Implementation of reuse of concrete elements in large scale – condition assessment and quality assurance for prefabricated and in-situ cast concrete in Sweden

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Abstract. Strategic reuse of disassembled concrete elements in new buildings may be one of the solutions that will support the transition to circular construction. However, there are no EN standards instructing how to tackle quality assurance of concrete elements for reuse. The work on the Swedish standard for the reuse of prefabricated concrete elements was initiated within the national standardisation committee based on multiple experiences from previous and ongoing projects. This paper describes a methodology for material and structure investigations combining non-destructive on-site testing with traditional laboratory tests of samples extracted from the structures. The proposed method divides structures into four types depending on their production technology and according to CE-marking rules: 1) Hollow-core decks, 2) Prefabricated elements with prestressed reinforcement, 3) Prefabricated elements with standard reinforcement 4) In-situ cast concrete elements. The proposed approach was validated on the results from six demonstration projects, where real buildings in Stockholm and Gothenburg (Sweden) were reused or prepared for reuse to different extents. The analysed buildings had different functions (housing, office, parking) and structures (prefabricated elements and in-situ cast concrete), representative of the Swedish building stock. One of the buildings has been already dissembled and the prefabricated hollow-core slabs have been successfully reused for a housing construction.

1 Introduction and background

A sustainable society must be built on circular material flows. The government's "Action Plan for Sweden's Transition" (2021) [1] identifies the construction and real estate sector as one of the prioritized resource streams. The reason is the large extraction of virgin materials, high energy consumption, and extensive waste production that the building construction sector is responsible for today. Reusing concrete elements can significantly reduce the environmental impact of the construction and real estate industry in terms of:

- Reduced resource use, extraction of virgin resources,
- Reduced waste amounts,
- Reduced emissions of environmentally hazardous substances and impact on the environment and climate.

Significantly higher safety requirements are placed on load-bearing structural parts than other building products, which requires the development of new methods for quality assurance of elements for reuse that differ from new production. Within the Återhus-Buildings from buildings project [2] RISE has developed a methodology for quality assurance of structures for reuse that includes four steps:

1. Analysis of existing documentation
2. Site visits with non-destructive testing,
3. Sampling and laboratory testing
4. Statistical analysis of results from laboratory tests and conclusions.

Concrete structures can be easily divided into two main types: prefabricated elements and cast-in-place, which require completely different approaches when it comes to quality assurance. The Norwegian standard [3] describes a methodology for condition assessment of hollow-core slabs, which is a very specific case. There are no other standards or even recommendations nationally or internationally regarding other element types and cast-in-place structures. Similar quality assurance processes exist for structural steel at the European level [4] and nationally in Sweden MVR BS04:2021 [5]. No similar publication with guidance and process description are available for concrete structures and still assessments are performed on a case-to-case basis, mostly within innovation projects [6].

The innovation project Återhus has developed processes, methods, and techniques for reusing heavy building parts of concrete over several years, and the final phase of the project (Återhus 3.0) is now underway, focusing on the large-scale implementation of reuse of frames. At the same time, in recent years, RISE has carried out several assignments and collected significant experience and data from quality assurance of real concrete structures for reuse. These experiences can be compiled and described in the form of guidelines for property owners, contractors and consultants, and by ensuring and increasing the quality of reused concrete products, which leads to increased efficiency and sustainability for the construction industry.

This guideline aims to ensure the quality of construction with reused concrete elements in Sweden and by creating security in the reuse process, promote circular construction. The guideline can be used in the future during inspections/condition assessments of existing concrete structures for reuse and complements ongoing work within the standardization committee TK191 Prefabricated Concrete Products on a first standard for reuse of prefabricated concrete elements.

2 Methodology for quality assurance

The details of the methodology used for quality assurance of concrete elements for reuse have been previously published in a conference paper [7] and a report [8]. A summary of the methodology is presented in Figure 1.

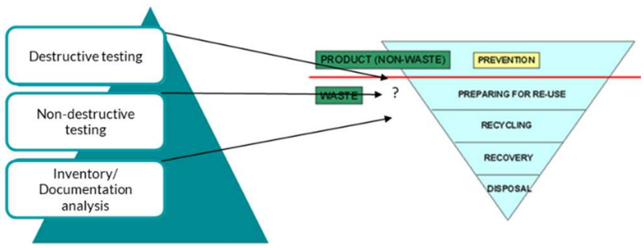

Fig.1 The methodology for quality assurance for reuse of concrete elements

To aid real estate owners and structural engineers in making informed decisions about reusing concrete elements, and to provide a systematic method for calculating the remaining service life of these elements, a simple Excel tool was developed. The tool was validated using multiple examples of buildings in Sweden within previous project Återhus UDI2 and other commercial projects like reuse of IKEA building in Gothenburg [8]. The project also validated a developed condition assessment scheme, described in more detail in. The analysis of buildings for reuse included:

- Analysis of existing documentation – drawings, technical specifications and structural design calculations if available.
- Site visits and non-destructive testing (evaluating compressive strength with a Schmidt hammer, reinforcement scanning with georadar, determining concrete cover with a reinforcement detector, and mapping of cracks and other damages).
- Extraction of drilled cores and reinforcement samples for destructive testing in the laboratory (toxic substances, compressive tests for concrete, tensile tests for steel, carbonation depth, ASR-reactivity and chloride content if relevant).
- Evaluation of results, service-life calculations and recommendations for element classification for reuse.

The calculation tool was then used with data from the condition assessment. Each element was assigned two lifespans: (I) Degradation of concrete cover (initiation based on Fick's 2nd law) and (II) Corrosion of steel (propagation based on corrosion rate in a specific atmosphere). For the first lifespan, the diffusion coefficient was calculated based on the status from laboratory tests and the age of the structure. Applying this value in simple diffusion models provided a conservative estimate of the remaining time until steel corrosion initiation. During disassembly, elements were cut at the ends when removed from supports and thus reducing their span. The span reduction coefficient was used to calculate the additional load-bearing capacity gained by the span reduction considering limit states (bending, shear, deflection) and tested material strength with safety factors adjusted for the new design but with the same design loads. Target loads should be used in this calculation, but these depend greatly on the actual design and can be added by the tool user. The user is also asked to define the target environment (e.g., if the element will be used in a garage exposed to chlorides or just carbonation and relative humidity). The corrosion rate and remaining service life of the element are calculated based on the relationship between relative humidity in the target environment and the corrosion rate from literature. Finally, additional factors are added based on [10], considering:

(A) Inherent performance level;

(B) Design level;

(C) Work execution level;

(D) Indoor environment;

(E) Outdoor environment;

(F) Usage conditions and maintenance level.

These factors are arbitrary, and their values should be decided by experienced engineers. The reference service life is calculated as $L_{ref}= t_i+t_p$, where t_i is initiation time from *life I* and t_p is propagation time from *life II*. The residual service life L_{res} is a result of applying factors $L_{res}=(L_{ref})\phi_A\ \phi_B\ \phi_C\ \phi_D\ \phi_E\ \phi_F$.

The methodology is still under development and will be updated based on the new demonstration projects described in the next chapter.

3 Demonstration projects

Within the project, 6 real-life and full-scale demonstrations are being conducted, with 5 focusing on concrete structures and one on a laminated timber structure. The projects are described briefly below.

Demo 1 - Lindome Centrum – Residential buildings containing in-situ cast concrete from the 70s in an area with social challenges in Lindome Center, Gothenburg, Sweden (Figure 2). The area is planned to go through renovation and reconstruction to improve the quality of living and the social conditions of the inhabitants. Three buildings (3000 m^2 with 70 inhabitants) are planned to be reused including structural elements (e.g. slabs, walls, staircases) and other building products (e.g. heating elements, installations). The main challenge for quality assurance is the methodology for sampling in the in-situ cast elements. Apart from that the design of connections in the new building to ensure the same structural performance is being considered.

Fig. 2 Demonstration project Lindome Centrum, Gothenburg (Image by : QPG-arichtects)

Demo 2 - Yrket 4 – Office building (Figure 3) with prefabricated hollow-core slabs from the 80s in the Stockholm metropolitan area will reuse 8000 m^2 of slabs in the new office building to be constructed on the same plot. For this project to large extend, the Norwegian standard [3] will be followed with some considerations to reduce the amount of full-scale tests recommended in the standard.

Fig. 3 Demonstration project Yrket 4, Stockholm (Image by: NCC)

Demo 3 - Ekelund 1 – A previous research institute building in Stockholm (Figure 4) with an in-situ cast concrete structure will be partially maintained and change function. The parts to be disassembled are intended for reuse if feasible. The main challenge is the quality assurance of two-way reinforced slabs and connection with external concrete walls and internal columns ensuring the correct interaction of reinforcement (with special focus on the top reinforcement over the internal support).

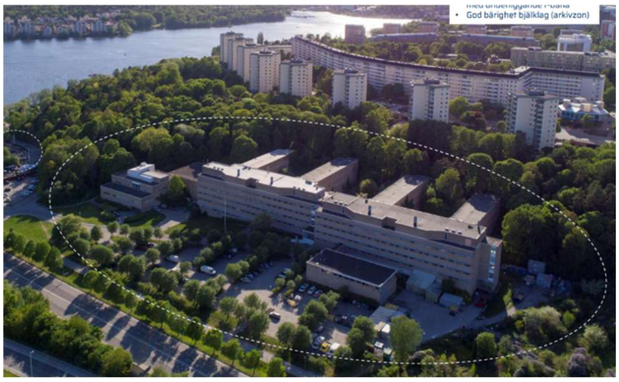

Fig. 4 Demonstration project Ekelund 1, Stockholm (Image by: HSB)

Demo 4 - Teknikhöjden – The building of the Royal Academy of Technology (KTH) in Stockholm (Figure 5) with the main part in a mixed structure of in-situ cast slabs on beams and columns and prefabricated external façade elements (Figure 5). The building needs to be demolished due to urban development plans. The goal of the building owner is to reuse as much material as possible for future use in their development projects or sell the elements. The challenge is to assess the quality of façade elements to include properties beyond mechanical and service-life aspects, such as thermal and acoustic comfort, and to define a methodology for quality assurance of the in-situ cast internal structure that will be divided into discrete elements.

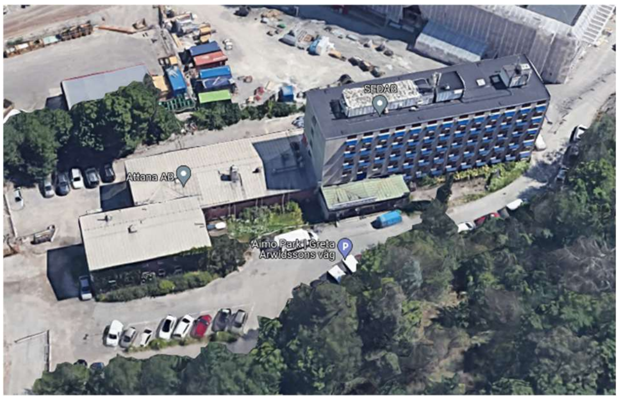

Fig. 5 Demonstration project Teknikhöjden, Stockholm (Image by: Google maps)

Demo 5 - Vårby Udde – A complex of buildings of the old brewery (Figure 6) from the 50s until the late 70s with different types of structural solutions from in-situ cast concrete, masonry to an industrial hall with ca. 400 roof and 100 slabs in prefabricated concrete elements (TT-beams). The total area of analysed buildings is around 200,000 m^2. Here the main challenge is to simplify the methodology for quality assurance taking into consideration the large number of elements. Also adapting the methodology proposed in the Norwegian standard for hollow-core decks to TT-beams and address the problem of shear-failure in the analysis.

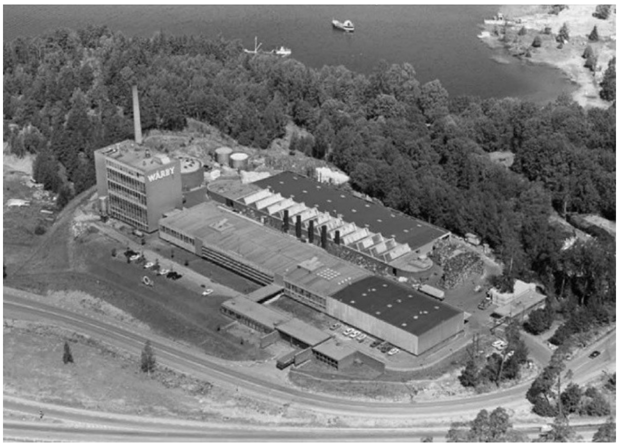

Fig. 6 Demonstration project Vårby Udde, Stockholm (Image by: Magnolia Bostad)

4 Preliminary results from on-site investigations

Based on steps 1 (analysis of technical documentation) and 2 (site visit with visual inspections and non-destructive testing) of the quality assurance process described in Section 2, all the buildings show good potential for reuse of concrete elements with specific challenges to be addressed.

The number of potential elements for reuse were assessed based on the drawings available for the building owners and the documentation available at manufacturers in the case of prefabricated elements. Also, at this stage, environmental inspections were performed to identify possible toxic substances in the buildings. No dangerous substances were identified in the analysed structural elements. Table 1 below summarizes the preliminary results of the investigations with non-destructive testing (Schmidt-hammer – for concrete strength class with calibration on drilled cores, GPR scanning for concrete cover) and local carbonation tests with thymolphthalein.

The overall preliminary results indicate that the concrete strength class is the same or higher than the one from the technical documentation due to age which can be related to the advanced hydration of cement. Therefore, the mechanical performance of concrete elements is considered fulfilled as for new structure.

The analysed elements were not exposed to chlorides during their initial service-life. For some elements (façades) chloride samples indicated concentrations lower than 0,1 % by mass of binder which according to EN 206 [11] is an acceptable level for protecting the steel from corrosion. Moreover, no freeze-thaw or Alkali-Silica Reaction (ASR) cracks were observed in the visual inspection of the elements exposed to the outdoor environment. The only durability aspect to be considered in the service-life analysis is then the carbonation-induced corrosion risk assuming that the elements will be reused in the same or milder environment. Carbonation of concrete is a natural process where CO_2 is absorbed by the products of cement hydration in the presence of water or humidity. During this process, calcium hydroxide transforms into calcium carbonate, which lowers the pH from around 13 to 8-9. Reinforcement steel may start to corrode when the surrounding concrete's pH drops to 11.

Table 1. Preliminary results of quality assurance.

Project	Structure type	Concrete class	Carbonation depth/ concrete cover [mm]
Demo 1	In-situ cast slabs (one-direction)	C25/30	6/20
Demo 2	Hollow core slabs	C40/50	TBD/30
Demo 3	In-situ cast slabs, columns and walls (two-direction)	C30/37	12/20
Demo 4	In-situ cast structure, precast façade elements	C25/30 C50/60	7/25 3/25
Demo 5	Mixed, large number of pre-cast TT-slabs	C45/55	TBD/20

This process occurs in almost all concrete structures but at varying rates, primarily depending on the humidity level. The most severe conditions that accelerate carbonation occur at around 50-70% relative humidity (RH), often involving wetting and drying cycles, such as those experienced by building facades. However, carbonation also occurs at a slower pace in drier environments, like indoors. Considering these factors, the study utilized a basic diffusion model with an effective diffusion coefficient estimated from data collected during condition assessments, specifically carbonation depth measured with thymolphthalein, and the age of the structure.

The measured carbonation depth was in almost all cases lower than 50% of the concrete cover. The basic model for carbonation depth progress can be written as:

$$X_c(t) = k\sqrt{t} \rightarrow t_i = \left(\frac{d}{k}\right)^2 \quad (1)$$

Where $X_c(t)$ is the carbonation depth, t is the age, k is the carbonation rate for specific concrete and exposure conditions and d is the concrete cover. When the carbonation depth and the exposure time are known, the carbonation rate can be simply calculated. Assuming the same exposure conditions of the element in the new structure, the carbonation depth depends entirely on the square root of time, which means that for elements with less than half of the cover carbonated the initiation time for carbonation-induced corrosion is much longer than the one in the currently analysed structure, which is the case for all the demonstration projects. Of course, the specific analysis taking into consideration the measurements uncertainty must be performed defining the predicted initiation time and minimum and maximum predicted time of carbonation front reaching the reinforcement level.

In the next step the drilled cores are taken from the structures and analysed in terms of compressive strength and carbonation depth testing in laboratory conditions verifying the measurements by non-destructive methods and testing on-site. Moreover, the testing of leaching of dangerous substances (mainly focusing on Cr(VI) in case of concrete) is also performed. The tests are ongoing and the authors intend to present the results in the conference presentation.

5 Swedish standard for the reuse of prefabricated concrete elements

As a result of this work, an initiative was taken within the Swedish standardisation committee SIS TK191 – Prefabricated Concrete Products, to formulate a national standard for the reuse of prefabricated concrete elements. The motivation for the work is that there is currently no European standard for the reuse of prefabricated concrete elements, and existing standards such as EN 13369 [12], SS 137005 [13], and EN 1168 [14] are only applicable to the manufacturing control of new elements. By publishing that standard, it can be ensured that the materials (concrete and steel) in reused elements meet the requirements for load-bearing elements in terms of strength, durability and service life. The standard does not have the ambition to tackle the process of deconstruction, transport, refurbishing or installation of the elements. Its scope is limited to the assessment part.

The main concept of the standard is based on the Norwegian NS3682 [3] mentioned before with the following improvements:

- Extension of the scope from only hollow-core slabs to all prefabricated concrete products,
- Linking the number of samples to statistical uncertainties and types of elements (intervals for testing in the NS3682 are pre-defined ex. extraction of drill cores of 1/20 elements with a minimum of 8 samples.
- Improved service-life calculations (non-prescriptive, in NS3682 if carbonation is less than 6 mm the carbonation is assumed as not relevant without relation to the concrete cover thickness).
- Adding requirements for testing reinforcement.
- Opening for using non-standardized non-destructive testing methods.
- Reconsidering the requirement for full-scale testing (perhaps in certain cases).

The Swedish standard will be moreover based on the following assumptions:

- Characterization of properties according to relevant manufacturing standards.
- Different procedures depending on CE marking schemes – inspiration for the recommendations of testing structural steel with 4 different procedures depending on the structure age and documentation. In the Handbook "Reuse of steel in load-bearing structures – requirements and process description", 4 different protocols are proposed depending on the manufacturing year and availability of the documentation. The Swedish standard for concrete is considering differentiating the requirements for testing intervals on the element type: Protocol A – Hollow-core slabs, Protocol B – Elements with prestressing reinforcement and Protocol C – Non-prestressed elements.

The work within the standardization committee is ongoing and this paper is only highlighting the concept. The Authors intend, with this paper, to gather more relevant knowledge and scientific evidence to support the work within the committee.

6 Conclusions

Reuse is the second step in the waste pyramid after service life extension due to preservation of the embodied value and, as such, it has minimal impact on the environment. To accelerate the transition from a linear to a circular economy, new methods for assessment and quality-assurance of concrete elements need to be established and shift from innovation projects to the industrial standard. For this, implementation of national and European standards are required. Based on the research performed in this study the following conclusions may be drawn:

1. The methodologies used today for the assessment of existing concrete structures can be adapted in quality assurance of concrete products for reuse, paving the way for reducing the amount of waste and utilization of raw materials while reducing the climate footprint of buildings.
2. The 5 investigated demonstration projects indicate a high potential for the reuse of structural concrete in terms of concrete strength and durability resulting in thousands of m^2 of concrete elements, both prefabricated and cast in-situ, changing them from waste to a product. The potential service life based on carbonation depth exceeds the primary service life in the original building and goes far beyond the 50-year service life assumed in climate declarations in Sweden today.
3. Different building typologies and functions imply technical and logistical challenges in reuse, however even in-situ cast elements (specially reinforced in one direction and designed originally as simply supported) have the potential for becoming circular products if new design solutions are implemented.
4. Swedish industry and research actors are working together on the national standard for prefabricated concrete elements to accelerate the adaptation of reuse from innovation projects and single demonstrators to the industrial practice, basing its work on the only standard in Europe, but extending it to multiple types of prefabricated concrete products opening for up-scaling of reuse.

Acknowledgments

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References

1. Action plan for circular economy implementation in Sweden, Swedish Government 2021, https://www.regeringen.se/contentassets/4875dd887fd34edabd8c1d928a04f7ba/cirkular-ekonomi-handlingsplan-for-omstallning-av-sverige.pdf Accessed: 2025-02-16
2. Återhus 3.0 - bygga hus av hus | RISE, Accessed: 2025-04-08
3. Standard NS 3682:2022 "Hollow core slabs for reuse", Standards Norge, 2022
4. Draft of standard N1105 CEN-TS WI 00135033 "Reuse of structural steel" CEN/TC 135 N 1105, 2023.
5. Handbook "Reuse of steel in load-bearing structures – requirements and process description" National Council of Mechanical Workshops, 2021 https://www.mvr.se/wp-content/uploads/2021/05/mvr-bs04-2021-aterbruk-av-stal-i-barande-konstruktioner-krav-processbeskrivning-utgava-1-april-2021.pdf
6. Brander, L., Boubitsas, D., Gabrielsson, I. Rivningsobjekt – från kostnad till resurs: Pilotstudie återbrukspotential för tunga stomdelar i två rivningsobjekt RISE Report 2021:58.
7. Suchorzewski, J., Santandrea, F., & Malaga, K. (2023). Reusing of concrete building elements – Assessment and quality assurance for service-life. Materials Today: Proceedings. https://doi.org/10.1016/J.MATPR.2023.07.195
8. Suchorzewski, J., Santandrea, F., & Malaga, K. (2023). Quality assurance for reused concrete building elements. https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-64292
9. Håldäck från IKEA återbrukas - bör hålla i minst 300 år - Forum Betong Accessed: 2015-02-16
10. Standard ISO 15686–8:2008 Buildings and constructed assets – Service-life planning – Part 8: Reference service life and service-life estimation. (ISO 15686-8:2008, IDT).
11. Standard EN 206:2013+A1 Concrete - Specification, performance, production and conformity. European Committee for Standardization. 2016.
12. Standard EN 13369:2024 Common rules for precast concrete products. European Committee for Standardization. 2024.
13. Standard SS137005:2023 Precast concrete products – Common rules – Application of SS-EN 13369:2018 in Sweden Swedish Institute for Standardization 2023.
14. Standard EN 1168:2005+A3:2011 Precast concrete products – Hollow core slabs. European Committee for Standardization. 2024.