Reusability Assessment of Obsolete Reinforced Concrete Structural Components

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Abstract. The production of concrete, the most widely used construction material, detrimentally affects the environment. Obsolete reinforced concrete (RC) load-bearing structures, even when still in good condition, are today prematurely crushed and landfilled or recycled into new concrete mixes. Little known and rarely implemented, the reuse of RC structural components is an alternative strategy towards more circularity in the construction industry. Since 2021, RC component reuse has been implemented in a series of construction and deconstruction projects in Switzerland.

This paper identifies existing process sequences for RC-reuse projects and proposes one that involves a new assessment procedure to evaluate the reusability of the components early on and facilitate their future reuse planning. The paper discusses the application of this procedure to three deconstruction projects. Results are encouraging with regard to the durability of RC components. Almost 90% of the RC components of a building could be reused for new purposes with the same stability and exposure as in the donor building.

Keywords: Circular Economy · Existing Structures · Reuse · Reinforced Concrete

1 Introduction

Embodied carbon – i.e. greenhouse gas emitted during the production, construction, transformation, and demolition of buildings – represents approximately one-third of total building emissions [1] and is mainly due to the load-bearing structure construction. Regardless of this embodied carbon, existing buildings are frequently demolished for non-technical socio-economic reasons [2], when their structure, often made of reinforced concrete (RC), could have served for longer. Demolitions imply greenhouse-gas emissions, material recycling, and disposal of a large part of the materials. Concrete alone represents 30% of waste generated by the construction sector [3]. There is thus a need to reduce the emissions of new constructions while at the same time reducing demolition waste.

Preservation of an existing building should always be encouraged. However, when not feasible, reusing structural components in new applications is a circular strategy that

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reduces generally the detrimental environmental impacts of new construction [4]. In this strategy, RC components are carefully dismantled from obsolete buildings without being crushed and reused while maintaining as much as possible their pre-existing geometry and properties. For a structure made of prefabricated components, deconstruction almost inverses the original construction process, illustrated on Fig. 1(a) for a 1964 building, by separating components where they had been initially joined. In the case of a cast-in-place structure, the deconstruction pattern, e.g. using diamond blade saws as on Fig. 1(b), is not trivial and must be defined beforehand.

To make reuse feasible, an assessment of RC components at an early stage of the deconstruction and new-construction projects is required, implying changes in the design phase sequences. Today, no existing methods for obsolete structures identification and audit are adapted to RC components reuse. Thus, the following paper focuses on the assessment of existing soon-to-be demolished RC buildings aiming at characterizing and promoting the potential for reuse of its components.

The paper is organized as follows. Section 2 describes previous experiences in Switzerland while highlighting the project design process sequences. Section 3 proposes a procedure for assessing the reuse potential of existing RC buildings. Section 4 presents the main results of the procedure applied to three case studies. Finally, Sect. 5 discusses and concludes the results.

Fig. 1. (a) Careful construction of prefabricated RC structure in 1964 and (b) sawing of an existing RC wall. Image credits: (a) Baugeschichtliches Archiv (BAZ) Stadt Zürich, Köhli Ernst; (b) Diamcoupe S.A.

2 Design Process Sequences of Reuse Projects

Two types of design process sequences are identified from recent and ongoing projects in Switzerland that reuse RC components. In the first type, adequate obsolete structures are identified after the preliminary design. This timing has been used in several projects incorporating RC components and built in Switzerland in the two last years [5]. These projects include three main ones. First, the Re:Crete arch footbridge, Fig. 2(a), designed and built by EPFL in Fribourg and then installed in a temporary site in Wallis, was made of 25 reclaimed cast-in-place concrete blocks [6]. The blocks came from the walls of a building undergoing transformations. Second, in Meyrin, concrete blocks from several local transformation or demolition sites were reused to build the inside and outside carriageable pavement, on Fig. 2(b), of two new operating buildings [7]. The third project, on figure Fig. 2(c), is the construction of 12 new column foundations in Zürich with reused RC blocks cut out from the slabs of an existing building [5]. In these projects, the concept and the preliminary design of the new *receiving* project were sketched before finding one or several *donor* buildings that could match their needs. Sometimes, the sourcing was done progressively, in several steps, as adequate sources were identified. The final design then had to be completed, to a certain extent, adapted to the identified donor structure. The timeline of this design process phasing is illustrated on Fig. 3(a).

The second design process sequence involves an obsolete structure identification prior to the project conceptualization and its preliminary design. This sequence has been used in other projects in Switzerland, that are currently being designed with reclaimed RC components from specific donor structures. One of them is the EPFL student project rebuiLT that plans to reuse RC modules reclaimed from a soon-to-be-demolished building in Renens to build a new demonstrative low-tech pavilion [8]. A second project is a new office building in Basel for which a floor system with reused RC slabs, from a nearby donor building, and placed over reused steel profiles is planned. In both cases, donor buildings identified near the project sites nourished the initial project concept and guided the preliminary designs. To complete the detailed design, specific investigations were required to characterize the obsolete structure. The timeline of this design process phasing is illustrated on Fig. 3(b).

For both project sequences, once a *donor* structure is identified (obsolete structure identification), the *donor* structure must be characterized (obsolete structure audit), which consists in the assessment of the RC components – i.e. geometry, condition state, material properties, etc. In the first project sequence, identifying an adequate obsolete structure and its characteristics only after the preliminary design phases, shown on Fig. 3(a), compels designs with high degrees of flexibility regarding the material and geometric characteristics of the reused RC components. In the second project sequence, shown on Fig. 3(b), the obsolete structure and its main geometrical characteristics is known before the conceptualization step. However, the preliminary design is based on assumptions on the reused RC components structural characteristics and capacity. Obsolete structure audit is conducted at the same time as the detailed design, followed shortly by deconstruction of the donor structure. Designing with uncertain information can lead to heavy modifications during the detailed design step. In both cases described here, late audit of the obsolete structure can lead to abandoning reuse and opting for new components.

To address these problems, Fig. 3(c) proposes an ideal design process that increases chances of successfully reusing the RC components of an obsolete building in new projects. Once the obsolescence of a structure is stated, an early assessment is conducted. It aims (1) to collect all relevant data and information about the donor structure – i.e. quantities, properties, and geometries –, and (2) to assess the reusability of the components. Therefore, all relevant information is available for the designs of new structures. However, since it is possible that not all the required knowledge of the obsolete structure

Fig. 2. RC reuse project built in Switzerland: (a) Re:Crete footbridge in Wallis, (b) carriageable pavement in Meyrin, and (c) column foundations in Zurich. Image credits: (a) EPFL; (b) FAZ Architectes; (c) baubüro in situ.

is anticipated, further investigations can be carried out during the preliminary design as needed. The rest of the design process is unchanged. Section 3 proposes a procedure for the reusability assessment of an obsolete RC structure, aiming at reducing as much as possible the subjectivity.

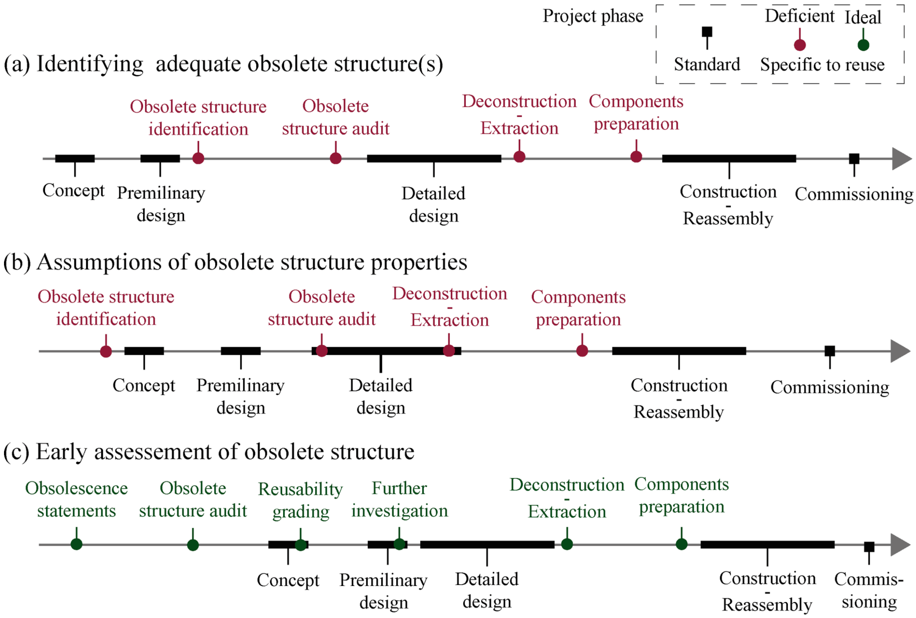

Fig. 3. The design process for reuse projects (a) by identifying an adequate obsolete structure after the preliminary design, (b) based on assumptions of donor structure properties, and (c) an ideal design process with early assessment of (various) sources.

3 Reusability Assessment

3.1 Goal and Overview

In the current literature, procedures for obsolete structure audit exist to manage the reuse of building components [9]. However, they mainly consider non-structural components such as interior components or furniture, rarely include load-bearing components and when this is the case do not tackle the structural capacity and durability characteristics of RC components. The reuse potential of RC components is highly influenced by damages and anomalies.

In the field of existing structures, condition assessment is usually conducted to identify any required rehabilitation intervention. Visual inspection is a simple and economic method [10]. In many studies, the classification of damages is based on their cause, extent, and severity. Bertola and Brühwiler [11] included also a risk class that expresses the consequences for durability, serviceability, or structural safety on the whole structure in case of component failure. The results of condition assessments of existing structures do not consider the specificities of a reuse project such as a change of exposition or a change of structural role.

Consequently, this research proposes a new reusability assessment procedure that is organized in two steps. The first step is the inventory and evaluation of the components of the RC load-bearing donor structure. It intends to provide quantitative information related to dimensions, quantities, volume, material properties, cross-section resistances, embodied environmental impact, etc. It also summarizes qualitative information such as the construction year, the location of the component in the structure, its current exposition and color and its accessibility. This information can be obtained in various ways such as a review of existing data, on-site visits, or investigations. Components are classified into categories to simplify the assessment.

Then the reusability grading, presented in the following section, gives indications on the best way to reuse RC components considering preexisting damages, the intended use in the receiving structure, and the planned intervention on the component before reuse.

Table 1. The two-step reusability assessment procedure carried out on donor and receiving structures.

	Step 1 Obsolete structure audit	**Step 2 Reusability grading**
Donor structure	Inventory and evaluation	Damage assessment
Receiving structure	-	Definition of the use and intervention classes

3.2 Reusability Grading

The proposed method for grading the reusability of RC components is based on the risk-based methodology by Bertola and Brühwiler [11] for bridge condition assessment by visual inspection. The reusability grading depends on three factors, namely the damage, use and the intervention classes. The damage class is the only one established for the donor structure, the other two classes – use and intervention – depend on the receiving project and serve as decision-support tool to choose a reasonable reuse strategy.

Damage Class. The damage assessment is the most complex task of the reusability assessment of structural components because damages must be properly interpreted and understood. Concrete damages include cracking, spalling, water damage and steel rebar corrosion.

The visual inspection is performed on the obsolete structure before its deconstruction and the results are included in the obsolete structure audit. Damages are graded in four classes defined in Table 2, based on the extent (local, wide or extensive), the severity (light, moderate or heavy), and the incidence (unique or frequent) of the damage. The severity of damages is not always measurable by visual inspection and the damage class can be corrected after further investigations – i.e. measure of carbonation depth or steel section reduction due to corrosion.

Table 2. Damage class definition

Damage class	Damage description			Consequences
	Extent	Severity	Incidence	
A (Good)	None	-	-	-
	Local	Light	Unique	
B (Acceptable)	Local	Moderate	Unique	Durability
	Wide	Light	-	
C (Deviant)	Local	Light	Frequent	Serviceability
	Local	Heavy	Unique	
	Wide	Moderate	-	
	Extensive	Light	-	
D (Bad)	Local	Moderate	Frequent	Serviceability or security
	Wide	Heavy	-	
	Extensive	Moderate	-	
E (Failure)	Local	Heavy	Frequent	Security
	Extensive	Heavy	-	

Use Class. For the reusability grading, the structural demand of a component is defined by how it will be used in the receiving structure. The use class, in Table 3, of a component, depends on two parameters. The stability criteria in its new use – defined according to the magnitude of a failure consequence – as well as its exposure to water – according to the exposition class of the codes [12].

Table 3. Use class assignments based on stability and exposition classes

Use class	Lightly exposed	Moderately exposed	Highly exposed
No stability criteria	I	II	III
Self-stable	II	III	IV
Stable under external loads	III	IV	V

Intervention Class. Interventions on the components are possible and will affect their reuse potential with regards to their damage and use classes. Decisions related to the level of interventions on the reused components must be balanced with all other decisions and givens of the project. Interventions on reclaimed components should remain proportionate from an economic and environmental point of view. However, it is useful to understand that various levels of interventions can be carried out which is translated into the intervention class in Table 4. The intervention class describes the actions that could be made on the component to modify, restore or strengthen it.

Table 4. Intervention class definition

Intervention class	Maintenance measures	Geometry modifications
a	No action	No further cutting after extraction
b	Preventive maintenance, light strengthening	Simple cutting
c	Curative maintenance, rehabilitation, medium to important strengthening	Complex cutting or modification

Reusability Class. The combination of the damage class, the use class and the intervention class, presented on Fig. 4, results in the reusability class. During the design process of a new structure, the definition of the reusability class allows deciding the best reuse solution for a reclaimed component. It is a decision-support tool and requires the analysis and good judgment of engineers to be interpreted and used correctly. It does not give a unique solution but guides engineers to provide an objective, proportionate, and adapted analysis of the situation by trying to slow down as much as possible the downcycling of the reclaimed RC component.

A component defined as "*reusable*" is as good as a new one or one with only small damages affecting the durability and requiring occasional controls. If the intended use and intervention on a component yields "*questionable reuse*" on Fig. 4, its condition or damage class does not exclude impact on serviceability and structural safety. A reduction of resistance must be considered, and regular and careful control are recommended. When combining all three factors on Fig. 4 yields "*not recommended reuse*", the structural safety is highly impacted by the damages and interventions are most likely not proportionate.

4 Building Case Studies

The reusability assessment procedure presented above was developed by adapting the procedure used to assess existing structures. It was improved iteratively through three case studies. First, the Triemli Stadtspital Personalhäuser in Zurich, built between 1964 and 1969, Fig. 5(a). It is three 15-story high buildings made of cast-in-place and precast RC components. The Lagerhalle Erlenmatt Ost in Basel built in 1975 is the second case study, Fig. 5(b). It is a storage building made of cast-in-place RC for the load-bearing structure and precast light concrete panels for the facades. Finally, Socinstrasse 59 in

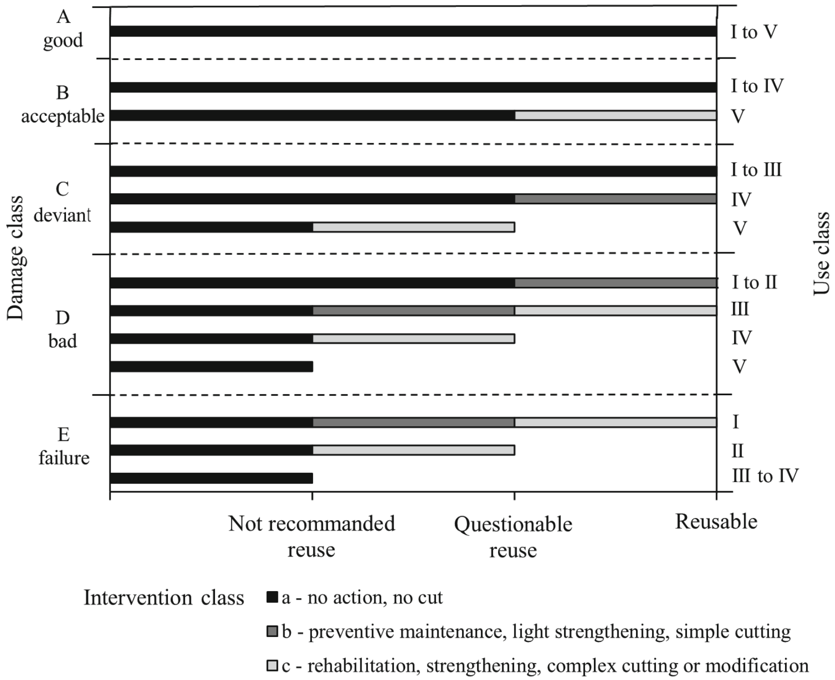

Fig. 4. Reusability grading by combination of damage, use and intervention classes.

Basel built in 1965, Fig. 5(c). This third case study has a load-bearing structure that is entirely made of cast-in-place RC, and some precast RC panels are used for the facades.

Fig. 5. Building case studies: (a) Zurich Triemli Stadtspital Personalhauser, (b) Basel Lagerhalle Erlenmatt Ost, (c) Basel Socinstrasse 59

Conducting the inventory phase for these three case studies has shown the importance of collecting and reviewing existing data. Indeed, missing reinforcement drawings complexifies the analysis and the determination of structural capacity of RC components. Other investigations must be planned to obtain the reinforcement layout, such as localized demolition of the cover concrete or non-destructive scanning using a ground penetrating radar.

For all three case studies, the RC components have been visually inspected to classify their damages. Results show that more than 80% of RC components in these case studies are in good condition (damage class A in Table 1). This observation concerns mainly the interior components which also represent about 80% of the total volume of a building's components. Facade components, exposed to outdoor conditions, generally have a lower damage class. According to Fig. 4, interior components with a damage class A are thus fully reusable. Considering facade components, reusability gradings for the three case studies show that 88% to 97% of RC component volume is reusable for a use class identical or similar to their first use cycle. With change of stability criteria, exposure or considered intervention, this proportion can reach around 92 to 99%. To summarize, the analysis shows a very good potential for reuse of the RC components for all three case studies.

5 Discussion and Conclusion

The reusability assessment procedure for soon-to-be-demolished structures aims at collecting all information required to design with reclaimed RC components. Conducting this assessment at the early stage of both deconstruction and new construction projects allows an efficient and adequate reuse of the reclaimed RC components. It prevents design adaptation in late project stages, gains time, and leads to more successful results compared to other design processes previously experienced. Moreover, to make the reuse strategy more efficient, the reusability assessment of soon-to-be-demolished buildings should be systematically done once demolition is decided.

The reusability grading is a design tool helping designers to evaluate the reuse potential of RC components and to explore different reuse options, considering its durability. Additional to structural capacity, the durability of RC components has a key role in the reuse feasibility. It is influenced by pre-existing damages of the RC components and is an output of the reusability assessment. In addition, the reuse potential is influenced by the intended use case of the reclaimed component in the receiving structure as well as any interventions made to the component. This reusability assessment does not result in a unique solution and the reuse potential is obtained through an iterative process based on the receiving structure design. The proposed tool intends to reduce the subjectivity of the assessment of reuse potential of RC components.

Future work would extend the procedure to integrate structural capacity assessments in the methodology. The upgraded tool should give a quick and easy estimate of RC component reuse possibilities in terms of durability as well as structural capacity. In this respect, another future work would be to adapt this procedure to adaptive reuse to also assess the potential of a building for in-situ reuse and thus limit demolition as much as possible.

The high reuse potential of the components from the three assessed case studies is an encouraging result. The main challenge is to integrate the obsolete structure audit in today's practice for any soon-to-be-demolished building in order to try and valorize as many RC components as possible. The risk in starting the process too late is that the implementation of reclaimed RC components in a new project becomes difficult. If obsolete structure audit of RC structures become a mandatory process in deconstruction projects, it will open new horizons towards a more circular and sustainable construction industry.

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