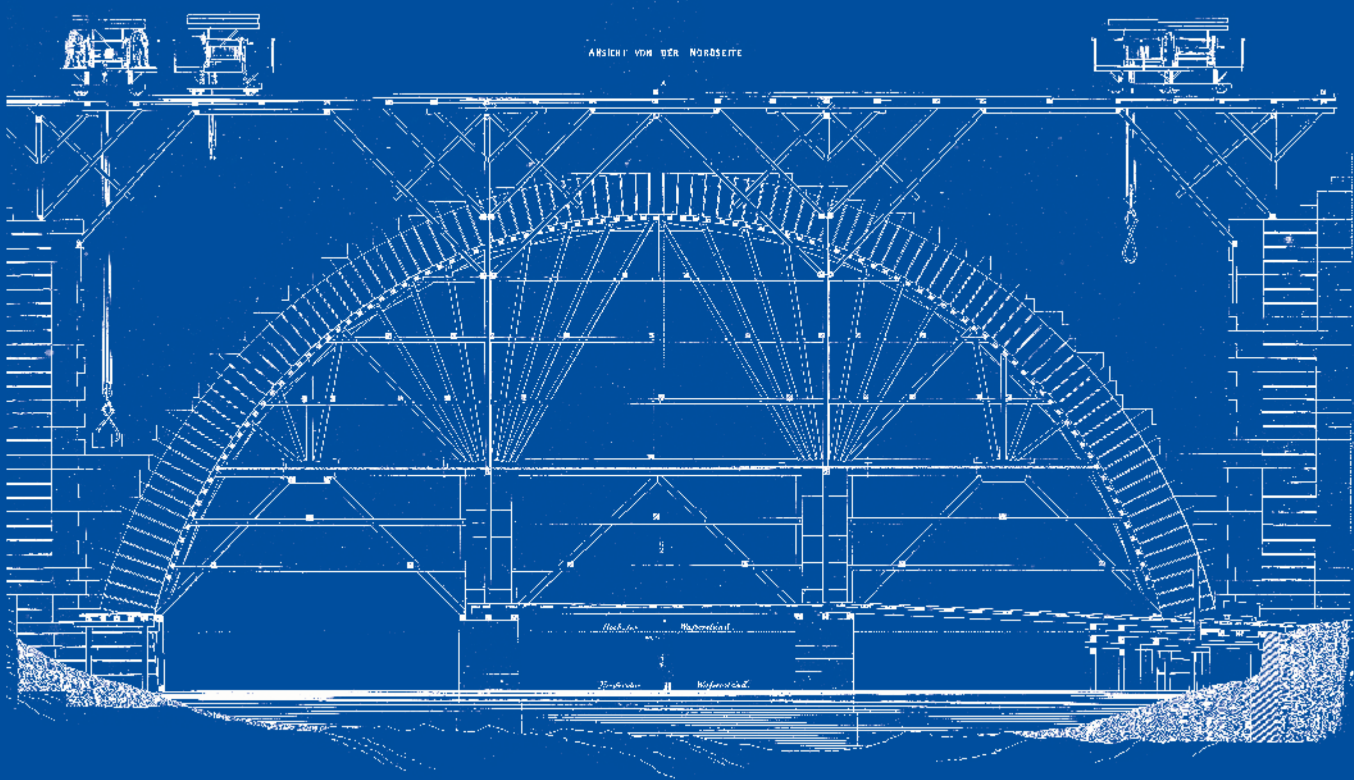
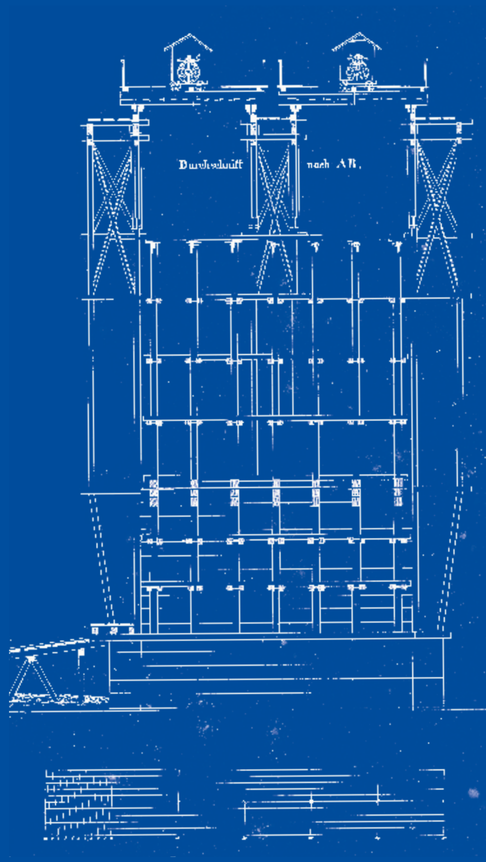
Proceedings of the 8th International Congress on Construction History

Stefan Holzer, Silke Langenberg, Clemens Knobling, Orkun Kasap (Eds.)



Construction Matters



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Structural component reuse of precast and cast-in-place reinforced concrete in architecture since the late 1960s in Europe

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Abstract: The reuse of concrete pieces salvaged from structures undergoing transformation or demolition into new architectural projects has gained a sudden and visible interest over the past five years. However, the practice of reusing concrete pieces in new structures has a little-known several-decade-long history, with documentation referring to precedents as old as the late 1960s. Based on a pre-existing database of built and unbuilt precedents in Europe and new literature search, this research discusses the co-evolution in time and space of the reuse of two types of reinforced concrete: precast reinforced concrete and cast-in-place reinforced concrete. Results highlight the diversity of precast elements reused since the late 1960s and the emergence of cut cast-in-place concrete reuse since the late 2010s. More importantly, the study highlights the scarcity of the practice and how its nature compares to other material reuse activities. Finally, the study questions how, in the absence of a radical decrease of demolition activities, reusing concrete rather than crushing it may become a more common practice.

Introduction

Until the late Industrial Revolution, economic pragmatism and, to lesser extents, symbolic reappropriation encouraged the salvation and reuse of structural construction materials. For instance, once their host building came to obsolescence, timber, bricks, and stones were often reused elsewhere, with century-old examples still brought to light today (Labbas 2019; Guibert et al. 2019). Progressively, over the 19th and 20th centuries, globalization and industrialization not only decreased the interest in material reuse because of cheap manufacturing but also introduced new materials in the construction industry, one of which is reinforced concrete.

Reinforced concrete has been massively used since the 1940s to rebuild cities after World War II and accommodate a growing population. Today, a large share of the European built environment is made of reinforced concrete, with a yearly production of 30 billion tons (Monteiro, Miller, and Horvath 2017).

Simultaneously, a trend consisting of demolishing ever younger (Aksözen, Hassler, and Kohler 2017) and still structurally sound buildings for socio-economic reasons consolidated, fueling a continuously evolving built environment (Thomsen and Andeweg-Van Battum 2004; Abramson 2016). Because of its low production economic costs, the lack of environmental concerns, and the efficiency of demolition equipment, discarded concrete has been—and still is—massively crushed and landfilled or downcycled as infill material or recycled aggregates.

Besides this mainstream end-of-life, another strategy for discarded concrete structures consists of carefully deconstructing obsolete systems into elements and reusing them in new structures after no or minor modifications. The first documented application of this approach in a built project is believed to date 1967 (Küpfer, Bastien-Masse, and Fivet 2023; Mettke 1995). Other precedents built from the 1980s to the 2020s have been documented in a segmented way, in studies often focusing on one precedent or a spatiotemporal sub-set. For example, Huuhka et al. (2019) carefully documented four examples built in Northern Europe reusing precast panels; Mettke (1995) studied the reuse of precast elements in Germany until the early 1990s; and Küpfer (2022) analyzed two projects reusing blocks extracted from cast-in-place concrete and built in Switzerland in 2021.

Throughout this recent history, projects have reused two types of concrete sources:

- Precast concrete elements, i.e., elements produced in a factory before on-site assembly. Although precast elements may be tailored to specific building projects, many generic precast systems have been produced in series in an area or country. The joints between precast elements are frequently sealed with some mortar or concrete. When a structure made of precast concrete elements is carefully deconstructed, the precast elements are typically separated on the existing joint lines using hydro-demolition or sawing. They are then reused in similar or different combinations at their original dimensions or after trimming.
- Cast-in-place concrete, i.e., monolithic structures built on-site using formworks. Cast-in-place concrete structures are often unique and, if ever, only copied in small numbers. The careful deconstruction of a cast-in-place concrete structure is not trivial because the sourced structural system is not made of distinct elements. Thus, where to cut the structure is not straightforward and will always end in creating cut pieces that would never have existed as such before. Their reuse necessarily implies new design combinations.

Because of material similarities but subtle technical and cultural differences, the evolution of reused precast elements and cut cast-in-place pieces is worth studying in parallel.

This paper aims to understand the evolution of concrete reuse in built projects in Europe, from the first application until today, focusing on the similarities and differences in the evolution of the reuse of precast and cast-in-place concrete. The study is limited to built or ongoing projects where carefully salvaged concrete elements are reused as is or after minor alteration for load-bearing (structural) purposes in a new design built in Europe without further geographical restrictions. This study attempts to understand the evolution of the specificities of projects over time in this scattered, nearly negligible, little-known production, which has not yet really lost its pioneering undertones.

The paper is organized as follows. The material collection method is presented in Section 1. Section 2 provides a first overview of the collected precedents. The historical evolution of the collected precedents is then chronologically presented in Sections 3, 4, and 5. A cross-analysis is presented in Section 6. The method and results are discussed in Section 7.

1. Material

The material collected for this research combines:

- 53 precedents built in Europe listed in an existing database built in May 2022 (Küpfer, Bastien-Masse, and Fivet 2023).
- 22 precedents built or under planning/construction in Europe found in a new literature search, with documentation made available between May 2022 and today, October 2023.

In total, this study collects and compares 75 built (or ongoing) precedents in Europe between 1967 and 2023. The method used for the new literature search repeats the method used to build the existing database, as detailed in Küpfer et al. (2023). In short, records were searched first in four scientific databases and then through internet search engines. Searches were conducted in English and a subset of other languages, including the official languages of countries where precedents were identified or presumed. Precedents were manually extracted from collected records. The authors acknowledge that precedents may be missing from the material collection because of the search methodology or the absence of documentation.

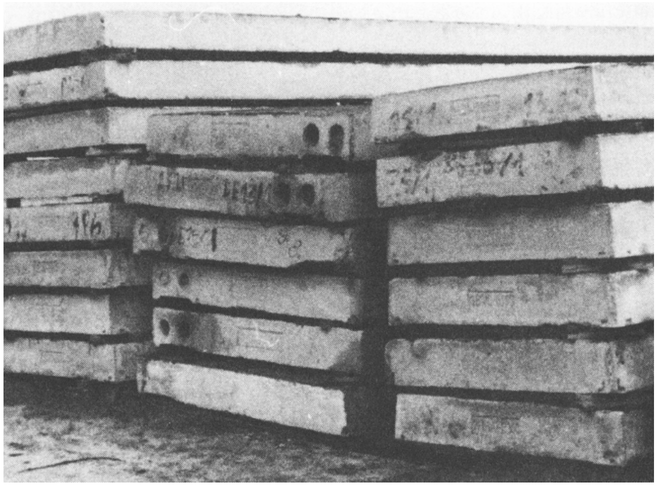

Figure 1. Storage of roof cassettes before reuse in Germany (circa. 1990) (Source/Credits: © Mettke (1995), *Wiederverwendung von Bauelementen des Fertigteilbaus*. Taunusstein: Blottner, p. 66).

2. Overview

Overall, less than 100 built or ongoing projects reusing concrete pieces as structural members were identified in Europe. Despite search methodology limitations, building with reused concrete appears to be a sporadic design approach. Figure 2 plots all 75 identified built and undergoing structural precedents designed with reused concrete in Europe between 1967 and 2023. Precedents reusing precast concrete elements are above the timeline, and precedents reusing cut cast-in-place concrete pieces are below it. Circle colors indicate the receiver-project location.

The figure shows the prevalence of precast element reuse over the reuse of cut cast-in-place concrete pieces among the identified precedents. Until 2017, all precedents but one reused prefabricated elements, and since 2017, the intensification of concrete reuse concerns both types of concrete. The figure also shows that identified precedents are located in Western and Northern Europe, with prevalent German precedents for precast and Swiss for cast-in-place concrete reuse. The authors suppose that the piecewise nature of precast structures made their reuse more intuitive and, thus, the chances for a project to start greater. The location of pioneers and motivations behind research-oriented projects to reuse concrete structures typical of a place might explain some geographical prevalences.

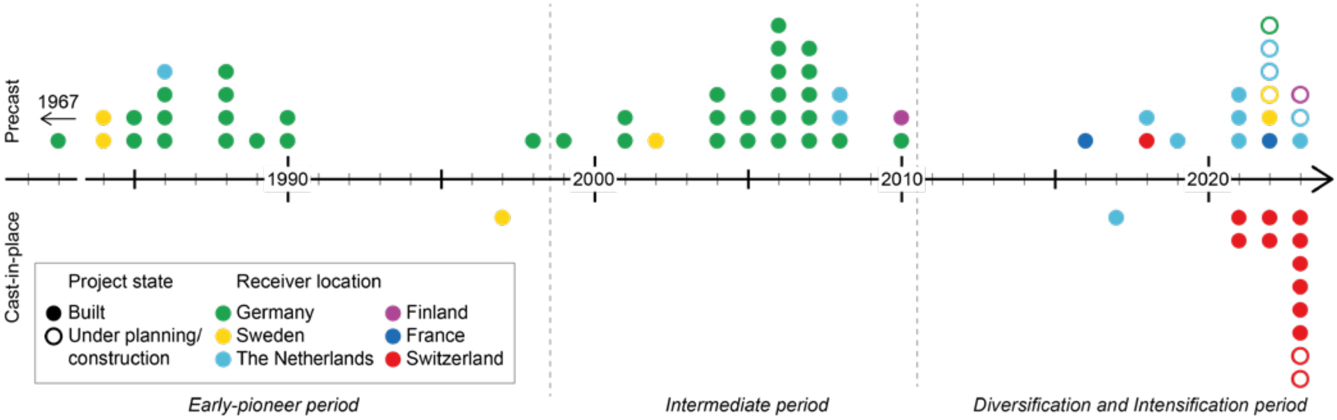

Figure 2. Timeline of identified precedents.

Following an attempt to identify precedent sub-sets with similarities in concrete reuse approaches and construction context, three time periods are identified and further described in the following Sections:

- An early pioneer period, from 1967 until 1999, with the first identified applications.
- An intermediate period, from 1999 until 2010, marked by a few dozen projects reusing precast panels, mostly from discarded multi-story German housing buildings.
- An intensification and diversification period since 2011, marked by an increase of reuse projects with both types of sourced concrete.

Figure 3. On the top left is the remaining donor building in Middelburg (NL), of which the upper-level panels were carefully dismantled and reused to build 3 mid-rise housing buildings in the same city in 1986, shown on the top right.
On the bottom, the 7-story building and some of the low-rise houses built with reused panels salvaged in the Gothenburg urban area (S) in 1984. Credits: EPFL.

3. Early pioneers (1967–1998)

From the perspective built from the identified precedents, projects presented in this section are early pioneer projects. By their construction approach, these early projects can be chronologically presented in three sub-groups that inform the first applications of precast and cast-in-place concrete.

3.1. Reuse of precast elements from and within industrial sites

The earliest identified example of structural concrete dates from 1967 and reused precast floor slabs to reinforce the ground floor of a new plant in Germany (Mettke 1995). This precedent was followed by 12 other German precedents built between 1985 and 1991 that reused various precast elements—including trusses, wall panels, roof cassettes, and columns—for similar or different uses, generally in small-scale operations (Figure 1). Most of these applications reused precast elements salvaged from industrial low-rise buildings in projects located within the same site or less than 20 kilometres away (Mettke 1995). Given the very short distance between the donor and receiver sites, the authors reasonably presume that the reuse was driven by stakeholders' common sense of using locally available resources for which production costs could be avoided.

3.2. Large-scale opportunities from careful height-reduction of existing precast buildings

Within the same period, the practice of reusing precast elements was marked by two large-scale operations in the 1980s. The scale of the two operations remains unrivaled to date, even if the ambition of the ongoing RECREATE precast-panel reuse project (Stenberg, Hernández Vargas, and Huuhka 2022) echoes it.

These two operations, conducted in 1984 and 1986, reused large quantities of precast panels salvaged from the partial demolition of 16- and 14-year-old housing buildings to build new housing buildings in the Netherlands and Sweden, respectively (Figure 3) (Huuhka et al. 2019; Coenen, Lentz, and Prak 1990; Mühlestein 1987; Gieselmann 1991). In both cases, the donor buildings were multistorey housing buildings that were lowered down but not entirely demolished. Thus, the top floors had to be removed carefully so that the remaining lower floors were not damaged and could be renovated and used longer at the original location. In the Swedish precedents, 320 new dwellings were built reusing façade and slab panels. Reusing the panels was made possible by the hooked connections between the panels, which eased the disassembly and the assistance of the original precast-system developer, who provided technical support during the disassembly and reassembly phases. 80 to 85 % of the dismantled panels were reused (Huuhka et al. 2019).

3.3. A solitary cast-in-place first example

Only one project reusing cut cast-in-place concrete elements was identified in this period. This project reused 1,850 tons of concrete wall elements, floor beams, and foundations from two large buildings to build a new 22-flat apartment building in Sweden (Roth and Eklund 2000). Unfortunately, very little documentation has been found on this case study, notably on the decision-making process for the cutting scheme and the new connection details.

4. Intermediate period (1999–2010)

During this period, most identified projects reused precast panels from German mass-housing buildings built with large-panel systems, the "Plattenbau". The scale of the built operations is smaller than that of the earlier projects reusing precast panels in Sweden and the Netherlands. Multiple projects reused panels from the same systems since they had been mass-produced during the Cold War. The repeated experiences with similar systems fed extensive knowledge of their reuse. During this period, no project reusing cast-in-place concrete was identified. The subsequent sections detail these diverging productions.

4.1. Precast reuse: the iconic case of the German panels

During this period, twenty-one low-rise housing buildings, garages, and community buildings were built in Germany, reusing wall and slab panels from demolished "Plattenbau" erected during the Cold War. Most panels are salvaged from

Figure 4. The "Plattenvereinigung" project reused precast panels and staircase elements from East-German and West-German buildings (2010). Credits: EPFL.

East-German "Plattenbau" initially assembled in the late 1960s, 1970s, and 1980s. Only three recorded projects were built outside Germany: two in the Netherlands, with German panels, and one in Finland, with local panels.

The existing documentation suggests that the German project benefited from the collaboration between research and construction activities involving researchers from TU Berlin and BTU Cottbus (Heyn, Mettke, and Thomas 2008; Heyn et al. 2008; Fischer et al. 2012), like the "Plattenvereinigung" project (Figure 4). The diversity of the applications studied to reuse the "Plattenbau" panel suggests the cultural and material importance of the question for the network of researchers involved.

During this period, the first projects reused wall and slab panels for the same function, and their original dimensions were preserved, which saved the costs of additional sawing and new connection construction. Researchers claimed that economic savings can reach up to 26 % compared to a new concrete structure if the panels are optimally reused (Asam 2007). Some projects also used resized panels, with dimensions adapted to the new projects, as in the Berlin-Schildow 2nd pilot project. Cut wall elements were reused as triangular roof slope elements, and new connection details had to be developed (Asam 2007).

During the same period, a few projects planning to reuse precast panels were also abandoned or only partially completed. An incomplete example is a large 500-apartment Swedish project, of which only 54 were built with reused panels (Eklund et al. 2003; Addis 2006). This reuse-operation interruption is believed to have arisen from the lack of coordination caused by the different contractors tasked with deconstruction and reassembly (Addis 2006).

4.2. The absence of cast-in-place concrete reuse?

No precedent reusing cast-in-place concrete in new structural design was identified during this period. The authors assume that the likelihood of considering the reuse of cast-in-place structures at that time was probably minimal due to a lack of awareness regarding the unique precedent at this time, the absence of specific documented theoretical or applied research, and the lack of economic or environmental incentives.

5. Recent diversification and intensification period (2011–today)

While all but one identified precedents built during the first two periods reused precast elements in four countries but mainly in Germany, the third period witnessed a diversification of concrete reuse practices regarding both the type of concrete and project location. Since 2016, the number of projects kept increasing, both with precast and cast-in-place concrete. The following Sections describe these evolutions.

5.1. Precast girders and panel reuse: towards a large-scale application?

Building on technically and environmentally successful precedents coupled with growing environmental concerns, new precast-element projects have multiplied since 2016, searching for scalable solutions to use reused concrete as a substitute for newly produced and highly CO_2-emitting cement-based construction materials. For example, a group of Dutch researchers, designers, and contractors studied the reuse of bridge precast girders, which are repetitive components in bridges, for the same function (R. Vergoossen, van Eck, and Jilissen 2022). Research results supported the completion of two projects and the planning of another one (R. P. H. Vergoossen, van Eck, and Jilissen 2023). This project echoes the early reuse of precast trusses and purlins in Germany during the 1980s. Another project that illustrates this ambition to scale up the reuse of precast concrete elements is the RECREATE project (Stenberg, Hernández Vargas, and Huuhka 2022). In close collaboration with the industry, this large European research project studies the reuse of precast panels via full-scale applications in four countries. This project echoes the reuse of panels in the first pioneer applications in the 1980s, as well as the applied research project carried out in Germany in the 2000s.

5.2. Cast-in-place concrete reuse: from explorations to generalization?

Coupled with growing environmental concerns, the reuse of cast-in-place concrete pieces gained interest over the past few years, with a growing number of applications. Despite the regrettable absence of detailed statistics, cast-in-place concrete was and is another prevalent construction technique in some territories, thus explaining the local interest in reusing its pieces, for example in Switzerland. One of the rare statistics reports that only 6 % to 23 % of new housing buildings were built with precast concrete in Geneva (Switzerland) in the early 1960s, while this rate was at 45 % for Amsterdam or 100 % for Dordrecht (the Netherlands) at this time (Bovet 1963).

The absence of pre-existing connections in cast-in-place concrete structures does not constrain the cutting scheme. Therefore, different geometry of pieces can be extracted from concrete monolithic cast-in-place structures. Since 2017, three types of concrete pieces have been reused in new projects (Figure 5):

- The first type are concrete blocks that must be combined to be used in structures, primarily working in compression. This type of piece was used to build a footbridge and

Figure 5. Geometry of reused pieces cut from cast-in-place concrete structures: blocks (top), assemblies (left), slab or wall elements (right). Credits: EPFL.

different parking pavements (Küpfer et al. 2022; Devènes et al. 2022). This approach requires less information on material properties since the new design only relies on the compressive strength of the blocks. This approach refers to stone and brick construction techniques. Blocks can be supplied via concrete-sawing companies' existing activities, which mostly concern the extraction of rather small pieces in buildings undergoing transformation.

- The second type are large assemblies encompassing both vertical and horizontal elements with the aim of recovering the moment-resisting capacities offered by the reinforced concrete connections. This approach was used to build a low-rise exhibition building in the Netherlands (Superlocal 2018) and a community pavilion in Switzerland (Küpfer et al. 2024; RebuiLT 2023), where existing continuous connections between horizontal and vertical elements could be preserved. Unseen original forms of architecture can emerge from this approach, which nevertheless requires heavy lifting equipment, non-standard transportation processes, precise knowledge of both steel and concrete properties, and synchronization between donor and receiver projects. No equivalent precedent was found with precast concrete since connections between vertical and horizontal elements are typically used as separation lines.
- The third type are wall or slab elements that span a new-structure main dimension with the aim of recovering the bending-resisting capacity offered by the steel reinforcement. This approach is planned to be applied to wall elements for a new building in Switzerland (Claessens-Vallet 2023) and was used to build a new floor system prototype in Switzerland in 2023, developed at EPFL (Küpfer, Bertola, and Fivet 2023). This approach echoes the older precedents reusing slab and wall precast elements, but without much information on the first pioneer cast-in-place precedent, had to be adapted to the specificities of cut cast-in-place concrete reuse. The main specificities are that cut cast-in-place concrete pieces have never existed as such before deconstruction since they were part of a larger monolithic structure and that the continuity of the connections is lost during sawing. In the perspective of scaling up reuse, this approach does not necessarily require matching one donor to one receiver since rectangular, adaptable elements could be extracted from donor structures. Still, scalability remains limited by the prevalence of demolition over deconstruction activities.

Overall, since 2017, three main approaches have been explored. Despite an increasing optimization and adaptation of the component reuse process, in terms of supply chain, construction ease and costs, massification objectives would call for a systemic change in building demolition approaches.

6. Cross analysis

This section analyses the age group of the donor buildings supplying concrete reuse projects since 1967, the distance between donor and receiver projects, and discusses the specificities of concrete reuse in reuse history and local construction history.

6.1. Donor buildings built during the 1960s, 1970s, 1980s

Figure 6 plots the construction year of donor buildings and the component age at the time of reuse, for projects for which the information was available in existing literature. On average, since 1967, components were aged 30 years when the reuse operation starts. Besides three outliers, all documented donor buildings were originally built between the 1960s, 1970s and 1980s. Overall, the construction period of donor buildings has only little evolved over time, with donors built in two or three of the above-mentioned decades. This construction period corresponds with the building age group that is today increasingly at risk of being demolished, e.g. in Switzerland (Wüest & Partner 2015).

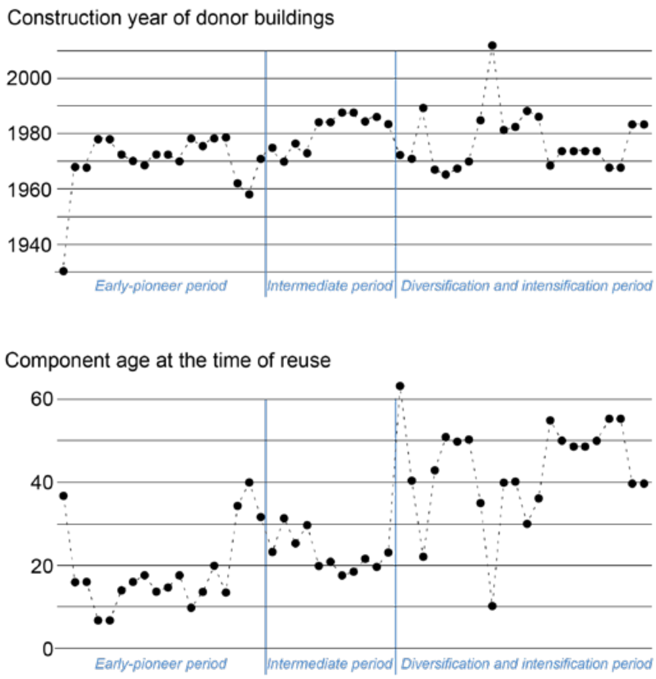

Figure 6. Construction year of donor building and reused component age at the start of the reuse operation for the collected case studies (when information is available).

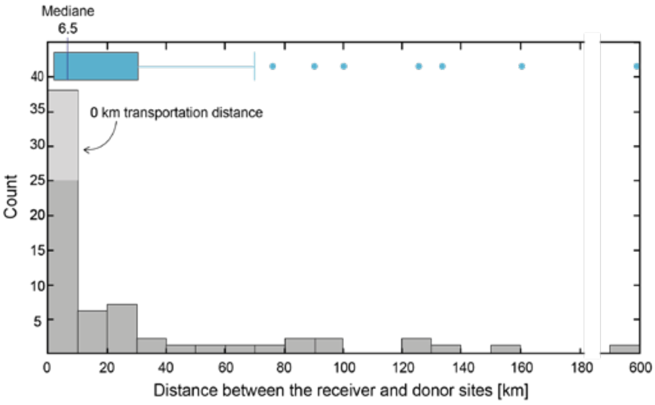

Figure 7. Distance distribution between receiver and donor sites (when information is available). In light grey, precedents with a 0 km distance between the two sites.

6.2. Vicinity of donor and receiver projects

Figure 7 plots the distribution of the distance between donor and receiver projects when the information is available in the literature. More than half of the projects were located less than 10 km away from the donor building, and about 20 % reused components on the donor site. Overall, the median distance from donor to receiver projects is 6.5 km, reflecting the general vicinity and local supply of the concrete reuse projects and the role of local opportunities in practice.

The components that were transported over the longest distances are wall and slab panels or elements. No project transported the reused concrete beyond 160 km except for one. That project is the "Plattenvereinigung" project (Figure 4) that, for symbolic reasons, reused together elements sourced from two donors, one located in old East Germany (100 km) and one in old West Germany (600 km).

6.3. Concrete reuse: what role in reuse history and local construction history?

Considering the full extent of construction history, reinforced concrete with modern cement is a recent material. Its mass premature demolition is an even more recent phenomenon that happens in a context where materials are relatively cheap to produce and eliminate since costs do not account for the high negative externalities on society and the environment. Consequently, reusing concrete is a relatively new question in the history of construction component reuse. Yet, the large quantities of discarded concrete make it urgent to tackle. Reused concrete is also a catalyst for questioning current ways to build and discard buildings.

Nevertheless, the production of reused concrete projects is extremely small, and projects reusing concrete are outliers in the concrete construction history. The production seems highly dependent on a handful of pioneers willing not to waste available resources and local opportunities.

For a large share of concrete reuse precedents, the final aesthetics of the projects do not seem to visibly differ from the built environment erected at the same time and place. This is less the case for an increasing share of recent projects. Techniques used to build with reused concrete are comparable to those used with new precast concrete, and reused concrete projects undoubtedly benefitted from combining techniques and knowledge available locally.

7. Discussion

7.1. Cut cast-in-place concrete as a new prefabricated concrete?

This work studied the evolution of precast and cast-in-place concrete component reuse. It showed that, until 2016, all identified precedents except one reused precast concrete, due to supposed technical ease. However, technical challenges to reassemble reused cast-in-place and precast concrete pieces resemble when precast elements are trimmed before reuse. Indeed, in this situation, the dissimilarity of the trimmed precast elements with the initial design requires new design explorations and verifications. Despite the possible additional costs of adapting the elements to the new design, this situation is an opportunity to explore other structural and architectural design options with reused elements.

More generally, prefabrication in construction is appreciated as it speeds up construction time, and also facilitates the production of repetitive elements with non-standard shapes or finishes (Marchand 2022). Cut cast-in-place elements are delivered as elements ready to be assembled on the receiver site and thus could be considered as a new type of prefabricated concrete elements despite their original construction method. Therefore, forthcoming research endeavours could explore the optimization of cut cast-in-place concrete reuse to capitalize further on its characteristics similar to precast concrete.

7.2. What future of a decade-long and diverse but scarce history?

Overall, the history of concrete reuse spreads between 1967 and today, with the first large-scale projects realized in the 1980s. Nevertheless, concrete reuse remains a niche practice since only 75 built or undergoing projects were identified.
Compared to the beginning of the 2010s, the number of precedents has increased since 2016. While the first projects were driven by a supposed pragmatic use of the locally available material at probably low costs, projects in the latest and still ongoing period have been driven mainly by ecological concerns and sometimes coupled with a quest for new aesthetics.

A question that arises at this point is how this last trend will evolve in the forthcoming years or decades. Past precedents have shown the technical feasibility of a large set of new structural designs with reused concrete, the large environmental benefits, and even some economically beneficial projects (Küpfer, Bastien-Masse, and Fivet 2023). However, since its first applications, the reuse of concrete has been limited by the prevalence of fast, cost-effective demolition and impeded by synchronization and design challenges. In the absence of new incentives encouraging the substitution of environmentally detrimental materials with more sustainable alternatives, a pertinent question arises regarding the broader adoption of concrete reuse practices by industry practitioners and clients beyond those already convinced by the architectural, social, and environmental assets of repurposing existing materials: will the reuse process and economic system progress to a stage where opting for concrete reuse becomes the default choice over conventional crushing methods?

Nevertheless, the maximum potential for new material substitution through reuse is constrained by the proportion of current demolition activities relative to construction activities. In Switzerland, the annual demolished floor area corresponds to approximately one-seventh of the newly constructed floor area (Federal Statistical Office 2020). Consequently, the maximum theoretical potential of component reuse in the country would be reached with only one-seventh of the new floor area built with reused materials. While reuse activities at the construction scale are currently negligible, the only approach to altering this 1/7th ratio sustainably is by reducing both demolition and deconstruction activities.

7.3. Importance of precedent knowledge

Knowledge of precedents is paramount for understanding the evolution of design practices. However, it is pertinent to acknowledge that existing literature on precedents of concrete component reuse still needs to be expanded, particularly regarding connection details and the relationships with the local construction contexts. Therefore, an imperative need exists for archival endeavours focused on the systematic documentation and dissemination of design processes and details. Such an expansion of knowledge from the past would support future advances in the field of structural reuse and sustainable construction.

Conclusion

The structural reuse of concrete pieces is a relatively new practice with a scarce but diverse set of built projects. Based on new literature research, this study highlights the co-evolution of cast-in-place and precast concrete reuse from 1967 to the present. Key findings reveal the slow evolution of precast concrete reuse from the 1980s until today and the recent emergence of cast-in-place concrete reuse, yet nourished by a quest for sustainability and design exploration for what could be considered a "new" construction material. Projects reusing concrete pieces have probably benefitted from a combination of locally available knowledge and tools. Nevertheless, new inquiries and analyses of little-documented case studies could further inform on the relationship between these singular projects and local construction contexts. Finally, while waiting for a radical decrease in demolition activities, the authors are hopeful that interdisciplinary design and (de-)construction teams will more and more systematically consider soon-to-be-demolished concrete structures as potential new mines of valuable construction materials.

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