(a) impactful* or *(b) not impactful* on the reuse design and de-/re-construction process.

***4 – Preservation of existing connections*** evaluates the extent to which existing connections between structural components, typically a wall and a slab, are maintained in the new assembly. *(a) Complete* preservation happens when the existing connection is maintained entirely by extracting and reusing two (or more) structural components together without separating them. *(b) Partial* preservation requires carefully separating the components - generally PC - at their existing connecting point. Reassembly usually requires only light reconstruction work for the connections. *(c) Zero* preservation happens when components are separated regardless of their existing connections, and entirely new connection details must be designed and built.

***5 – Geometric extent of new material input*** accounts for the shape and hence the quantity of new material needed to build the new systems. Five types are considered: *(a) no* additional material required; *(b) point* application (e.g., a steel plate reconnecting two pieces); *(c) line* application (e.g., some mortar on a linear connection); *(d)* a thin *surface* application (e.g., a layer of high-performance material strengthening a concrete piece); or *(e)* a more extensive *volume* application (e.g., a matrix of steel rebars and mortar embedding the reused pieces).

***6 – Constraint on the new design layout*** distinguishes between three levels of constraints that the reused-concrete approach imposes on the new design layout: *(a) high* when the initial dimensions of the reclaimed components and the connections between two or more must be maintained; *(b) medium* when distinct structural components with their original dimensions must be reused; and *(c) low* when the new design layout is relatively independent of the donor structure layout, which typically happens when components are not reused with their initial full dimensions.

***7 – Re-utilization rate*** refers to which level the structural capacities of the concrete are reused in the new systems compared to their use in the donor system. This rate can be *(a) decreased* (less demanding use in the receiving system), *(b) equivalent*, *or (c) increased* (more demanding use).

**Table 1.** Illustrated summary of comparison criteria.

| Criterion | Type | | | | |
|---|---|---|---|---|---|
| extraction method | demolition | | | deconstruction | |
| reclaimed structural capacities | compressive strength only | | | compressive and tensile strengths | |
| influence of the donor construction method | impactful | | | not impactful | |
| preservation of existing connections | complete | | partial | | zero |
| geometric extent of new material input | absent | on points | on lines | on surfaces | volumes |
| constraint on the new design layout | high | | medium | | low |
| re-utilization rate | decreased | | (nearly) equivalent | | increased |

## 4. Panorama of concrete reuse approaches and first comparison

Based on over 85 examples of reused concrete projects, the work identifies five primary forms of concrete piece reuse with different project implications, summarized in Table 2.

***Assemblies*** are large structural pieces sourced via deconstruction and encompassing vertical and horizontal structural components that are kept together, preserving the existing connections. Assemblies are generally reused for equivalent utilization in new projects that reclaim their bending resistance. The donor structure layout highly constrains the new design layout. This approach has been used in a limited set of precedents. In the Netherlands, assemblies encompassing four wall and slab components have been sawn and extracted from CIP concrete structures to build three exhibition or housing building prototypes [5]. In Switzerland, the EPFL student project *RebuiLT* is reusing six assemblies encompassing a column and two slab pieces each [6]. Those precedents highlight this approach need for special shoring and lifting equipment.

***Wall and slab panels, beams, and columns*** are regular pieces sourced via deconstruction and generally big enough to cover a main space dimension (e.g., room span or height). This type of piece is usually reused with an equivalent utilization rate in the new project, which takes advantage of the bending resistance of the reinforced concrete. The de-/re-construction process is impacted by the donor system construction method, i.e., PC or CIP. Usually, some additional material is required to reconnect the components. More material is typically required when original connection details are lost, which is the case for cut CIP and trimmed PC pieces. Regarding precedents, several dozen built projects have reused PC panels, beams, or columns Europe since the 1980s, with studies reporting $CO_2$ reductions exceeding 50% [2], [7]. Building on this potential, ongoing research projects study the mechanisms for a broader implementation of PC concrete reuse, such as [8]. Nevertheless, PC is not predominant in all territories; thus, recent research has also focused on reusing cut CIP pieces. Tackling the urgent need to lower the building floor embodied $CO_2$, studies have developed new floor systems reusing as-is cut CIP slab pieces [9], and re-allocation algorithms to design floor slabs using strengthening techniques [4]. These studies have reported drastic $CO_2$ emissions reduction compared to conventional techniques, with quantified examples over 80% and 75%, respectively. Nevertheless, built examples reusing CIP components are still missing.

***Blocks*** are regular, plane pieces sourced via deconstruction but typically smaller than full panels, beams, or columns. Several blocks must generally be reassembled to build a structural system able to cover a main space dimension. The new projects reuse concrete existing compressive strength but do not rely on its bending resistance. Thus, the reuse of blocks implies a decreased utilization rate of the discarded concrete. New project layouts are little constrained by the reuse of blocks since the latter can be cut and recombined in several ways. A small set of precedents have been built using this approach: for example, parking pavements, which reduce $CO_2$ emissions by over 80% [10], or the *RE:CRETE* footbridge, which reduces $CO_2$ emissions by 63% compared to a conventional concrete design [11]. In this approach, possible bending moments can be withstood with added material, such as prestressing. The economic analysis of precedents has shown that block sizes and new systems should be optimized to reduce operations on blocks, connections, and sawing [10].

***Flat debris*** is debris with two parallel faces linked by angular-shaped surfaces. They typically result from structure demolition that uses hydraulic crushers and can be reused in new systems that use their existing compressive strength, implying a decreased re-utilization. Flat debris has irregular contours, meaning that a non-neglectable volume of additional material is to be considered when assembling them; however, the two parallel faces may be a useful design feature in new projects. A few conceptual design studies have explored this approach, like [12] and ongoing work at EPFL [13].

***Irregular debris*** is angular-shaped rubble that typically results from demolition using hydraulic crushers. Reusing such debris only takes advantage of its existing compressive strength, implying a decreased re-utilization rate. The reassembly is either similar to traditional dry masonry or to cyclopean concrete, substituting stone rubble for concrete debris. In the latter approach, pieces are held together in a matrix of new material, which requires additional material. Bellastock has developed low-garden walls and benches using the dry-assembly debris approach [14], but no documentation on structurally more demanding built precedents is yet known. As for flat debris, this approach uses the form of concrete waste predominantly produced by the industry today.

**Table 2**. Comparison of reused-concrete approaches with different piece types.

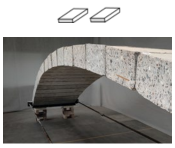
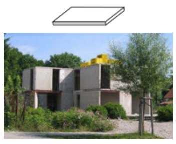
| | Irregular debris | Flat debris | Blocks | Wall/slab panels, beams, columns | | Assemblies | |
|---|---|---|---|---|---|---|---|
| **Reused pieces** |  |  |  |  | |  | |
| **extraction method** | demolition | demolition | deconstruction | deconstruction | | deconstruction | |
| **reclaimed structural capacities** | compressive strength only | compressive strength only | compressive strength only | compressive and tensile strengths | | compressive and tensile strengths | |
| **influence of the donor construction method** | not impactful | not impactful | not impactful | impactful | | impactful | |
| | | | | CIP / trimmed PC | full PC | CIP | full PC |
| **geometric extent of new material input** | volume | volume | line | line/point (surface) | | no need | |
| **preservation of existing connections** | zero | zero | zero | zero | partial | complete | |
| **constraint on the new design layout** | low | low | low | low | medium | high | |
| **re-utilization rate** | decreased | decreased | decreased | equivalent | | equivalent | |

Image credits (from left to right): Bellastock Guillaume Clément; Bellastock Alexis Leclercq; EPFL; Heyn et al. 2008; Superlocal.

## 5. Discussion

Existing literature reports that the piecewise reuse of concrete vastly reduces natural-resource consumption compared to conventional design options and drastically minimizes greenhouse-gas emissions compared to "recycled" concrete [2]. However, an environmental study comparing the five identified approaches is still missing and would help prevent possible pollution shifts regarding little documented approaches. Such analysis should test the hypothesis that environmental burden is most reduced when the fewest additional material is needed in the new systems and that optimal resource management calls for reusing most structural capacities of reinforced concrete.

Approaches that make the most of the structural capacities of the reinforced concrete pieces (i.e., bending resistance) generally support (nearly) equivalent re-utilization rates. Those approaches (wall and slab panels, column, or slab and assembly reuse) are supplied via deconstruction. Conversely, approaches procured by demolition (irregular and flat debris) generally imply a decreased re-utilization rate. Thus, to reuse most of the reinforced-concrete structural capacities, the authors call for reconsidering the relevance of deconstruction over the current predominance of demolition of concrete structures.

## 6. Conclusions

Identifying and comparing five concrete reuse approaches led to the following conclusions:

- Approaches to reuse various types of concrete pieces extracted via demolition or careful deconstruction exist. However, approaches that allow the best re-utilization rate of the structural capacities are less compatible with current demolition practices, as they require careful deconstruction techniques that are less common.
- Irregular and flat debris are logistically less demanding than other approaches, as demolition processes continuously produce such pieces. Nevertheless, further research and applications are required to understand to full potential and limitations of their reuse in structural applications.

- Reusing wall and slab panels, beams, and columns is an environmentally and architecturally promising approach as it implies a low to medium level of constraints of the new design while re-utilizing the discarded reinforced concrete (nearly) equivalently and requiring no large volume of new material input. Nonetheless, built precedents applying this approach to CIP concrete are lacking, despite greenhouse-gas emissions reduction estimated at over 75%.
- Reusing assemblies is the only approach allowing a complete preservation of the existing connections. Still, it highly constrains the design and requires special shoring and lifting equipment, which may result in additional costs.

Future work should conduct further environmental and economic comparisons and develop additional criteria addressing, among others, social, aesthetic, exposure class, durability and design complexity aspects.

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