BUILDINGS & CITIES

Reuse of cast-in-place concrete: overcoming industry barriers

SPECIAL COLLECTION: MAINSTREAMING BUILDING COMPONENT REUSE

RESEARCH

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ABSTRACT

Mainstreaming the reuse of elements extracted from cast-in-place (CIP) reinforced concrete (RC) structures beyond pilot projects requires more than environmental motivation: it requires resolving technical, logistical, contractual and institutional barriers. Research has so far centred on prefabricated systems, leaving CIP structures only partially addressed. The latter are monolithic: recovering elements requires saw-cutting, and every transaction currently demands bespoke negotiation between donor and receiving projects. This bilateral matching does not scale. A systemic analysis is presented of three recent Swiss deconstruction case studies. Four categories of barriers are identified that together prevent the formation of an industrial reuse market. Drawing on a steel-section analogy and a synthesis of systemic interdependencies, three conditions are formulated for creating a viable market for CIP reuse involving a decoupling of supply and demand (a normalised dimensional grid, versatile connection systems, and a stock-holding and guarantee function). Elements would therefore be cut and stocked before any receiver is identified. Standardising element dimensions proves limiting for a heterogeneous stock and a small demolition flow. A set of more versatile connection details would reduce costs and enhance the reuse of CIP elements.

PRACTICE RELEVANCE

To mainstream CIP concrete reuse beyond pilot projects, three changes in industry practice are immediately actionable. First, pre-demolition reusability assessments with standardised factsheets should become routine inputs to design, reframing the engineer's role from a specifier of new products to a characteriser of an existing material stock. Second, template donor–receiver contracts allocating liability, custody and inspection should replace case-by-case negotiation. Third, the design community should converge toward a versatile family of connection details (timber, steel or concrete substructures accepting a range of element dimensions), so that elements from different donor structures remain interchangeable with each other and with new slabs. The Simplon case (CHF128/m², about €137/m², for extraction alone versus CHF200/m², about €213/m², for an equivalent new slab) indicates that extraction is economically viable. What remains is the value-chain reorganisation that downstream coordination requires.

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1. INTRODUCTION

1.1 CONTEXT

Sand and gravel are the most extracted solid materials on Earth. The production of concrete used some 20 Gt of virgin aggregates in 2020 (Watari *et al.* 2023). Cement production causes about 5–9% of global CO_2 emissions (Küpfer *et al.* 2024b). Downstream, Switzerland generates about 17 million t of mineral construction waste a year (BAFU 2023); and the Canton of Vaud already lacks landfill capacity for inert waste (Canton de Vaud 2024).

These pressures converge toward structural concrete reuse as a relief strategy. Reuse consists in reintegrating load-bearing elements in new structures, with their original configuration or with minimal modifications. Unlike recycling, which crushes demolished concrete into aggregates and destroys the structural order achieved during production, reuse preserves the geometry, reinforcement layout and mechanical capacity of the original element. Built prototypes (the RE:CRETE footbridge, the FLO:RE floor and the rebuiLT pavilion) report 50–94% reductions in global warming potential compared with new equivalents (Devènes *et al.* 2022b; Küpfer *et al.* 2024a, 2025). The question is therefore not whether structural reuse is desirable, but whether it can function within a construction market where standardised products, guaranteed properties and structured supply chains remain the baseline.

Technical feasibility is increasingly established. Precisely sawn faces let concrete-to-concrete joints approach the plastic capacity of the section in compression (Sanio *et al.* 2024). A review of 77 precedents since 1967, 54 of them built, documents a long-standing, if still niche, practice (Küpfer *et al.* 2023). Although standards and deconstruction protocols have emerged for prefabricated elements—notably NS 3682 for hollow-core slabs (Standards Norway 2022), the associated openBIM validation workflow (Fonsati *et al.* 2026) and the quality-management procedure of the ReCreate pilots (Huuhka *et al.* 2023; Räsänen *et al.* 2024)—no equivalent framework exists for cast-in-place (CIP) concrete reuse. The existing literature has treated concrete reuse primarily as a technical problem of extraction and characterisation. This article reframes it as a process and market structure problem.

1.2 DISASSEMBLY VERSUS EXTRACTION

The vast majority of documented structural reuse cases involve prefabricated elements (Küpfer *et al.* 2023), whereas CIP reuse remains confined to a handful of pilots: RE:CRETE, FLO:RE and rebuiLT (Devènes *et al.* 2022b; Küpfer *et al.* 2024a, 2025). Deconstruction here denotes selective dismantling to recover elements, as opposed to demolition. Deconstruction can take two forms: disassembly or extraction. Recovering prefabricated elements is an act of disassembly. CIP structures, designed as monolithic systems, require an act of extraction that runs counter to the structural logic of the original design: the sawing layout becomes a design variable, element properties must be characterised rather than specified, and every transaction currently requires bespoke negotiation between donor and receiving projects.

Beyond the technical act of extraction, the economic viability of CIP reuse depends on a chain of interdependent operations (assessment, extraction, transport, storage, reassembly), each of which must function for the system to work.

1.3 SUPPLY, DEMAND AND COUPLING IN A REUSE MARKET

A market is understood here as the institutions that allow repeated transactions between parties who need not know each other. Supply is the flow of elements that deconstruction makes available, in dimensions and at dates fixed by the donor; demand is the set of receiving projects able to integrate them, in dimensions and at dates fixed by their own programme. Reuse is demand driven when the receiver defines what is extracted, and supply driven when the donor defines what is offered. Coupling is the degree to which a receiver must be identified before an element is cut. Economies of scale arise when repetition lowers the unit cost of a transaction; in reuse they require that transactions share a specification rather than a donor. Mode is used below as a descriptive label for a coupling configuration (see Section 2.1), not as an economic category.

Market design identifies three conditions for a market to function: thickness (enough participants on both sides), absence of congestion (offers can be evaluated without time pressure) and safety (taking part is simple and safe, with no need to trade outside the market or to play strategically) (Roth 2008). Over a product's life-cycle, variety narrows and the product becomes standardised (Utterback & Abernathy 1975); the configuration on which producers and users then converge is known as a dominant design. Construction is project based and site specific, so convergence there occurs on components and interfaces rather than on whole products (Winch 1998). A modular architecture is one whose components can vary independently because their interfaces are standardised (Baldwin & Clark 2000). It allows economies of substitution: designing a better system by retaining some existing components costs less than designing it afresh (Garud & Kumaraswamy 1995).

1.4 RESEARCH OBJECTIVES

This study examines why CIP concrete reuse has not yet transitioned from pilot projects to an industrial process. By comparing three recent Swiss deconstruction projects, each following a distinct strategy, it identifies the levers and barriers conditioning scalability and distinguishes between contingent obstacles, addressable through better organisation, and structural constraints rooted in the economics and physics of the material system. Lysbüchel parking in Basel (Figure 1a) is used as the demand-driven reference; Marcelin in Morges (Figure 1b) is used as the closed institutional circuit; and Simplon parking in Lausanne (Figure 1c) is used as the central, most extensively documented case.

2. METHODS

2.1 CASE STUDY SELECTION AND COUPLING MODES

The three case studies (Figure 1 and Table 1) form a coherent spectrum of alignment strategies between donor supply and receiving demand, sharing a common regulatory context (Switzerland), and represent a genealogy in which each strategy resolved the limitations of the preceding one while exposing a deeper layer of constraints. They correspond to modes A, B1 and B2 (Figure 2); mode C (discussed in Section 4) is the hypothetical end-state of structural decoupling through standardisation. Prefabricated precedents elsewhere in Europe (Huuhka *et al.* 2023) serve as a comparison, not as additional cases. With three heterogeneous cases the comparison is analytical, not statistical.

The modes are defined by two variables (Figure 2): which side fixes the element dimensions, and whether a receiver is identified before cutting. The second does not follow from the first, as mode B2 shows. In mode A the receiver fixes the dimensions and is identified. In mode B1 a single owner controls both sides: dimensions follow identified internal receivers, and the surplus is cut to a standard size without a pre-identified receiver. In mode B2 the donor fixes the dimensions and receivers are sought on the open market before cutting. Mode C, a limit utopian today (see Section 4.5), would fix dimensions independently of any receiver and decouple the two sides through a stock. Between modes B2 and C lies the hypothesis of this study, the versatile interface: the donor fixes the dimensions within a window the receiving connection accepts, so no receiver need be identified before cutting and none waits for a donor. The modes coexist; their ordering reflects the learning sequence observed, not a necessary trajectory.

Lysbüchel parking in Basel (mode A: receiving demand dictates donor supply) is a four-storey structure built in 1970 using prefabricated prestressed ribbed slabs, originally produced by Stahlton AG, and deconstructed in the period 2024–25 by the real estate department of Canton Basel-Stadt (Immobilien Basel-Stadt—IBS). Its organisational logic follows mode A (one-off competitions for two identified receiving sites). For a prefabricated donor the first variable has no object, since the element dimensions pre-exist the operation; Lysbüchel is in mode A by the second variable alone, its receivers being identified before dismantling. Because dimensions were fixed and catalogued at the source, it eliminates the negotiation over geometry, acting as an idealised benchmark against

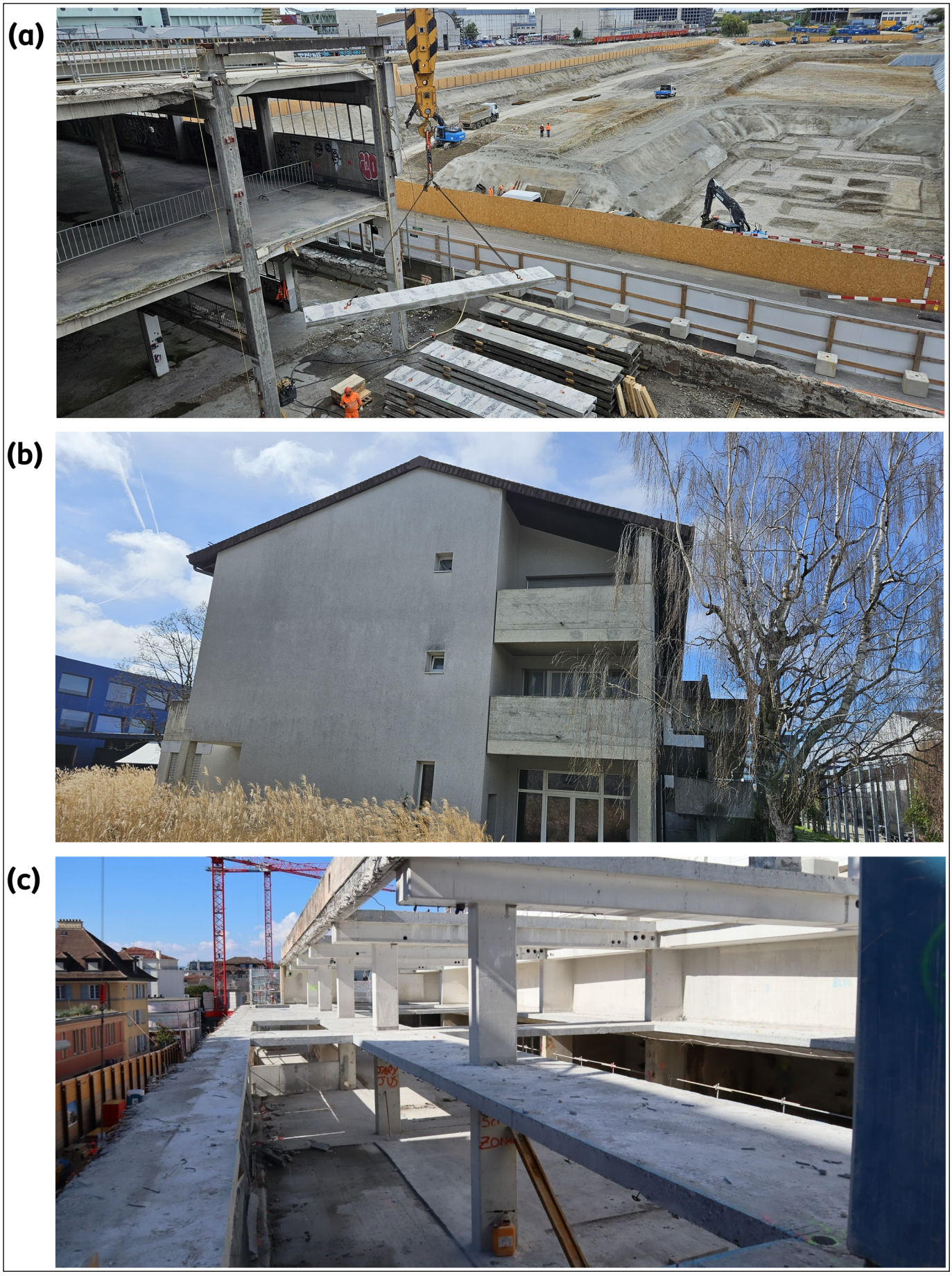


Figure 1: Site views of the three case studies: **(a)** Lysbüchel (Basel) during deconstruction; **(b)** Marcelin (Morges) prior to deconstruction; and **(c)** Simplon (Lausanne) during deconstruction.

which the subsequent CIP cases are measured. Mode A is not limited to prefabricated systems: in a design study, Widmer *et al.* (2023) drew most of a residential structure from the components of two CIP donors, the receiving project dictating the sawing layout, which ties donor and receiver tightly together.

Marcelin boarding house in Morges (mode B1: closed institutional circuit, demand driven for identified projects, with a standardised offer for surplus elements) is a CIP building constructed in 1981. The building comprises a basement, ground floor and three upper levels; the slabs are in reinforced concrete (RC) and the walls in masonry and RC. It was deconstructed in the period 2024–25 by the Canton of Vaud to produce a total of 242 slab elements. The first batch of 148 elements is to be reused by three projects (landscaping, patios, foundations) on the same site and for the same client (Canton of Vaud, demand-driven reuse). The remaining 94 elements, cut to a standardised size of 3000 × 2500 mm, were offered to external receiving projects not identified before cutting (supply-driven reuse). These applications load the slabs below capacity, yet the case is structural reuse by the definition in Section 1.1; its interest lies in the extraction and allocation process.

Simplon parking in Lausanne (mode B2: hybrid iterative), built in 1986 next to Lausanne train station, is a six-level CIP structure whose slabs rest on beams and columns on a regular grid, with decks exposed to de-icing salts near the entrances. As part of the transformation of the train station by the Swiss Federal Railways (CFF),[1] it is scheduled for deconstruction in two phases: phase 1 beginning in 2026 and phase 2 in 2027. A call for interest was issued to match the donor supply with receiving demand on the open market. The donor fixed the dimensions, hence mode B2.

Table 1: Comparative overview of the three case studies.

Note: CIP = cast-in-place; RC = reinforced concrete.

	PROJECT		
	LYSBÜCHEL	**MARCELIN**	**SIMPLON**
Location	Basel (BS)	Morges (VD)	Lausanne (VD)
Year built	1970	1981	1986
Structure	Prefabricated, prestressed ribbed slabs	CIP RC slabs on masonry/RC walls	CIP RC slabs on beams and columns
Deconstruction	2024–25	2024–25	2026–027 (planned)
Owner	Real estate department of the Canton Basel-Stadt (Immobilien Basel-Stadt—IBS)	Canton of Vaud	Swiss Federal Railways (CFF)
Reuse volume	1,607 elements; 8,166 t (Zeltner 2024)	242 elements; 1,162 t	About 705 elements; about 2,800 t; about 5,800 m²
Approach	Demand-driven (competition)	Closed circuit (demand-driven 1–3) + standardised offer (4)	Hybrid iterative (call for interest)
Coupling mode	A	B1	B2

2.2 ANALYTICAL FRAMEWORK

The comparison is structured around five dimensions: (1) sawing layout strategy; (2) logistics and site management; (3) contractual framework; (4) design integration; and (5) scalability potential. The first four follow the chain of operations of Section 1.2 and the criteria of Küpfer *et al*. (2021); the fifth synthesises them. Each case was analysed individually against these dimensions before cross-case patterns were identified. Table 3 also assesses each case against the mode C conditions of Section 4.5.

2.3 DATA COLLECTION AND EVIDENCE STATUS

For Lysbüchel and Marcelin, data were drawn from owner-provided resource assessment reports and factsheets (Devènes *et al.* 2022a; Bastien-Masse 2025). The second author was part of the assessment team for both projects. The final Marcelin quantities and the fate of its surplus stock up to 2026 were provided by the owner (Canton of Vaud, personal communication, 2026).

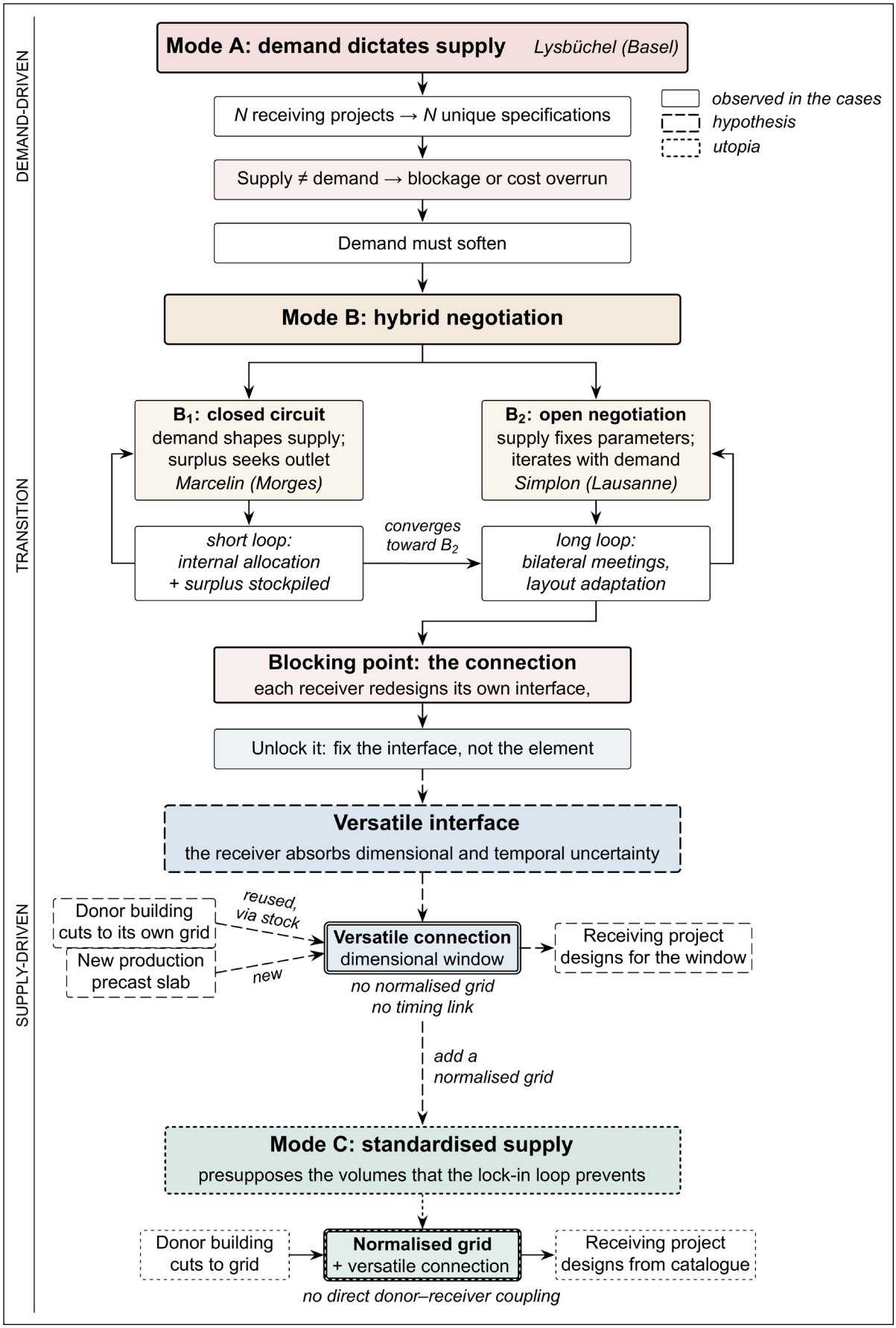


Figure 2: Supply–demand coupling continuum for cast-in-place (CIP) concrete reuse.

Note: Modes A, B1 and B2 are observed; the versatile interface is a hypothesis and mode C is a utopian limit; the connection system is the blocking point.

For Simplon, both authors were part of the expert team accompanying CFF during deconstruction planning. The empirical material combines documentary analysis with participant observation, including 20 bilateral meetings with owners and design teams of potential receiving projects and coordination sessions with CFF, its engineers and reuse experts.

The Simplon observations cover the call for interest and the search for receivers in 2025, up to the first signed reservations; deconstruction was validated as an alternative to traditional demolition, and extraction, which began in September 2026, is not covered. The dataset therefore captures planning and negotiation rather than extraction outcomes. Statements resting on it are labelled anticipatory in Section 3; Table 3 records each case's evidence status.

3. RESULTS

3.1 LYSBÜCHEL

3.1.1 Building assessment

The Lysbüchel case benefits from a structural advantage that distinguishes it from the two CIP cases: because the building was constructed with prefabricated elements, no sawing layout decision was required. The ribbed slabs, manufactured by Stahlton AG in six standardised subtypes, were all 1495 mm wide, 480 mm deep and 5790–10,390 mm long (Devènes *et al.* 2022a) (Figure 3). Deconstruction therefore consisted of cutting the joints between prefabricated elements, an act of disassembly rather than extraction.

Figure 3: Extracted Stahlton ribbed slab at the Lysbüchel site.



The Canton of Basel-Stadt, through IBS, commissioned an inventory and structural assessment to validate the reuse potential of the elements. The resulting factsheets (Devènes *et al.* 2024) summarised geometry, reinforcement layout, concrete compressive strength and prestressing steel tensile strength for each element type, and put the reusable share of the ribbed slabs at about 90%, an estimate to be confirmed at dismantling (Devènes *et al.* 2022a). These factsheets were integrated into a catalogue included in the terms of two architectural competitions held in the period 2022–23: Wohnüberbauung Walkeweg Baufelder C/D and Schliengerweg 31, both commissioned by IBS (Kanton Basel-Stadt n.d.-a, n.d.-b). The two winning projects proposed to reuse a large portion of the Lysbüchel elements, underscoring the value of early assessment and catalogue-based design briefs.

3.1.2 Contractual framework and logistics

Elements were stored on a neighbouring IBS site and inspected after extraction, absorbing the temporal mismatch within the owner's perimeter. The contractual framework reflects the same institutional absorption. As a public client, IBS bore the cost of inventory, assessment and competition organisation, removing donor–receiver negotiation from the transaction. Architects committed to reuse through the competition itself: using the catalogue was strongly encouraged by the client rather than mandatory, and the winning entries bound their authors to the elements they proposed. The contractual chain that conventional construction distributes between supplier, contractor and receiving party was, in this case, internalised by a single public actor.

3.1.3 Design integration and scalability

While the organisational logic followed mode A (Figure 2), the technical supply was effectively frozen into fixed types. Architects received the inventory as an input and designed with these specific components, a stock-constrained design in the sense of Brütting *et al.* (2020).

Lysbüchel shows, as the ReCreate pilots do elsewhere in Europe (Huuhka *et al.* 2023), what reuse can become when elements are modular, catalogued, traceable and matched to demand through a single institutional mechanism. Its scalability is limited: the competition was a one-off mechanism for two identified sites, with donor–receiver coupling as tight as in any mode A operation.

3.2 MARCELIN

3.2.1 Building assessment

The Marcelin assessment focused on the slab elements, which represent the largest concrete volume of the building (Bastien-Masse 2025). Existing data were almost absent: only architectural plans, with no reinforcement or material information. Four openings were made in the concrete cover to inspect reinforcement bars, verify cover thickness and identify connection details. Carbonation depth measurements showed that the concrete cover on the slab undersides (15–25 mm) was thinner than the carbonation depth (20–45 mm), indicating a corrosion risk in the presence of moisture. Slab thicknesses measured by drilling just before deconstruction (210–220 mm) also differed from the 190 mm on the architectural plans; the receiving projects were not affected, but the case shows that as-built geometry must be verified.

As for Lysbüchel, the factsheet summarised geometry, reinforcement layout and material properties for all slab elements, following the methodology proposed by Devènes *et al.* (2024).

3.2.2 Sawing layout

Unlike Lysbüchel, Marcelin required a sawing layout. The resulting colour-coded plan shows a mosaic of elements, each colour corresponding to a receiving project with its own dimensional requirements (Figure 4). In total, 242 elements were extracted, representing 1162 t and 2055 m² of slab area, and allocated to four projects.

Project 1 (exterior landscaping) required 136 elements of varied dimensions in at least eight subtypes. Projects 2 and 3 served on-site uses (gymnasium patios; bicycle shelter foundations on the 350 mm civil-protection slab) with bespoke dimensions. Project 4 comprised 94 standard elements of 3000 × 2500 mm, stockpiled for future external reuse (Figure 5a). These dimensions suit standard truck transport and reuse as wall or slab elements (Bastien-Masse 2025), and factsheets were prepared to support future receiving projects or competitions.

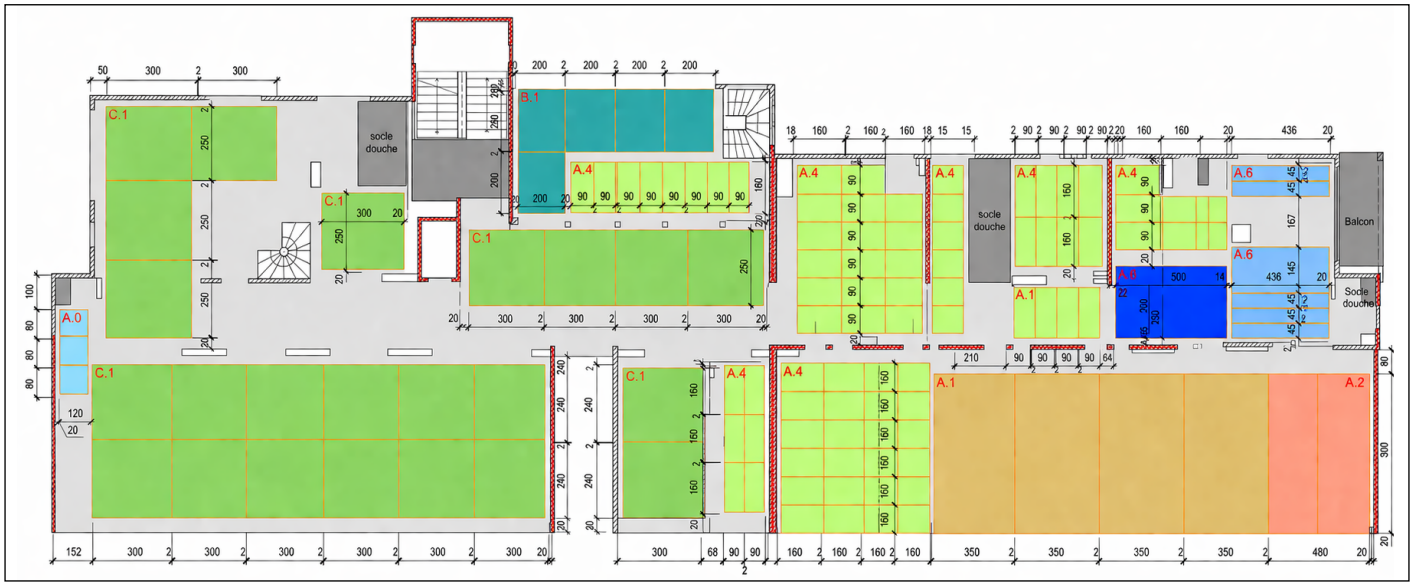


Figure 4: Sawing layout of the Marcelin slab (level 2), colour-coded by receiver.

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(a) (b)

Figure 5: (a) Stockpiled slabs; and **(b)** pin and plate lifting system, Marcelin.

Sources: (a) M. Grangeot and (b) C. Küpfer, both École Polytechnique Fédérale de Lausanne (EPFL).

The sawing layout reveals two distinct logics. For projects 1–3, it is a bespoke patchwork optimised to satisfy multiple simultaneous demands: each module is a unique response to a specific downstream use, requiring complex adaptation with associated costs. For project 4, by contrast, experts imposed a standardised grid, deliberately decoupling supply from any identified receiving party, an early attempt at mode C logic.

3.2.3 Logistics

Once the building was stripped of facades, timber roof, masonry partitions and floor finishes, sawing lines were traced on the slab's surface. A 70 mm bore was drilled in each element for lifting via a pin/plate system (Figure 5b). Each slab was shored with at least four props before sawing, and rails were fixed to guide the remote-controlled diamond saw.

Three operational lessons emerged. First, the sawing layout must minimise saw displacement while ensuring that all planned elements can be extracted, a non-trivial logistical problem when several element types come from the same donor floor. Second, the deconstruction method must ensure safety throughout the works, with complexity increasing when multiple element types are required. Third, some slab edges and corners were damaged during extraction, requiring post-deconstruction inspection, a contractual risk in the bespoke logic, where each element is already committed to a specific receiver.

3.2.4 Design integration

Design integration in Marcelin operated in the inverse direction of Lysbüchel. Where Lysbüchel's architects designed around a fixed catalogue, the Marcelin catalogue was tailored to demand, transferring the integration cost from the receiver to the sawing process. It thus differs from stock-constrained design, in which an available stock is taken as given and the receiving structure is designed or optimised around it (Brütting *et al.* 2020; Küpfer *et al.* 2024b).

3.2.5 Contractual framework and scalability

Marcelin demonstrates that extracting CIP concrete elements is operationally feasible at meaningful scale: 242 elements were sawn, lifted, handled and stored on-site. Its central lesson, however, is that extraction does not guarantee reuse. Within the closed institutional circuit, where the Canton of Vaud controlled both donor and receiving projects, elements for projects 1–3 were successfully allocated. By contrast, the 94 standardised elements of project 4 found receivers only in 2026, after nearly 18 months (nine for a pop-up installation on site, 85 for landscaping on a third-party site). Cutting without pre-allocation had a cost in interim storage, logistics and resale price.

This shows, as Lysbüchel does, that reuse currently operates more easily when supply and demand are already coordinated within a closed framework, where property variation risk is internalised within a single accounting perimeter and no formal donor–receiver contract is needed. These observations are interpreted in Section 4.5.

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3.3 SIMPLON

3.3.1 Building assessment

A reusability assessment of the Simplon structure was commissioned by CFF prior to the call for interest. It relied mainly on non-destructive techniques (ferroscan and ground-penetrating radar for the reinforcement, visual damage surveys) for geometry, complemented by tests on concrete cores and rebar samples for material properties. Carbonation was also locally assessed after nearly four decades of service. The building was divided into three zones (Figure 6); damaged areas and areas of complex geometry near columns and openings were excluded. Some 5835 m² of slabs, an estimated 705 elements in four lots, were found extractable (Table 2). These quantities are planning estimates.

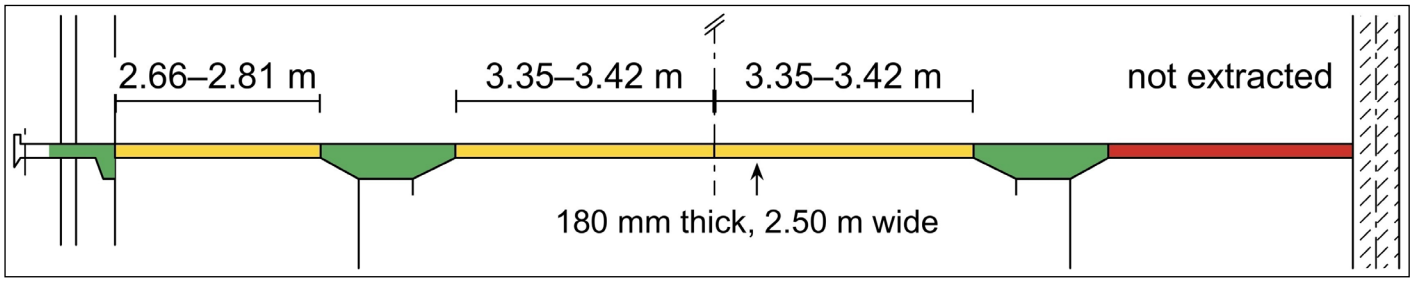


Figure 6: Transverse cross-section of a typical Simplon bay.

Note: Yellow = extracted slabs; green = beams and columns retained; red = not extracted.

Source: Adapted from CFF (2025b).

LOT	N	LOCATION	DIMENSIONS (mm)	THICKNESS (mm)	APPROXIMATE WEIGHT (t)
I	443	Central-bay parking slabs	3350 × 2500; 3420 × 2500	180	3.7
II	192	Lateral-bay parking slabs	2810 × 2500; 2660 × 2500	180	2.9–3.1
III	55	Platform 5 slabs	5000 × 2500	300	9.1
IV	15	Platform 5 slabs	5000 × 1900	300	6.9

Table 2: Slab elements identified for reuse at Simplon, organised into four lots (planning estimates).

3.3.2 Contractual framework and logistics

Rather than offering standardised elements without identified receivers, as in Marcelin's project 4, or organising a competition around an available stock, as in Lysbüchel, Simplon adopted an intermediate strategy: a call for interest open to any construction or renovation project within 400 km of the site (CFF 2025b), a radius well inside the 765 km up to which reusing slabs still lowers floor emissions (Küpfer *et al.* 2024b).

The response confirmed genuine market interest: 20 potential receiving projects came forward, ranging from public institutional buildings to private residential and commercial developments.

Most teams were motivated by embodied-carbon reduction. Yet when the available dimensions and reservation conditions were presented, three barriers emerged: timeline mismatch with the deconstruction schedule; absence of storage between availability and need; and contractual commitment through take-back agreements with penalty clauses for non-collection and payment due at delivery. Several teams withdrew during negotiation, not because of lost interest but because no mechanism bridged the gap between intention and commitment. A total of 12 projects confirmed their interest by signing a letter of intent, which allowed the Simplon owner (CFF) to validate the deconstruction by sawing rather than traditional demolition. Eight of them have since signed, with 417 elements assigned to date, and further projects are joining the list as extraction proceeds (CFF 2025c). Extraction began in September 2026.

3.3.3 Sawing layout

The sawing layout itself remained largely stable; what evolved through multiple iterations was the allocation of elements between receiving projects: who would take which elements, and which projects would have priority. The initial proposal defined standard module types based on

the structural grid of the donor building (Table 2 and Figure 6). The Simplon team's strategy was to recommend this dimensional framework strongly and to ask receiving projects to adapt their designs accordingly; alternative sizes remained possible within the constraints of the existing structure (CFF 2025b). The aim was to shift the adaptation burden from supply to demand, moving toward a standardised grid, or mode C (Figure 2).

Contrary to expectations, most receiving parties did not contest the dimensions. The 2500 mm width was broadly accepted as compatible with standard truck transport. Adjustments to the sawing plan remained minor; the main task was allocating quantitative demand across the layout. This rests on design-stage meetings and awaits built receiving designs.

3.3.4 Design integration

The meetings revealed a consistent pattern: receiving projects proposed a new supporting frame onto which the reused slabs would be laid. None had a settled solution: substructures in timber, in steel inspired by the FLO:RE prototype (Küpfer *et al.* 2025) and in new concrete, were all under consideration. The choice of interface in turn fixed what each receiver required of the element: lifting points, edge condition, tolerances and delivery sequence. The interface was thus an open, bespoke problem for every receiver; no dominant design (see Section 1.3) emerged among the projects met, nor among the research prototypes, whose diverse connections have not yet been applied beyond pilots (see Section 4.5).

3.3.5 Costs

The cost of a reused Simplon slab was established at CHF128/m² (about €137/m²), based on competitive tenders solicited by CFF from deconstruction contractors (CFF, internal tender results, 2025). This covers extraction: shoring (of both the extracted element and the residual donor structure), sawing, lifting, initial handling and on-site logistics. It compares with CHF200/m² (about €213/m²) for an identical new CIP slab.

However, this comparison is incomplete. The CHF128/m² excludes three downstream cost categories that conventional construction internalises: transport, whose cost depends on distance, mode (road or rail), element size and load efficiency; storage, if the receiver cannot take immediate delivery; and reassembly, including connection systems and any slab adaptation such as re-cutting, drilling or surface treatment.

The cost structure reveals a critical asymmetry: extraction is largely solved, but downstream problems are interdependent (the connection choice constrains the on-site methodology, which constrains the delivery requirements), and a competitive total cost depends on solving them jointly.

3.3.6 Scalability assessment

At Simplon, four categories of barriers emerged during the matching process. They are reported here as planning-phase observations, not as outcomes of extraction; their theoretical interpretation follows in Section 4.

- *Technical*

  No receiver had a ready connection strategy to integrate the Simplon slabs: substructures in timber, steel or concrete were all under consideration, with no convergence on a single approach. Each project treated the slab-receiving structure interface as an open, bespoke design problem.

- *Logistical*

  Intermediate storage for 2–4 t structural concrete elements is technically feasible but was offered by no actor at the time; the call for projects designated a reuse intermediary (Matériuum) as formal supplier of the slabs, without a storage solution (CFF 2025b). With the donor schedule fixed by the railway programme and some receivers unable to take delivery months in advance, matching must occur in real time.

- *Contractual*

  The draft contracts proposed by CFF required receiving parties to commit to using a specified number of elements within a defined time window, exposing them to financial penalties if they did not, with payment due at delivery; at their request, CFF could organise rail transport to the nearest station. In practice, most receiving parties were signing letters of intent while their building's form, budget and even building permits remained uncertain. The chain of liability for elements without a manufacturer's guarantee had to be drafted from scratch as no standard contract for reused CIP elements exists.

- *Institutional*

  The institutional infrastructure that would underpin a CIP reuse market (guarantee schemes, insurance products, certification bodies, deconstruction norms) does not yet exist in Switzerland, and the workarounds developed for Simplon expose this absence. The call for projects announced two guarantee regimes, to be defined by a legal study (CFF 2025b); at the time of the analysis no certified guarantee attested to the structural performance of the extracted slabs, and no insurance product covered the residual liability associated with elements lacking a manufacturer's guarantee.

3.4 CROSS-CASE COMPARISON

The three cases form a genealogy rather than a ranking (Figure 2 and Table 3). Lysbüchel shows that reuse works when elements are dimensionally fixed, catalogued and institutionally absorbed. Marcelin demonstrates that CIP extraction is feasible at meaningful scale, with 242 elements sawn and stored, but also that allocation remains easier within a closed institutional circuit than on an open market. Simplon then tests open-market demand at larger scale, with some 5800 m² and 705 potential elements. The call for interest confirms that demand exists; yet storage, contracts, connection systems and timing mismatches still prevented stated interest from becoming routine transactions. Read against Table 3, no case meets all three mode C conditions; Lysbüchel came closest because its elements were prefabricated.

Table 3: Cross-case comparison: analytical dimensions, cost reference, evidence status and mode C conditions.

Note: CIP = cast-in-place.

DIMENSION	LYSBÜCHEL (A)	MARCELIN (B1)	SIMPLON (B2)
Sawing layout	Not required (prefabricated structure); joint cutting	Bespoke mosaic: three receiving projects and standard surplus, eight or more element subtypes	Supply-side standard (four lots)
Logistics	Storage on a neighbouring site with the same owner; post-extraction inspection	On-site storage (nearly 18 months for the surplus); post-extraction inspection	No storage solution; 400 km transport radius; temporal mismatch
Contractual	Owner absorbs costs via competition; public framework	Internal circuit (same owner) for projects 1–3; no donor-receiving party negotiation	Take-back contracts with penalties; receiving parties signed without confirmed budgets
Design integration	Architects design with catalogue (stock-constrained design)	Dimensions dictated by receiving projects 1–3; project 4: standardised offer, no receiving party before cutting	Each receiving party proposes a different substructure (timber, steel, concrete)
Scalability	Limited: prefab modularity and bespoke competition	Limited: internal circuit bypasses the market; surplus placed only after nearly 18 months	Most advanced, but blocked by storage, liability and transport (cost of delivery)
Cost reference	Not published	Not published	CHF128/m² (about €137/m², extraction only, tender price) versus CHF200/m² (about €213/m²) estimated for an identical new CIP slab (placed). Costs of transport, storage and reconstruction to be added. €2025 average rate of CHF0.937 = €1
Evidence status	Observed (completed)	Observed (completed)	Observed up to the signed reservations (eight projects, 417 elements); extraction under way since September 2026

(Contd.)

DIMENSION	LYSBÜCHEL (A)	MARCELIN (B1)	SIMPLON (B2)
Mode C condition 1: normalised dimensional grid	Present at source (six prefab subtypes)	Partial: standard 3000 × 2500 mm for surplus only	Partial: four supply-side lots accepted by receivers
Mode C condition 2: versatile connections	Absent: designs specific to Stahlton	Absent: bespoke details per project	Absent: divergent substructures per receiver
Mode C condition 3: stock-holding and guarantee function	Internalised by the owner	Internalised by the owner; no guarantee for surplus	Absent: no storage, no guarantee, no insurance

4. DISCUSSION

4.1 BEYOND BILATERAL MATCHING

The three cases show that scaling CIP reuse is not primarily blocked by extraction, but by the coordination cost of each transaction. In the process described by Devènes *et al.* (2024) (Figure 7), each receiving project adapts to the components of a specific donor; in practice this is a bilateral matching in which the receiving design absorbs the constraints of one donor at a time. The allocation waits for every preliminary design, each detailed design waits for the allocation, and all receivers must commit before extraction, on the donor's date; deliveries then follow each receiver's date, and the interval falls on storage (Figure 7). This works for pilot projects within a closed institutional circuit, but at *N* receivers the same constraints must be renegotiated *N* times, with no economies of scale. In the terms of Section 1.3, the market is thin (one donor, a few receivers), congested (matching in real time) and unsafe (commitment precedes certainty). Moving beyond bilateral matching does not mean replacing demand by supply authority. Rather, supply must progressively align with recurrent patterns of demand.

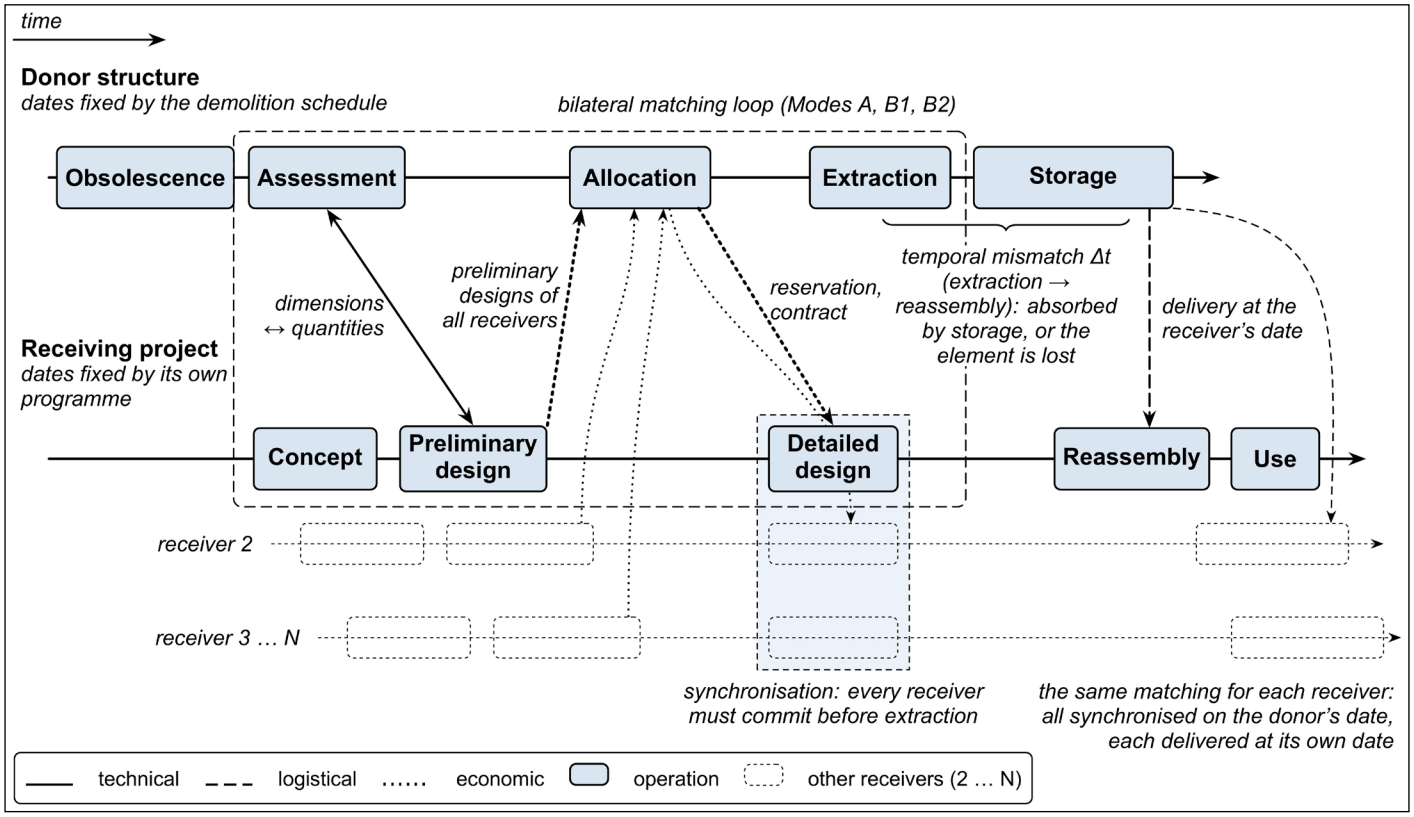


Figure 7: Donor–receiver coordination in a bilateral reuse operation.

Source: Adapted from Devènes *et al.* (2024).

4.2 MISSING REGULATORY FRAMEWORK

To understand why CIP reuse remains locked in a pre-commercial state (Figure 8), it is useful to compare it with a mature construction product: the hot-rolled steel section. Steel sections are catalogued, stocked, guaranteed and covered by a clear liability chain (CEN 2019).

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Here, a standard refers to elements of identical dimensions and guaranteed properties that can substitute for one another. A norm is the document that formalises this regularity by defining acceptance criteria, test methods and traceability requirements. A reused CIP slab has none of these properties. It is not catalogued, and its dimensions depend on the sawing layout of a specific donor building. Its mechanical properties are not guaranteed but estimated from limited testing. It is not available from stock; it becomes available when a specific building is deconstructed, at a date determined by the donor's schedule. It is not covered by a product standard; each element enters the market as a characterised unknown rather than a specified product.

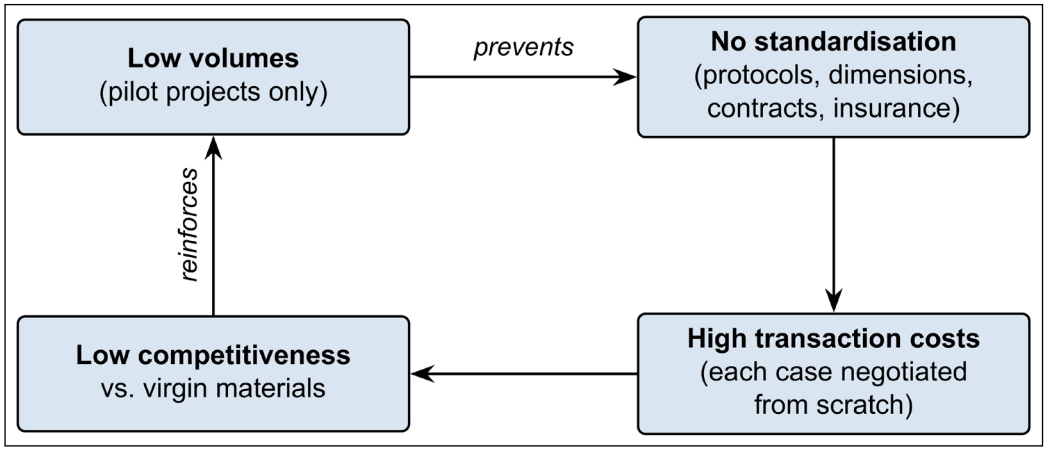


Figure 8: Feedback loop locking cast-in-place (CIP) reuse in a pre-commercial state.

Finally, the liability chain lacks a stable reference. For a steel section, characterisation, transport and installation are performed by distinct entities, but the product standard provides a common specification that flows through the chain. For a reused CIP element, no such anchor exists: each handover between characterising, extracting, transporting and installing parties must be redefined contractually.

This comparison identifies three requirements for CIP reuse to function as an industrial supply chain: a product classification system grouping elements by load-bearing capacity and geometry rather than provenance; a stock-holding function that decouples production from consumption, and a guarantee mechanism that allows engineers to specify reused elements with confidence.

However, standardisation is necessary but not sufficient. Structural steel reuse remains rare despite steel sections being catalogued, guaranteed, stocked and normed (Densley Tingley *et al.* 2017). The documented barriers lie elsewhere: a reclaimed supply known only at demolition, the cost of recertifying elements without a mill certificate, and costs split among actors who each capture only part of the benefit (Densley Tingley *et al.* 2017; Dunant *et al.* 2018). If standardisation alone has not created a large secondary market for steel, it will not do so for CIP slabs without complementary mechanisms.

A deeper, upstream weakness concerns the deconstruction process itself. Each CIP building is constructed differently (bespoke grids, mixed reinforcement detailing, individual incident histories), so the elements emerging from any deconstruction vary widely from one donor to another. Insuring or certifying them remains intractable without traceability: shared protocols that record sawing layout, characterisation results and element history from extraction to reassembly. By analogy with acceptance norms governing recycled aggregates for concrete production (CEN 2008; SIA 2021), regulating the deconstruction process would harmonise demolition outputs and reduce downstream variability.

4.3 GENEALOGY, MARKET FORMATION AND EUROPEAN PRECEDENTS

The progression from modes A to B1 and B2 (Figure 2) should not be read as a series of failures. In technological innovation systems, market formation is a distinct function: emerging technologies consolidate demand through niche applications before they can compete with incumbents

(Hekkert *et al.* 2007). The three cases here perform this function in successive registers: Lysbüchel formalised audit-and-catalogue procedures; Marcelin tested closed-circuit allocation; and Simplon tested open-market matching.

The nearest operational precedent is the ReCreate European research project (Horizon 2020, 2021–26), which reused prefabricated elements in pilots in Finland, Sweden, the Netherlands and Germany, with procedures for deconstruction and quality management and an economic assessment (Huuhka *et al.* 2023; Räsänen *et al.* 2024; Vigren *et al.* 2026). Its conclusions converge with the Swiss cases: reuse is viable only when supply, demand, logistics, quality assurance and liability are coordinated; a market needs an information layer recording what exists and in what condition; and the connection often has to be redesigned or retrofitted for the receiving project. They diverge on what the element brings from origin: prefabricated panels come in families, with known joints and a manufacturer, which CIP elements lack. The Swiss cases thus test a harder case than ReCreate, not a different problem.

Some of the missing conditions already have a European regulatory vehicle. The Waste Framework Directive set a target of 70% by weight, by 2020, for the preparing for reuse, recycling and other material recovery, backfilling included, of non-hazardous construction and demolition waste (European Parliament and Council 2008). The revised Construction Products Regulation extends its scope to used products (Art. 2(1)) and introduces a digital product passport (Arts 75–79), the traceability instrument that the institutional barrier of Section 3.3.6 calls for (European Parliament and Council 2024). Switzerland is not bound by them but aligns its technical rules with them. What they do not provide is the CIP-specific content a passport would carry: a characterisation protocol for saw-cut elements, admissible tolerances and a liability model for elements without a manufacturer.

4.4 SYSTEMIC INTERDEPENDENCIES

The interdependencies are mapped using the four-criterion framework of Küpfer *et al.* (2021): environmental, economic, technical and logistical. The environmental dimension provides the rationale, namely avoided greenhouse gas (GHG) emissions and material flows, but does not, by itself, organise the system. The remaining three dimensions structure the interdependencies shown in Figure 9, which is why the figure carries no environmental arrow.

Figure 9 maps eight nodes: five chronological operations, from assessment to extraction, storage, transport and reassembly, the last comprising the connection to the receiving structure as well as handling, positioning and site assembly; and three continuous constraints (norms, modularity, contract). Extracted elements always pass through storage, however brief, before transport and reassembly. Their relationships are circular rather than linear, meaning that each decision constrains the others.

Among these nodes, the connection system emerges as the keystone and the blocking point of Figure 2: it conditions what can be extracted, stored and reassembled. First, reassembly, of which the connection is the critical part, is the node with the most incoming constraints in Figure 9. Second, at Simplon the interface was the one item for which no receiver had a ready solution, whereas dimensions, contracts and logistics were negotiated once with CFF (see Sections 3.3.3–3.3.4); the research prototypes show the same dispersion (see Section 4.5). Third, it decides the environmental balance: the steel version of the RE:SLAB floor, a demountable system designed for open-ended component reuse, emits more than a conventional concrete floor over a single life, mainly because of its many steel connections (Estrella *et al.* 2024). Without convergence on a connection, each transaction remains a one-off design problem.

The contract node is the mechanism through which technical uncertainty becomes economic cost. Unlike a hot-rolled steel section, a reused CIP element carries uncertainty about production batch, loading history, degradation and residual capacity. This uncertainty is not eliminated; it is allocated. Clauses defining who guarantees capacity, who bears defect liability and who insures storage add risk premiums to the project cost. Trust, in this system, is technical certainty made contractual; risk is its absence translated into liability; cost is the residual that no other dimension has absorbed.

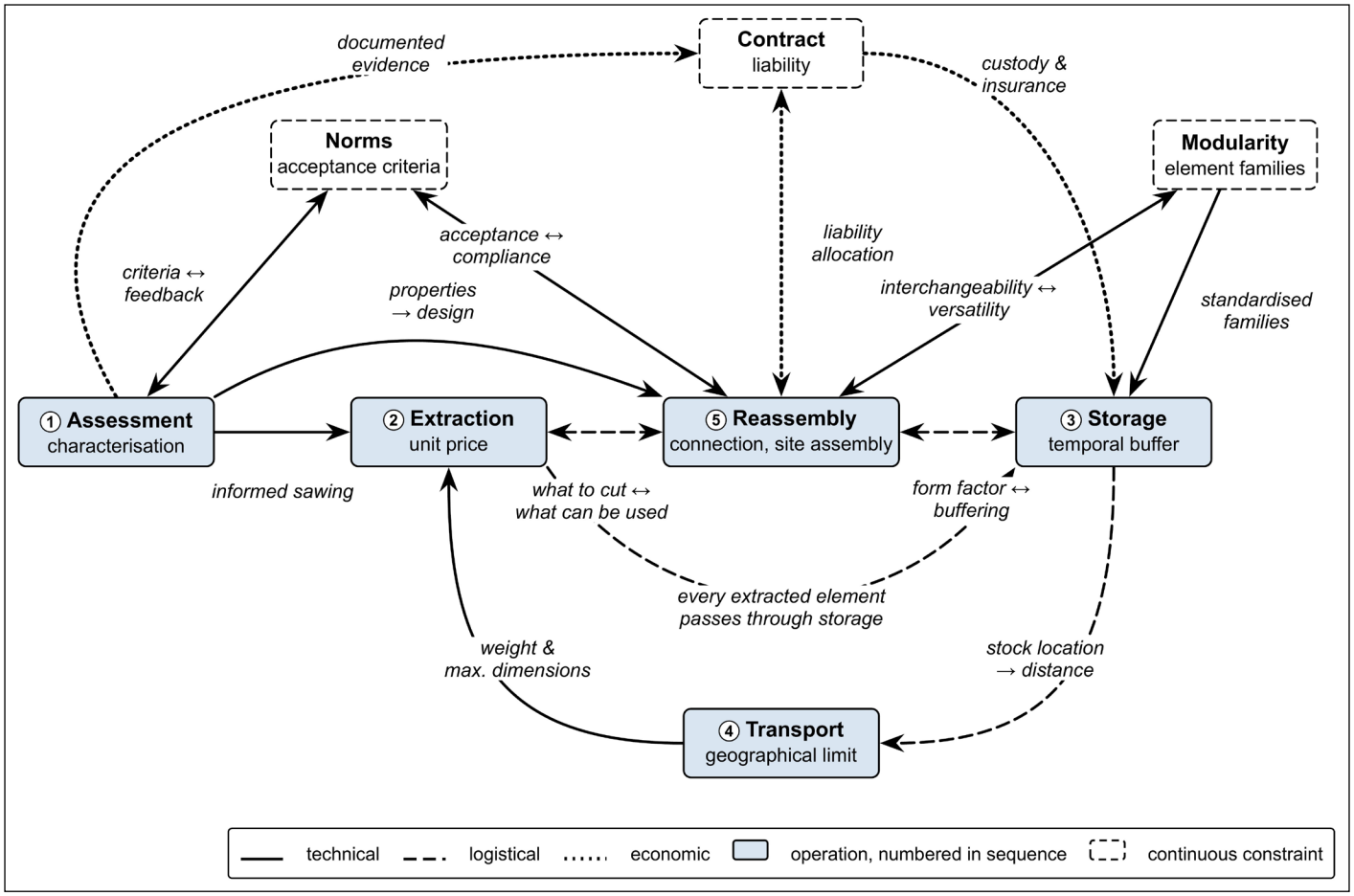


Figure 9: Interdependencies of cast-in-place (CIP) reuse: five chronological operations (assessment, extraction, storage, transport, reassembly) and three continuous constraints (norms, contract, modularity).

This was directly visible in the Simplon contracts, where liability allocation and custody during storage had to be negotiated in the absence of product certification or a commercial stock-holder. Contract thickness thus becomes a proxy for market immaturity: the more norms, certification and modularity are missing, the more risk must be priced through bespoke clauses. The maturity of a reuse market can be read directly in how thin its contracts can become.

4.5 MODE C: FROM STANDARDISED ELEMENTS TO A VERSATILE INTERFACE

Based on the case studies, three conditions can be formulated to activate mode C. They remain untested and should be read as a research hypothesis rather than a demonstrated outcome.

- *Normalised dimensional grid*

  If donor-side sawing and receiving-side design refer to the same dimensional standards, the iterative matching loop disappears. Simplon suggests that dimensional acceptance is not the primary obstacle: receiving parties broadly accepted the proposed modules. A standard should therefore emerge not by imposing supply authority, but as the historical residue of demand consolidated over many cases, the dominant-design mechanism of Section 1.3, applied to a component.

- *Versatile connection system*

  The interface between reused elements and new structures must be independent of element provenance, allowing any compatible element to be connected. Until a dominant connection system emerges, each project will design its own solution and no economies of scale can form.

- *Stock-holding and guarantee function*

  Absorbing temporal mismatch, holding inventory and guaranteeing quality, analogous to a steel stockholder. This function transforms a bilateral negotiation between donor and receiver into two standardisable transactions: donor–intermediary and intermediary–receiver.

For structural steel, four mechanisms have been proposed to this end (a supplier database, demonstrated client demand, technical guidance and government leadership; Densley Tingley *et al.* 2017), but they assume a manufactured, catalogued product.

The first condition is where the hypothesis meets its limits. First, the stock is heterogeneous: CIP buildings differ in grid, slab system, thickness, reinforcement and concrete grade, so a fixed grid, like any overly restrictive compatibility criterion, would sharply reduce the supply it is meant to organise (Schürmann *et al.* 2026). Second, the volume is small: in Switzerland about 1.78 km² of floors are demolished each year against 12.67 km² built (Küpfer *et al.* 2024b), a flow too small and irregular to sustain a catalogue of fixed formats; enlarging it beyond the demolitions already planned would mean demolishing more. Third, the Swiss stock is predominantly cast in place (Küpfer *et al.* 2024b; Arceo *et al.* 2025): it offers neither the element families that made Lysbüchel's catalogue possible nor a culture of system building on which a standard could lean. Fourth, a stock without demand is a liability: Marcelin's 94 standard elements waited nearly 18 months for receivers; cutting to a standard size does not create a receiver.

These limits make the catalogue form of mode C utopian today rather than impossible: no two donor–receiver pairs are alike, architectural identity resists a shared grid, and the volumes it presupposes are those whose absence locks the loop of Figure 8. Even achieved, a dimensional standard would lift only the temporal lock; its decoupling of supply from demand is relocated, not invalidated. If the element cannot be standardised, the interface can. A connection that accepts elements within a dimensional window rather than at fixed sizes, and that receives a new precast slab and a reused saw-cut slab in the same position, would absorb the uncertainty of supply, in timing as well as in dimensions, inside the receiving system: where no reused slab is available, a new one takes its place. This is standardisation of the interface in the sense of Baldwin & Clark (2000), converting economies of scale, which the demolition flow cannot deliver, into economies of substitution (Garud & Kumaraswamy 1995).

Transport, handling and the stock bound the dimensional window of such a connection, which Simplon receivers accepted at planning stage: a width of 2500 mm set by road transport; lengths of about 2700–5000 mm set by crane capacity; thicknesses of 180–300 mm. Capacity is declared per element from its factsheet, and the window, defined at the level of the floor element, is not specific to a building type. Existing systems each solve part of this: FLO:RE places unmodified sawn slabs on reused steel girders (Küpfer *et al.* 2025), CON, a demountable multi-storey mock-up, joins reused slabs serving as columns and floors with adjustable steel sleeves that accept different thicknesses (Kiesel *et al.* 2026), and prestressed segmental floors cut slabs to a fixed 2400 mm module and add new concrete (Pathé *et al.* 2025); none yet receives new and reused slabs alike within a declared window. Versatility is therefore not a finding of this study but the hypothesis its findings point to (Figure 2): a versatile connection backed by a stock-holding and guarantee function would decouple the two sides without a normalised grid.

Two boundary conditions apply. Reuse as studied here concerns buildings demolished for reasons independent of reuse; it should not become a reason to demolish, and adaptive reuse of the whole building remains the priority, lest a cheaper disposal route lower the threshold for demolition, a circular-economy rebound (Zink & Geyer 2017). The environmental case is also conditional on what the new frame and connections add (Küpfer *et al.* 2024b; Estrella *et al.* 2024).

5. CONCLUSIONS

In the three Swiss cases, a willingness to reuse concrete exists on both sides of the chain, but the supply-chain infrastructure that converts willingness into routine transactions does not yet exist. Four barrier dimensions (Küpfer *et al.* 2021) constrain the eight interdependent nodes mapped in Figure 9. Among them, the connection system emerges as the keystone, and the contract as the mechanism through which technical uncertainty becomes economic cost. Lysbüchel, Marcelin and Simplon are not failures but a genealogy of market formation, each absorbing learning costs that subsequent projects need not repeat. The Simplon findings remain those of a planning phase and await confirmation in extraction and reassembly.

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The distinction announced in Section 1.4 can now be drawn. Contingent obstacles are those that better organisation removes: the absence of a storage offer, of template contracts, of an insurance product and of routine pre-demolition assessment. Structural constraints are those no organisation removes: a heterogeneous stock characterised rather than specified; a supply that appears when a donor is demolished, not when a receiver needs it; and a small, irregular demolition flow. The mode C conditions address the contingent obstacles; against the structural constraints, a normalised grid is not the tool for today. A versatile interface absorbing dimensional and temporal uncertainty on the receiving side is the hypothesis this study leaves for further research.

- *For practitioners*

  Pre-demolition reuse audits documented through standardised factsheets (Devènes *et al.* 2024) should become a routine design input, and template donor–receiving party contracts that allocate liability and custody should replace case-by-case negotiation. The immediate priority is convergence toward a versatile connection system, capable of absorbing donor variability, and of receiving a new slab where no reused one is available, while remaining compatible with the receiver's architectural latitude.

- *For policymakers*

  Guarantee schemes, certification bodies and a regulated deconstruction protocol analogous to the norms governing recycled aggregates (CEN 2008; SIA 2021) are required, and the digital product passport of the revised European Construction Products Regulation offers a template for the traceability they presuppose. Carbon-adjusted disposal levies on structurally sound concrete still suitable for reuse and mandatory pre-demolition reuse assessments would channel the existing demolition flow toward reuse without enlarging it.

- *For researchers*

  Extending the cutting-stock paradigm of Brütting *et al.* (2020) from single-structure scope to a population of receivers, in joint co-design with a modular connection family, is the natural next step. Dedicated safety factors derived from testing campaigns on extracted elements are a complementary direction.

The progression from modes A to B1 and B2 is not the closure of a process but its first iteration. What the genealogy reveals is the direction: neither a standardised stock awaiting buyers nor bilateral coupling to a donor, but the configuration between them (Figure 2), in which uncertainty about the supply is absorbed rather than eliminated. What the empirical record cannot yet show is whether the technical, logistical, contractual and institutional conditions for reaching it can be assembled within the timeframe that climate and resource pressures demand.

NOTE

1 The Swiss Federal Railways is called *Schweizerische Bundesbahnen* (SBB) in the German-speaking cantons of Switzerland, *Chemins de fer fédéraux suisses* (CFF) in the French-speaking cantons, and *Ferrovie federali svizzere* (FFS) in Ticino and Italian-speaking areas. Because this paper studies the activity of the Swiss Federal Railways only in Lausanne in the French-speaking canton of Vaud, the abbreviation 'CFF' will be used throughout to refer to the Swiss Federal Railways.

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AI DECLARATION

Claude (Anthropic) was used for language editing, reformulation of draft passages and critical feedback on argument structure. Consensus (an AI-based academic search engine) was used for the literature search and reference identification. The authors thoroughly reviewed and edited the content as necessary and take full responsibility for the final content of the published article.

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AUTHOR CONTRIBUTIONS

M.R.: conceptualisation, methodology, investigation (case studies, participant observation), formal analysis, visualisation, writing—original draft, writing—review and editing. M.B.-M.: conceptualisation, investigation (reusability assessments of the three cases), supervision, funding acquisition, writing—review and editing.

COMPETING INTERESTS

The authors have no competing interests to declare.

DATA ACCESSIBILITY

The factsheets and resource assessment reports cited in this article are referenced. The Lysbüchel factsheet (Devènes *et al.* 2022a) and the Marcelin assessment report (Bastien-Masse 2025) were produced for the owners and are available from the authors upon request, subject to the owners' consent; the Simplon assessment and tender documents (CFF 2025a, 2025b) are the property of CFF. Anonymised meeting notes and contractual documents informing the Simplon analysis cannot be shared publicly owing to confidentiality clauses with the project owner; aggregate observations are reported in the main text.

ETHICAL APPROVAL

The study involved no experimental research on human subjects. Participant observation of professional meetings was conducted with the informed consent of the participants, and no personal data are reported. Ethics committee approval was therefore not required.

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REPRODUCIBILITY

No new code or computational model was developed for this study. The empirical material consists of document analysis (resource assessment reports, factsheets and contractual templates) and participant observation of 20 bilateral coordination meetings.

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