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Quality assurance process for reuse of building components

A. Räsänen & J. Lahdensivu
Tampere University, Tampere, Finland

ABSTRACT: Reusing building components has generated discussion increasingly. Current guidelines and practices are not suitable for the reuse process, and therefore new guidelines need to be developed. With new guidelines the quality of reuse can be ensured. The quality assurance process can be divided in five different stages including pre-deconstruction audit, structural condition investigation, deconstruction design and deconstruction, demands for redesign in new building and product approval and authorization. In the process, overall perspective of the building and its structures is required. This can be achieved by studying old documents and doing structural condition investigation. With the results, more exact information about the structural properties of the building components can be obtained. These results can be used in redesigning the components and in product approval. Also, the quality of the deconstruction stage needs to be ensured in order to avoid any effects on the structural properties of reusable building components.

1 INTRODUCTION

Construction industry consumes a vast amount of natural resources globally. In addition to natural resources, construction industry produces over 35 % of the EU's total waste generation. Also, greenhouse gas (GHG) emissions are estimated to be 5-12 % of total national GHG emissions. GHG emissions includes material extraction, manufacturing of new construction products, construction and renovation of buildings. Therefore, saving natural resources is one essential means of curbing climate change. (European Commission 2022)

In a Finnish apartment building carbon footprint from construction materials is average 26 % of the whole life cycle of the building. Most of the carbon footprint consist of energy consumption, which is approximately 63 %, since buildings requires heating during cold periods and cooling in hot periods in Finland. The carbon footprint of the whole service life may differ from this average value in individual cases, because it depends on energy efficiency of the building, carbon footprint of the energy production and the materials used in the building. (Ymparisto 2016) Currently zero-energy buildings have become more common and the emissions of energy production have been decreased. Therefore, the material emissions of the whole life cycle increase in proportion to the emissions of a whole building. Construction product industry has developed several construction products by which the carbon footprint of buildings can be decreased. With low-carbon concrete the carbon footprint of an usual apartment building can be decreased 34 % (Lahdensivu & Lahdensivu 2021). Reusing building components is one potential way to decrease the carbon footprint even more, because the carbon footprint of a product stage (A1-A3) is zero according to Finnish national guideline (Kuittinen 2019). According to German studies carbon footprint (A1-A3) of reused concrete elements is between 3 and 5 % (Mettke 2010). The product stage A1-A3 includes material supply, transport and manufacturing according to information modules of assessment of environmental, social and economic performance of the construction works in European standard SFS-EN 15643:2021.

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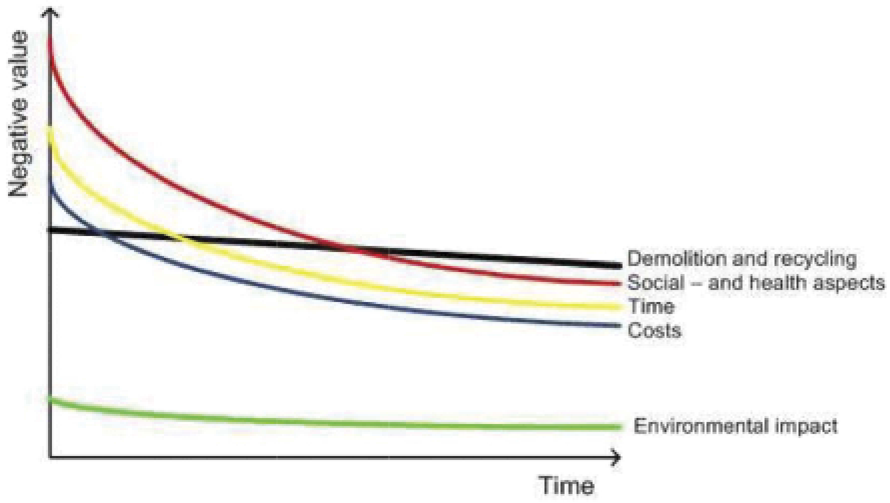

Figure 1. The progress of negative values for reuse of hollow-core slabs in the future compared to demolition and recycling (Naber 2012, p. 135).

Buildings are designed to service several decades. In Finland facades are designed typically for 50 years while frame and foundation structures are designed to service at least 100 years. However, industrial and office buildings have been demolished notably under designed service-life, typically after 20 to 40 years (Huuhka & Lahdensivu 2014). Therefore, building components have several decades of service-life left at demolition stage and potential for reuse.

According to European Union's directive 2008/98/EC of 19 November 2008 on waste and repealing certain Directives, reuse, recycling and other material recovery of construction and demolition waste should have been increased to a minimum of 70 % by weight by 2020. This varies between EU's member countries, but the most common way is using the waste as a substitutive material in land construction or as an aggregate in concrete. However, recycling is inferior to reusing in waste hierarchy in 2008/98/EC. Also, by reusing building components, for example concrete components, the carbon footprint and energy consumption can be decreased 96-98 % compared to a new product (Mettke 2010, ReCreate 2022).

Reuse of building components have been studied previously by several researchers (Mettke 2010, Lahdensivu et al. 2015, Huuhka et al. 2018, van den Brink 2020, RE:Source 2021, Zhu et al. 2022). From previous studies it can be concluded that reusing is possible. However, a main challenge found in previous studies is quality assurance process (Re:Source 2021, Zhu et al. 2022). The challenge includes especially ensuring safety and healthiness of the reusable building components and methods for investigate these.

Building components may deteriorate or material properties may change in-use. Also, the components may get damaged in deconstruction. Several national guidelines for condition assessment of façade structures have been developed (Lahdensivu et al. 2019, Lahdensivu et al. 2021), but for load-bearing structures there are no as united whole guidelines. This structural assessment is an essential stage for reuse process of building components since the properties and reusable components can be discovered before deconstruction. A problem is a lack of established practices of reuse, which increases negative values as costs, time, environment impact and social factors of reuse. These negative values may increase higher than in recycling and new construction. In the future after getting more utilized practices, negative values are assumed to decrease lower than demolition and new construction (Figure 1). (van den Brink 2020)

This paper presents a concept of quality assurance process for reuse of pre-cast concrete elements. The aim of the study is to create a practical process which can be used to ensure the quality of the reuse of building components. The current quality assurance processes are for new construction and for example in concrete industry these are for concrete batching. However, the properties of concrete vary in time and the properties in old structures may differ from the age of batching. Therefore, new processes need to be developed for old reusable components. The process in this study is supposed to promote the reuse of building components by providing a base for development of practices. This process will be developed during the Reusing precast concrete for a circular economy (ReCreate) project by using it in practice.

2 REUSE PROCESS

Several different further actions may be done after building's service life. The further action depends on the owner's decision of what is the future of the plot or the building. The decision may be maintenance, repair or upgrading works, demolition or deconstruction for reuse of building components. The deconstruction process differs significantly from usual demolition and new construction as far as designing and building practices. (Bertino et al. 2021)

Reuse process can be divided in four different stages: deconstruction, transport, storage and building. All these stages differ from new construction and should be considered in the reuse process as they increase the challenges of reusing without established practices. (Bertino et al. 2021) The current challenges in the whole reuse process are costs, design, regulation, market and deconstruction. The costs may be three to five times higher in reuse than in new construction, because deconstruction and design stages being unusual and thus taking more time (Rakhshan et al. 2020). Furthermore, the costs in reuse process may be lower than in new construction if labor costs are small and the deconstructed components have demand (da Rocha & Sattler 2009). In addition to these challenges, one of the main challenges, which must not be forgotten, is the quality assurance of the reusable building components as mentioned in the introduction. The quality assurance process will be discussed further in the following section.

3 QUALITY ASSURANCE PROCESS

There are several different stages in quality assurance process. Each of these stages are essential to consider in reuse process for safe and reliable reuse of building components. The process starts before deconstruction and ends to product approval after the deconstruction of the building. General flow diagram of the quality assurance process is illustrated in Figure 2.

3.1 *Pre-deconstruction audit*

Before deconstruction stage, it is essential to decide what needs to be done with the building. The decision may be to maintain the current building by renovating or deconstruct the building and reuse the components in a new building. Regardless of the decision, the properties of structures should be assessed in both cases. Only the scope and extent of investigation vary. There are no any strict rules for decision-making as the decision varies between individual cases, but before the decision, the structures of the building should be always studied. This study can also be helpful and support the decision-making.

Overall, at this stage it is essential to get a general overview of the building and its structures. This can be done by studying design basis, previous inspections and maintain records and occurred irregularities to get information about the properties and factors as dimensions, environment, joints etc. that affect to service life, deconstruction work and reusability of the structures. This stage is also known as pre-deconstruction audit.

3.2 *Structural condition investigation*

One of the essential stage in reuse process is to ensure reusability of building components. This includes mechanical properties for structural capacity design, durability properties for

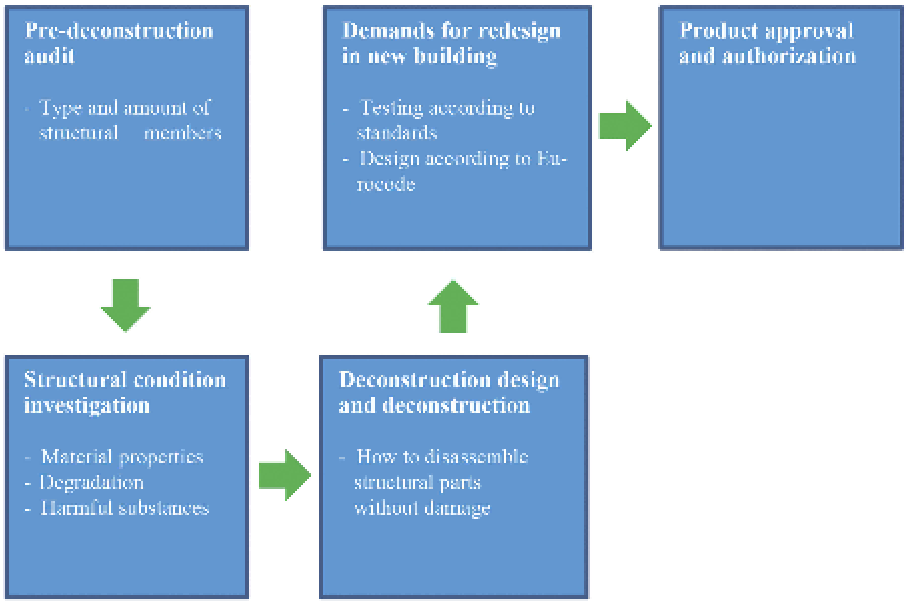

Figure 2. Quality assurance process for reuse of building components.

service-life assessment and hazardous substances for safe and healthy deconstruction work and reuse. These affects to the design process for a new building as well as to the product approval and authorization before the reuse. The properties can be assessed by structural condition investigation and assessment.

For a successful condition assessment, careful pre-planning is required. In the pre-planning it is essential to decide test methods, sampling spots and sample size for each test. Decision-making for testing reusable building components differs from usual condition assessment of a building, since the components are going to be redesigned according to current requirements and standards. For condition assessment of a building, the minimum performance requirement can be decided by the owner of the building, but in the reuse process, the minimum performance requirement is defined in standards and design guidelines for a new building. Thus, representative of test results, reliability of testing and threshold values for different deterioration mechanisms are emphasized in the structural condition investigation of reusable building components.

To get reliable and representative results, it is important to know every factor affecting to the results. For example, different non-destructive test methods (NDT) for testing bricks have uncertainty, and it is therefore important to select the right methods and sample sizes for each property (Räsänen et al. 2022). Also sampling spot and sampling should be considered in pre-planning, since they have a significant influence for example on the testing results in concrete structures (Haavisto et al. 2021). In addition to these examples mentioned above, other factors as location of the sampling spot and used equipment should be considered as well depending on the structure and building.

Threshold values for corrosion of reinforcement in concrete, for example, needs to be decided according to the demands from new building. The testing procedure needs to be as accurate as possible, since the threshold value is essential information for the service-life assessment. This procedure varies for different deterioration mechanisms. Therefore, it is very important to know if there are any ongoing deteriorating and what is the primary deterioration mechanism to be investigated and assessed. Deterioration mechanisms are not the only thing, since the components are going to be redesigned. The most important thing being the structural properties as strength and stiffness. These are the essential information for design and therefore the values for these must be as accurate as possible.

To achieve accurate results, on-site inspection is required. Visual inspections, non-destructive testing and destructive testing should be done to get a representative picture of all the structures. Using these methods mentioned above alone or together, this representative picture can be achieved. After having the results of the tests, the results need to be analyzed and assessed by a qualified person who can identify any factors of uncertainty.

3.3 *Deconstruction design and deconstruction*

Deconstruction process relates to occupational safety and is therefore essential stage in the quality assurance process. This requires thorough design process where every affecting factor to the occupational safety need to be considered. In the reuse process, it is also essential to design the deconstruction so that the properties of the building components are not being affected. The factors are for example deconstruction order, working method, support structures, lifting equipment and joints of the structures.

Before actual deconstruction work, the condition investigation results need to be assessed at general level. The reason for this is that possible damages before and after deconstruction must be separated so that the main reason and influence of the damage on the properties of structure can be assessed. At least visual inspection is required before and after deconstruction. Also, need for further investigations must be clarified, if needed.

In addition to the deconstruction of the building, storage and transport conditions must be considered. These conditions may have significant effect on the properties of structures, and it is essential factor. For example, in-door structures may have problems with freeze-thaw durability in cold climates if they are not protected sufficiently from moisture or cold air. Further investigations and assessment are required if there are any doubts of deterioration during storage or transportation.

3.4 *Demands for redesign in new building*

As mentioned before, reusable building components are designed according to current standards and guidelines. The values for these can be determined by condition investigation and assessment which cannot be over-emphasized in the reuse process. In the redesign of the components, reliability of the results from condition investigation is essential and needs to be considered by the designer. The reused building components cannot risk sustainability of the new building.

The current design equations may not represent the real performance in the structure, if the structure has been damaged. Thus, the factors in the design equations may require adjustment in the redesign stage. The way how these factors have been influenced by the damage need to be investigated and assessed. This requires expertise to understand the design equations and factors which may have been affected. In addition to the design equations, the joints may require full demolition, or they may be damaged during deconstruction, and therefore new joints and details may be needed. This may require more creative thinking because typical joints in new construction may not be practicable with reused components.

In addition to the structural properties, the designer must understand the meaning of fire and sound insulation of the structures. The requirements for these have changed during time, and reusable components may not fulfill these requirements without any improvement. All these demands must be considered for reusable components as in new construction with new components.

These factors affecting to the redesign of the reusable building components are just a few examples from several affecting factors. This indicates that there are several challenges in the reuse process, and it requires a lot of understanding to consider all the affecting factors. Also experience from practice will point out the typical challenges in the redesign stage in the future.

3.5 *Product approval and authorization*

Currently CE marking is required for new materials and components in EU. However, this is only for products manufactured after 2013, and therefore, for reusable building components manufactured before that, the CE marking is not required. Local and national authorities may still require product approval for ensuring safe reuse. This can be done by following each stage of the quality assurance process in Figure 2.

For a product approval it is highly recommended to create a document from each stage which can be used as an aid for proving the usability of the reused components. In these documents the results and decisions need to be stated. The documents are also helpful for designer who tries to figure out the uncertainty of the material properties and select the usable property value in design. Therefore, any uncertainty in different stages need to be considered in the documentation.

4 CONCLUSIONS

The quality assurance process of reusable building components has several stages. Each of these stages needs to be done with care, since they affect to the next steps and the whole process. The pre-deconstruction audit is important to get a general picture of the building and reusable components. This is an aid for designing structural condition investigation and assessment stage, which is a very important stage in the whole process. By the results of the condition investigation, the reusability of the components can be ensured. The requirements for the condition investigation comes from the demands from the new building because the building need to be designed according to the current standards and guidelines. To ensure that the components satisfy the demands for the new building, the deconstruction needs to be taken with care. In addition to the components, occupational safety is an essential perspective at this stage. At the end of the process, reusability of the building components can be ensured by following these stages above.

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