Environmental and economic analysis of new construction techniques reusing existing concrete elements: two case studies

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Abstract. As the most widely used construction material worldwide, concrete is the main cause of greenhouse gas emissions, material depletion, and waste generation by the construction industry. Typically, concrete waste is crushed and, at best, reclaimed into recycled aggregate or used as gravel. This process is energy-intensive and results in a reduction in material properties. In contrast, the direct reuse of concrete elements from obsolete structures offers great potential for significantly reducing the environmental impact of new constructions. To be reused, concrete elements are carefully sawn out of soon-to-be-demolished buildings. Elements are then used without other major transformations for another service cycle in a new assembly. This paper analyses two recent projects in Switzerland that showcase innovative applications of concrete reuse: a post-tensioned segmented arch footbridge and a parking pavement. Both projects reuse blocks extracted from cast-in-place concrete buildings undergoing transformation or demolition. In this paper, environmental and economic analyses provide a comprehensive understanding of the alleviations and costs involved. Results are compared to those of alternatives with conventional construction methods. The two projects reusing concrete globally showcase a drastically lower environmental impacts for comparable or higher construction costs, hence calling for future developments of such new circular construction strategies.

Keywords: cast-in-place concrete, reuse, life-cycle analysis, construction cost, circular economy.

1. Introduction

1.1 Strategies to lower the adverse environmental impacts of the construction industry

Construction and demolition significantly contribute to climate change, natural resource depletion, and waste accumulation. For example, cement production, a concrete constituent, is responsible for 8-9% of man-made global greenhouse gas emissions [1]. Faced with a growing environmental crisis, identifying and implementing effective strategies to reduce the environmental damages caused by the construction industry has become essential. In recent decades, industry efforts have been led to reduce the operational energy of buildings, i.e., the energy needed to operate buildings. Efforts must now also be made to reduce the embodied energy of buildings, i.e., the energy required to extract, produce, transport, transform and process the materials needed to construct, maintain, and dispose of buildings [2]. The use of bio-based materials, renovation strategies rather than demolition-reconstruction ones, or structural
optimization are examples of strategies to reduce embodied energy. A currently overlooked but promising strategy is the reuse of building materials salvaged from obsolete buildings in new projects. Reuse extends the use duration of elements in new projects, beyond their use in a first building, thus limiting waste from demolition and transformation sites. In contrast to recycling, reused material is not significantly altered between the previous and new uses. Reuse retains the mechanical and formal properties, history, know-how, and technology embedded in the materials and components through careful disassembly [3], [4].

1.2 Reuse of concrete
Since most of the embodied energy of buildings is due to their load-bearing system [2], [5], the reuse of structural elements showcases great potential to limit the environmental damages of the construction industry on a large scale. Prior to the industrial revolution, the reuse of bricks, stone, and wood was common practice [6]. Recently, the rising reuse of structural elements in industrialized countries has mainly been applied to wood and steel components, with very encouraging results in terms of environmental benefits [7], [8]. However, the largest construction waste stream today is concrete [9], the most consumed construction material on Earth [10]. In Switzerland, for example, 2,500,000 tons of concrete waste are generated annually [11].

Today, demolition concrete is at best crushed and recycled into road underlay or as aggregate in the production of new concrete mixes. Although recycled concrete reduces construction waste and the extraction of natural aggregates, its production, requiring cement, does not emit fewer greenhouse gas than new concrete [12], [13]. As buildings today are regularly demolished for reasons other than material degradation or structural safety [14], structural components are often in good condition at the time of demolition and they could still be useful for a longer service life. Sawing obsolete concrete structures and reusing their blocks in new assemblies therefore appears as a circular and sustainable solution when demolition is unavoidable. In addition to limiting demolition waste and natural resource extraction, concrete reuse is expected to reduce greenhouse gas emissions of new constructions [15], [16], as assemblies of reused components require little to no production of new cement.

To date, documented built examples of concrete reuse concern precast structures in the Netherlands, Sweden, Finland [17], Germany [18], the USA [19], and France [20]. In contrast, concrete reuse from cast-in-place structures are rare, even though this structure type is widespread. Thus, new architectural and structural explorations are needed to better frame the range of possibilities for this new construction method. In addition, the analysis of this design and construction strategy should extend knowledge on related environmental and economic impacts.

This paper presents and analyzes two pioneering projects that feature innovative strategies for reusing concrete elements. Both built in Switzerland in 2021, the first project is a post-tensioned arch footbridge and the second is a parking pavement, Figure 1. They both reuse concrete blocks extracted from cast-in-place concrete structures that underwent transformation or demolition. After describing the project design, concrete-block procurement, and construction, the concrete reuse strategies are assessed by analyzing their construction costs and environmental impacts. The paper is organized as follows. The arch and pavement case studies are presented in Section 2. Then, methods used for the environmental and economic analyses are described in Section 3. Section 4 presents the case study analysis results. The latter are discussed in Section 5. Section 6 ends the study with conclusions.

Figure 1. The two case studies analysed in this paper: a 10-m spanning arch footbridge (a) and a 233-m² parking pavement (b), both built with reused concrete blocks extracted from demolition and transformation sites.
2. Case-study presentation

2.1 Arch footbridge
The first case study is a 10-m spanning post-tensioned arch built with 25 reclaimed concrete blocks [21], Figure 1(a). The arch is a footbridge prototype designed and built in Fribourg, Switzerland, in 2021. It is designed to stand its self-weight and a 1.5 kN/m² live load.

Using circular diamond saws, the reclaimed concrete blocks are cut out from existing cast-in-place concrete basement walls of a building undergoing transformation, Figure 2(a). The building is less than 10 years old and located approximately 90 km away from the arch construction site. The 20-cm thick blocks are directly sawn at the final dimensions, 120x40 cm, on the transformation site. Once salvaged, blocks are transported to the sawing-company facilities, where two holes are drilled in each block for the post-tensioning cables. Blocks are then transported to the arch construction site, Figure 2(b). The reused concrete blocks are then placed on a timber centering in order to build the arch, Figure 2(c). Joints are then filled with mortar. After a 14-day curing period, the arch is post-tensioned and the centering is removed, Figure 2(d).

2.2 Parking pavement
The second case study is a 233-m² parking pavement built with reused concrete blocks in Meyrin, Switzerland, Figure 1(b). The pavement is designed to be accessible to less than 3.5-ton vehicles. According to the Swiss standards [22], the pavement must stand a distributed load of 2 kN/m² or a point load of 20 kN. The parking pavement is part of a project for a new operational building.

The blocks come from several demolished or transformed cast-in-place concrete buildings, all located within 15 km of the pavement construction site. The blocks are extracted from walls, Figure 3(a), and slabs, Figure 3(b), using circular diamond saws. They have various dimensions. Once the reclaimed blocks are delivered to the construction site, Figure 3(c), they are placed according to a layout that was generated manually and iteratively with the aim of minimizing the re-cutting of the blocks, Figure 3(d). By the end of the construction, 19% of the volume of delivered concrete is not used and disposed of in conventional ways.

![Figure 2.](image2.png) (a) Extraction of the blocks; (b) blocks ready for assembly in front of the timber centring; (c) construction of the arch; (d) completed arch.

![Figure 3.](image3.png) Extraction of the blocks in (a) walls and (b) slabs; (c) blocks of various thickness ready for on-site assembly; (d) completed pavement. Image courtesy: FAZ architectes for (a), (c), (d) and Ingeni for (b).
The composition of the pavement is summarized on Figure 5(a). The construction steps are the following: after stripping the existing topsoil, an unsorted-gravel layer of approximately 12-cm thick is placed and compacted. Then a 5/12-mm gravel bed with an average thickness of 12 cm is used as a sub-base for the reused concrete blocks. The average thickness of the blocks is 20 cm, but it varies between 12 and 30 cm, depending on their origin. Therefore, the thickness of the gravel sub-base also varies to guarantee the paving surface flatness. Eventually, joints between the reused concrete blocks are filled according to a predefined zoning: as summarized in Table 1, the 233-m² parking area is subdivided into three zones and a different jointing material is used for each zone.

Table 1. Distribution of joint-filling material for the reused-concrete pavement in Meyrin

| Sub-alternative code | Location               | Joint-filling material | Surface [m²] | Distribution over the total pavement area |
|----------------------|------------------------|------------------------|--------------|------------------------------------------|
| Pa1                  | Interior               | Mortar                 | 119          | 51%                                      |
| Pa2                  | Outdoor forecourt      | 5/12-mm gravel         | 96           | 41%                                      |
| Pa3                  | Outdoor washing area   | Bituminous sealant     | 17           | 7%                                       |

3. **Methodology**

3.1 **Environmental analysis methodology**

The environmental impacts are assessed through a Life-Cycle Assessment (LCA). For the arch, the functional unit, i.e., the quantity of the product being compared, is the construction of a 10-m spanning arch in Fribourg (CH) in 2021. For the pavement, the functional unit is the construction of 1 m² of parking pavement in Meyrin (CH) also in 2021.

System boundaries explicit which processes are included or excluded from the analysis. In this study, the systems include: the manufacture of new and recycled materials, the extraction and processing of reclaimed concrete blocks, the disposal of non-reused concrete blocks, material transport and assembly. Excluded from the comparison are the use, maintenance and end-of-life of the arch and the pavement. The construction of the other parts that are similar for all arch alternatives (railings, abutments, overlays...) or all pavement alternatives (pipes, ...) are also excluded from the analysis. Impacts linked to recycling or reused loops are allocated according to a cut-off approach [23], [24].

Impacts are expressed according to two complementary indicators. The first indicator is the global-warming impact, which is expressed in kgCO₂-eq and accounts for greenhouse gas emissions. The second indicator is eco-points (EP). With a single score, EPs weight different environmental burdens according to the "ecological saturation" approach, which reflects the ratio between the flux emitted or used by the product and the target value for the same flux in the Swiss climate objectives [25], [26]. EPs account among others for primary resource consumption, air and water pollution, and landfill waste.

Finally, the data for the impacts of each process are sourced in existing databases (mostly [27]) and through field measurements. Transportation distances of new or recycled material are set to 30 km and, in average, reused-concrete blocks are transported over 88 km for the reused-concrete arch and over 12 km for the reused-concrete pavement.

3.2 **Economic analysis methodology**

For the economic analysis, a construction cost estimate of preliminary designs is calculated. Only the costs of the construction of the new project are included. It excludes maintenance and end-of-life costs, as well as concrete disposal costs borne by demolition or transformation site clients. In line with the swiss standards [28], the degree of accuracy of the estimates in the pre-design phase is ± 15% for the arch and ± 20% for the parking pavement. Unlike LCA, which is linear, costs are subject to economies of scale. For this reason, the pavement costs are not calculated for 1 m² but for the whole surface of the pavement, 233 m². The unit prices used in the estimates correspond to those of summer 2021. Their values are estimated from construction companies bids, engineering office experience and the average unit prices in Switzerland published every semester by the Federal Statistical Office [29].

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1. Environmental analysis methodology
2. Economic analysis methodology
3. Table 1. Distribution of joint-filling material for the reused-concrete pavement in Meyrin
4. System boundaries explicit which processes are included or excluded from the analysis.
5. Impacts linked to recycling or reused loops are allocated according to a cut-off approach.
6. Environmental impacts are assessed through a Life-Cycle Assessment (LCA).
7. The functional unit is the construction of 1 m² of parking pavement in Meyrin (CH).
8. The global-warming impact and eco-points (EP) are two complementary indicators.
9. Transportation distances of new or recycled material are set to 30 km.
10. Reused-concrete blocks are transported over 88 km for the reused-concrete arch.
11. The construction of the other parts that are similar for all arch alternatives are excluded from the analysis.
12. The systems include: the manufacture of new and recycled materials, the extraction and processing of reclaimed concrete blocks, the disposal of non-reused concrete blocks, material transport and assembly.
13. The degree of accuracy of the estimates in the pre-design phase is ± 15% for the arch and ± 20% for the parking pavement.
14. The unit prices used in the estimates correspond to those of summer 2021.
3.3 Alternatives

The environmental and economic performance of reused-concrete arch and pavement is compared with that of four arch-footbridge and two parking-pavement alternatives constructed using more conventional methods. The comparative alternatives are typical of current practice and cover a range of common construction materials. All alternatives meet the same load requirements and have the same overall dimensions. Alternatives are listed in Table 2. The arch alternatives are presented on Figure 4 and the pavement alternatives on Figure 5. The reader should note that the P.a alternative combines sub-alternatives P.a1, P.a2 and P.a3 according to their surface in the reused-concrete pavement built in Meyrin, as presented in Table 1. In the result section, the results of P.a1, P.a2 and P.a3 are also expressed individually for a more comprehensive analysis.

Table 2. List of alternatives and corresponding alternative code.

| Code | Description                      | Code  | Description                                           |
|------|----------------------------------|-------|-------------------------------------------------------|
| A.a  | Reused-concrete block arch       | P.a   | Reused-concrete block pavement*                      |
| A.b  | Recycled-concrete block arch     | P.b   | Pavement with recycled-concrete slab                  |
| A.c  | Monolithic recycled-concrete arch| P.c   | Pavement with bituminous surfacing*                   |
| A.d  | Steel-beam arch                  |       | *see Table 1 for sub-alternative distribution        |
| A.e  | Timber-beam arch                 |       |                                                       |

*see Table 1 for sub-alternative distribution

Figure 4. Arch alternatives, as listed and coded in Table 2. Dimensions in [cm]

Figure 5. Pavement alternatives, as listed and coded in Table 2. Cross-sections. Dimensions in [cm]
4. Results

4.1 Arch footbridge

As shown in Figure 6, the reused-concrete arch (A.a) has significantly lower environmental impacts than recycled-concrete (A.b; A.c) or steel (A.d) arches. Compared to the latter, the global-warming impact is reduced between 63 % and 75 % and its ecological load between 48 % and 67 %. The reused-concrete arch also diverted 6 tons of concrete from disposal and avoided the production of more than 5 tons of concrete or 800 kg of steel.

Compared to a timber arch (A.e), the reused-concrete arch has nearly similar environmental impacts. The reused-concrete arch global-warming impact is 9 % higher and its environmental load is the same. Most of the impacts of the reused-concrete arch are due to the transport of the concrete blocks (33 % of global-warming impact and 21 % of ecological load) and the production of timber for the centering (34 % of global-warming impact and 47 % of ecological load). Reduced transport distance and further optimization of the timber centering (e.g., by using less material or ready-made scaffolding components) would lower the reused-concrete arch environmental footprint.

![Figure 6](image)

**Figure 6.** Environmental impacts of the arch alternatives (a) in kgCO₂-eq and (b) in Eco-points.

The construction cost estimate of the compared alternatives is the highest for the reused-concrete arch (A.a). As shown on Figure 7, it is followed by the recycled-concrete block arch (A.b) which is 24 % cheaper. The monolithic recycled-concrete arch is the less expensive, 54 % cheaper than the reused-concrete arch. Most of the costs for the reused-concrete arch are due to the preparation of the blocks. Indeed, 13 % of the construction costs are due to the additional sawing, 21 % to the drilling of the blocks for prestressing and 12 % to the transport of the blocks.

Focusing on the production of the recycled-concrete blocks (A.b) and comparing it to the preparation of the reused concrete blocks (A.a), the preparation of the reused block is 41 % more expensive but more than 80 % less harmful in terms of global warming.
4.2 Parking pavement

As plotted on the Figure 8, the reused-concrete parking pavement (P.a) drastically reduces the environmental impacts compared to conventional alternatives. Indeed, the reused-concrete pavement (P.a) has a global-warming impact 82% lower than the alternative with a recycled concrete slab (P.b) and 81% lower than the alternative with bituminous surfacing (P.c). The ecological load is also reduced by 65% compared to alternative P.b and by 77% compared to P.c.

For the full surface of the parking pavement in Meyrin (233 m²), the reused-concrete solution allows reducing greenhouse gas emissions by more than 14 tons, valorizing more than 110 tons of concrete and avoiding the production of more than 100 tons of concrete or 18 tons of asphalt, the elimination of which is today highly damaging for the environment.

![Figure 8. Environmental impacts of the pavement alternatives (a) in kgCO₂-eq and (b) in Eco-point.](image-url)
Regarding the reused-concrete sub-alternatives, the most environmentally promising sub-alternative is the one with gravel joints (P.a2), which, in addition, is the cheapest compared to P.a1 and P.a3 and is also slightly cheaper than pavement with a recycled-concrete slab (P.b), as shown on Figure 9.

Regarding the construction cost estimate, Figure 9, the reused-concrete parking pavement (P.a) has comparable costs with the recycled-concrete slab pavement (P.b). The cheapest alternative is the pavement with a bituminous surfacing (P.c) which is 35 % cheaper, but this alternative is also the most detrimental for the environment. When a pavement with a bituminous surfacing is considered environmentally too damaging by decision makers, a reused-concrete parking pavement should be considered, as it is environmentally more efficient than a pavement with a concrete slab and has a similar cost.

5. Discussion

The results show that both case studies perform very well environmentally, reducing up to 75 % and 82 % of the climate-change impact and 67 % and 77% of the ecological load for the reused-concrete arch and pavement, respectively.

From an economic point of view, most of the costs involved with reused concrete blocks are related to labor, which supports local employment. However, only the reused-concrete parking pavement can today compete with conventional alternatives from an economic perspective. This construction technique allows using blocks of varying dimensions, which reduces the need for additional sawing and increases the chances of finding suitable blocks nearby. In the case of the arch footbridge, the special transport of the 20-cm thick block and the numerous additional sawing and drilling operations have largely contributed to the increase of the price. Nevertheless, it can be expected that the economic balance will become more beneficial in the future, e.g. due to more coercive energy policies, higher disposal fees or increased prices for raw materials.

The cost estimates only account for the costs paid by the client of the new projects. However, in cases where the extracted concrete is not transported to a reuse site, the concrete waste generator site usually has to bear disposal costs. The savings in these costs through reuse could be monetized in the future and thus increase interest in reuse.

In terms of technology-development level, the arch was designed as a research prototype, whereas the paving was directly implemented on a public site and the strategy is already repeated on a second site. The arch prototype was used to demonstrate the feasibility of reusing concrete for a footbridge and study the implications in the design and construction process. Costs were not the first concerns and further optimization in the construction methods could help reduce them. In general, it seems economically preferable for construction techniques to use blocks of the maximum size allowed by the constraints of extraction, lifting and transport and with minimal processing.

The construction of the two presented reused-concrete case studies was made possible by the availability of sawn concrete blocks from demolition or transformation sites where sawing was the only
option to remove concrete, as nuisances and shocks (partial conservation, adjacent building, etc.) had to be limited. Today, most obsolete concrete structures are not sawn but demolished by crushing as it is a cheaper and faster process. This could be a future short-term limit to replicate the presented reused-concrete techniques.

Another limitation of the study is that it does not include maintenance and end-of-life impacts. However, as the service life of construction projects extends over decades, the study of the impacts of the latter will have high degrees of uncertainty. For a broader assessment, future work could also extend the analysis of the new reused-concrete construction techniques to additional performance criteria, such as supply-chain risks, design complexity and socio-cultural implications.

6. Conclusion

The description and evaluation of construction techniques that reuse concrete blocks is necessary to inform scholars and practitioners about the benefits, drawbacks and limitations of this new circular strategy. The environmental and economic analysis of two case-studies led to the following conclusions:

- Reusing concrete blocks can significantly reduce the environmental footprint of projects. Compared to conventional alternatives, the studied reused-concrete arch and pavement reduce up to 75% and 82% climate-change impact and up to 67% and 77% the ecological load, respectively.
- In comparison to using new or recycled concrete, the reuse of concrete can be economically competitive when operations on the reclaimed concrete blocks are limited. Excessive processing of the concrete blocks leads to higher costs.
- When a pavement with a bituminous surfacing is considered environmentally too damaging by decision makers, a reused-concrete parking pavement should be considered, as it is environmentally more efficient than a pavement with a concrete slab and has a similar cost.

Overall, the study confirms that reusing concrete is a promising approach to lowering the environmental impacts of structures and civil engineering works. For competitive costs, structural systems should be designed to reuse concrete blocks of the maximum size allowed by extraction, lifting, and transport constraints with minimal processing.

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