2023-2025

ADVANCE

ACCOMPANYING MEASURE FOR DISSEMINATION, VALORISATION AND COLLABORATIVE EXPLOITATION OF CIRCULARITY OF CONSTRUCTIONAL STEEL PRODUCTS

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Circular Economy of Steel-Based Building Components

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Executive summary

This report presents the results of the ADVANCE project, a RFCS Accompanying Measure that aims to develop and demonstrate circular economy solutions for steel and steel-based components in the construction sector. The project covers different aspects of reuse, such as design, testing, certification, business models, and sustainability assessment, and provides recommendations and best practices for policy makers, industry stakeholders, and researchers.

The report reviews the existing standards, guides, and technical specifications for the assessment and design of reused steel components and identifies the main barriers and challenges. It also showcases some innovative solutions and case studies of reusable steel and steel-based structures and dismountable connectors, and evaluates the environmental, economic, and social impacts of reuse and recycling of steel components using different methods and tools. Finally, the report analyses the existing and upcoming policies and regulations at the European and national levels that affect the circular economy of steel-based components and provides policy recommendations and proposals for new standards and guidelines to support the reuse and recycling of steel components. Annex A of the report presents glossary of terms and definitions used in this report and in the ADVANCE project in general. Factsheets of the newly developed Case Studies of structural steel reuse are presented in Annex B.

Contents

1. Introduction

The ADVANCE project is a RFCS Accompanying Measure funded by the European Union that aims to develop and demonstrate circular economy solutions for steel-based components in the construction sector. The project covers different aspects of reuse, such as design, testing, certification, business models, and sustainability assessment.

Reusing steel from the existing buildings is a complex process that requires coordination and information exchange between various stakeholders, as well as pre-deconstruction audits, testing, reconditioning, and certification of the products. The components for reuse are considered as potential resources for future use. This report reviews the existing standards, guides, and technical specifications for the assessment and design of reused steel components and identifies the main barriers and challenges in Section 2.1.

The ADVANCE project also provides recommendations and best practices for designing buildings that can be easily dismantled and reused in the future, considering the modularity, flexibility, durability, and recyclability of the structural system and the materials. Therefore, Section 2.2 of this report showcases some innovative solutions and case studies of reusable steel and steel-based structures and dismountable connectors.

Different methods and tools are reviewed in Section 2.3 to evaluate the environmental, economic, and social impacts of reuse and recycling of steel components, such as lifecycle assessment (LCA), product environmental footprint (PEF), material circularity indicators (MCI), and sustainability certification schemes. The project also develops methodologies to declare the environmental benefits of reuse and to calculate the circularity level of buildings.

The case studies presented in Section 3 illustrate the technical, economic, and environmental aspects of the circular solutions, as well as the challenges and opportunities for their implementation. They demonstrate the feasibility and the benefits of reuse and design for reuse.

The project analyses the existing and upcoming policies and regulations at the European and national levels that affect the circular economy of steel-based components, such as the taxonomy, the waste framework directive, the Construction Products Regulation, the Ecodesign for Sustainable Products Regulation, and the national building codes and laws.

2. State of the art

This section provides a state-of-the-art review of the circular economy of steel-based components in the construction sector. It covers three main topics: reuse of existing steel, design for future reuse and sustainability assessment. For each topic, it summarizes the existing standards, guides, technical specifications, challenges, and best practices, and presents some innovative solutions and examples of reuse and recycling of steel components. At the end of this section, several case studies are briefly introduced to demonstrate best practices in constructional steel reuse.

2.1 Reuse of existing steel

Reusing steel from the existing buildings is a complex process involving coordination and information exchange between the existing building owner, demolition/deconstruction contractor, material dealer and designer/developer of a new project with reused steel. It starts with pre-deconstruction audit and typically includes testing, reconditioning and certification of the products to be reused. Designers of new buildings from reused steel can take advantage of good practices documented in many existing use cases, for instance how to avoid issues with higher structural loads or lower design resistance of the components by shortening the structural spans or additional reinforcement. The material qualification and uncertainties in structural design were identified as the most severe barriers for constructional steel reuse because of the relatively high testing costs and lack of guidance. Therefore, this section will focus primarily on the development of the testing and re-certification protocols for reclaimed steel products. It should be noted that steel is in these aspects ahead of other materials because of the intensive work of the relevant groups of CEN/TC135 and CEN/TC250.

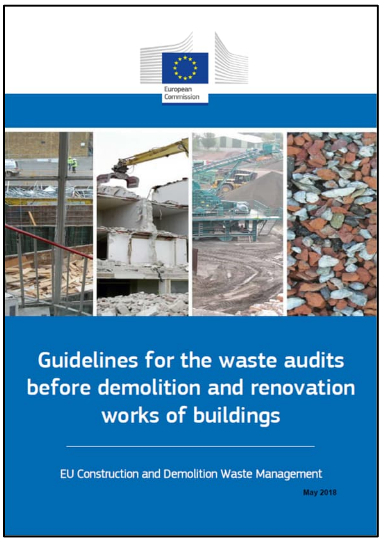
2.1.1 Pre-deconstruction audits

Audit is the process initiated and organized by the building or infrastructure owner. It involves any initiatives that result in a documented work. It is defined as a preparatory activity with the purpose of collecting information about the qualities and quantities of the materials that will be released during the demolition, deconstruction or renovation works and giving general and site-specific recommendations regarding the demolition, deconstruction, or renovation process [1]. Public authorities should decide upon the threshold for the audits. The audits take full account of local markets for Construction and Demolition Waste (CDW), reused and recycled materials. A good pre-demolition audit must be carried out by a qualified expert (the auditor).

In the broad sense of the “audit” definition, the pre-demolition, pre-deconstruction, or waste audit is performed in most of the Member States. In the case of hazardous waste (mainly asbestos and PCBs), most countries follow similar practices and legally enforce their identification prior to the relevant demolition, deconstruction or refurbishment works. For example, asbestos content must be analysed in all buildings built in Finland before 1995. However, for non-hazardous materials, the type of works for which an audit or inventory is prepared vary greatly, due to the differences in national and regional regulations. Demolition contractors ordinarily perform their own waste inspection too, to set the price or to prepare more detailed demolition and waste management plan. These audits are based on the expertise and common practices of the contractor and rarely conform to any regulation. The contractors may have internal rules, templates, etc. for their audits and sometimes they make very detailed demolition and waste management plans based on this inspection.

This section introduces examples of pre-deconstruction audit guides developed in EU or selected Member States. It should be noted that instructions for the inspection and documentation process are often provided in the standards and protocols dealing with the material qualification and testing, which are introduced in the following sections (e.g. CSTB diagnostic and performance evaluation methodology for the reuse of steel framing elements [11]).

<u>European Waste Audit Guidelines (2016) [1]</u>



The '*Guidelines for the waste audits before demolition and renovation works of buildings*' provide guidance on best practices for the assessment of construction and demolition waste streams prior to demolition or renovation of buildings and infrastructures, called "waste audit". The aim of the guidance is to facilitate and maximize recovery of materials and components from demolition or renovation of buildings and infrastructures for beneficial reuse and recycling, without compromising the safety measures and practices outlined in the European Demolition Protocol [2].

It introduces the '*inventory of materials and elements*' as the basic output of the audit based on the duty of the waste holder to gain knowledge about the objects and substances intended to be discarded and their potentially hazardous nature and contamination. The inventory of reusable elements (not to be discarded) is an optional part of the audit, but if applied, it is recommended to have a higher priority than materials recycling and waste management (see Figure 1). It should be noted that the revision of this document is under preparation.

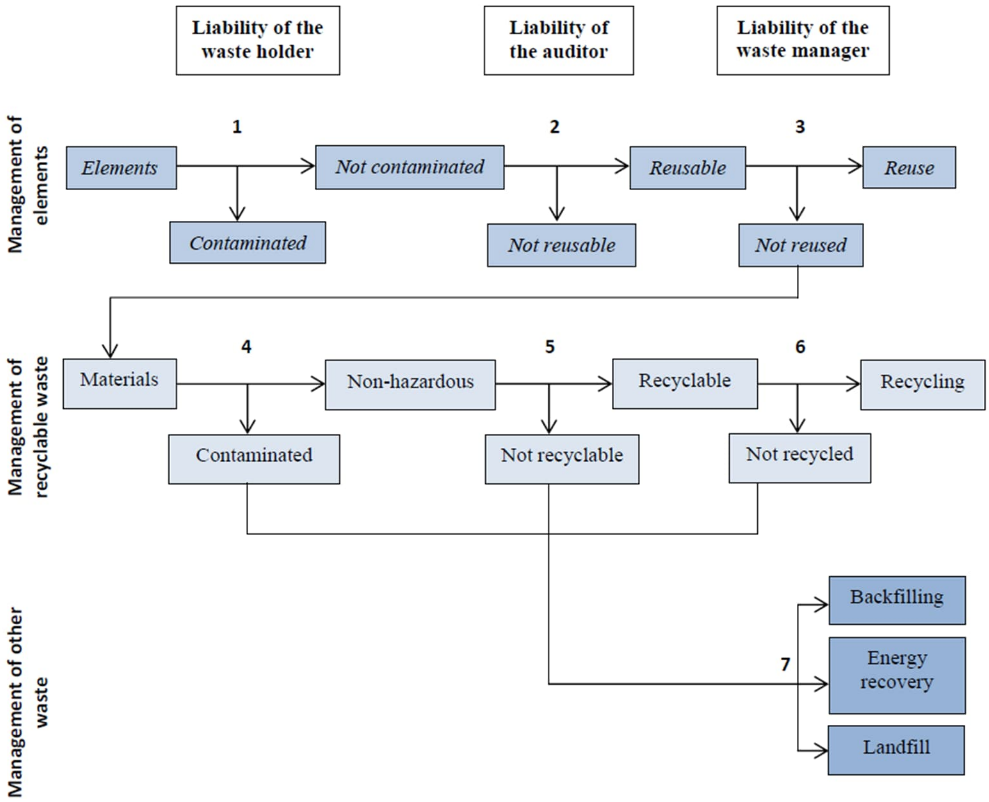
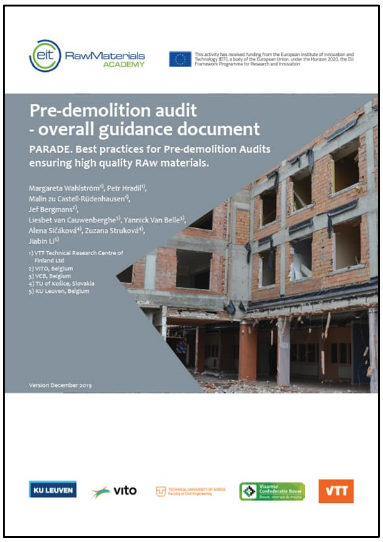


Figure 1. Decision-making process according to the European Waste Audit Guidelines [1]

Pre-demolition audit – Overall guidance document (2019) [3]



This document extends the Waste Audit Guidelines of the European Commission [1]. The guidance provides information about the best practices for the assessment of Construction and Demolition Waste streams prior to demolition or renovation of buildings or infrastructure, called '*waste audit*'. The aim of the Guideline is to facilitate and maximize recovery of materials and components for beneficial reuse and recycling without compromising the safety measures and practices outlined in the EU Construction & Demolition Waste Management Protocol [2].

The declaration of reusable components is optional, but the contend of such declaration is specified in the guidance.

Finnish guide for the pre-demolition auditor (2019) [4].

This guide is part of a series of three guides aimed at improving the quality of demolition projects in Finland. The purpose of the guide was to support Finland's objective is to reach the target of 70% material utilisation set for construction and demolition waste in the EU Waste Framework Directive [5] by 2020. The utilisation rate was around 54% at the time of its publication.

Pre-demolition audits in Finland are a voluntary measure for mapping out the materials and hazardous substances in buildings to be demolished. The purpose of the surveys is to create good conditions for the appropriate use of demolition materials while preventing environmental and health risks and ensuring a high-quality demolition process in all demolition projects. Finnish pre-demolition audit is based on EU initiated audit procedure and reusable products are managed the same was as recommended in the EU guide [1] and Overall guidance document [3].

PROGESS pre-deconstruction audit protocol (2020) [6]

2017-2020
PROGRESS
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

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Safe and efficient deconstruction

May 2020

The report D2.1a of PROGRESS project contains the guidance for pre-deconstruction audit of single storey steel buildings. It is the first guide of this type with the recommendations specific for the reusable steel components. It covers auditing of constructional steelwork and steel-based elements arising from deconstruction of single-storey buildings.

The report is aligned with European strategies for construction sector and waste management and follows the objectives of the Waste Framework Directive [5], which prioritize waste prevention and reuse over recycling and other recovery. It contains protocol, checklists, and a reporting template for the auditor to perform the survey in accordance with the material testing protocol developed in the same project [7].

The following checklists are provided to support the auditor's work:

- Preliminary assessment checklist
- Field survey checklist
- Admissibility of reclaimed steelwork and condition evaluation checklist
- Checklist for the materials and waste management recommendations

The audit report template is then divided into four parts:

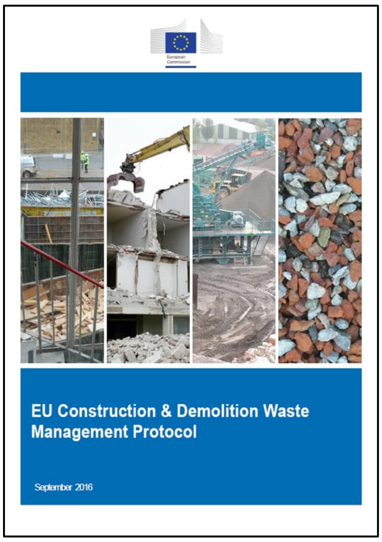
- General information form (Part A)
- Free text description of the audit and recommendations (Part B)
- Tables of the inventory of reusable components (Part C)
- Table of the inventory of waste and hazardous substances (Part D)

The information about reusable components in Part C is divided into General information (e.g. dimensions, quantity, location, year of fabrication and decision about reuse), Material information (manufacturer, grade, and material testing procedure) and recommended treatment (overall treatment, repairing and surface reconditioning). Example of the audit report is included as Annex A of the PROGRESS deliverable D2.1a [6].

2.1.2 Deconstruction

It is estimated that large part of the existing European constructional steelwork can be deconstructed and reused instead of the usual practice of recycling. The share of reusable elements can be over 80% for instance in the primary and secondary steelwork of single-storey steel buildings [8]. Many existing structural steel components are inherently reusable due the nature of their design and construction. Therefore, the deconstruction of such components is one of the essential steps to ensure successful reuse process.

<u>EU Construction & Demolition Waste Management Protocol (2016) [2]</u>



The Protocol aims to increase confidence in the Construction and Demolition Waste management process and the trust in the quality of recycled materials. This is achieved by improved waste identification, source separation, collection and logistics, improved waste processing and quality management, and appropriate policy and framework conditions.

The document provides general guidance for selective demolition and dismantling, but its focus is on separation of materials for recycling rather than deconstruction and reuse of the whole components or component assemblies.

<u>PROGRESS Deconstruction Protocol (2020) [8]</u>

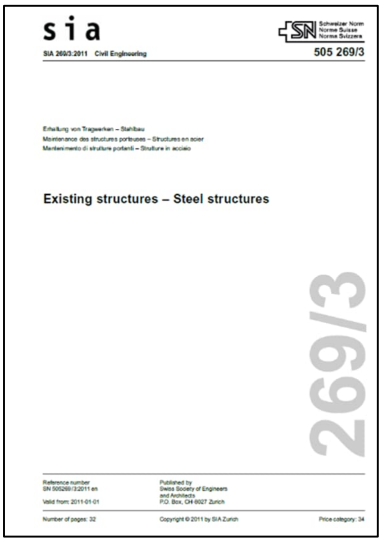
The deliverable D2.1b of PROGRESS project presents a deconstruction protocol for single-storey steel buildings (SSB) to ensure safety in deconstruction and integrity of the deconstructed elements. The aim of this protocol is to encourage the safe reclamation of structural steel elements from such buildings in the EU so that the reclaimed elements can be reused in subsequent construction applications. The protocol creates a unitary system for the deconstruction of single-storey steel framed buildings.

Generally, it is assumed that the deconstruction of a steel frame is the same process as its erection with additional effort to maintain the integrity of the disconnected components. The additional considerations that need to be done during the deconstructions are discussed in the document.

2.1.3 Selection, acceptance criteria and design considerations

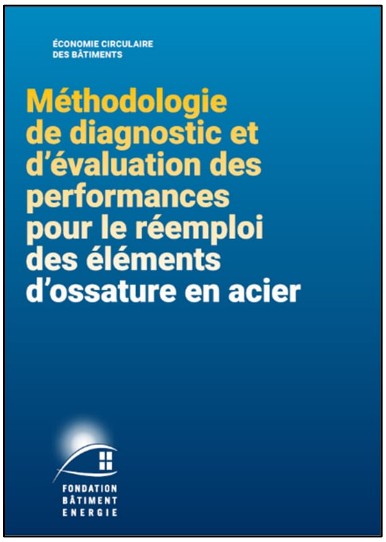
This section discusses the selection and acceptance criteria for the reuse of existing steel in construction, as well as the design considerations that must be considered when reusing steel from existing buildings.

<u>SIA 269/3. Existing structures – Steel structures (2016) [10]</u>



The Swiss Code SIA 269/3 is part of series of standards dealing with the assessment of existing structures. It describes the procedures to be followed in extending the service life of constructional steel. It addresses specialists in the preservation of structures as well as owners of construction works and specialists involved in construction management and the execution of construction works. It focuses on materials and connections (including riveted joints) and provides guidance for condition survey, interventions, and structural verifications of those. The standard is generally used for verification and extending life of existing heritage structures and bridges, but many parts are applicable for reclaimed structural components as well.

<u>CTICM/FBE: Diagnostic and performance evaluation methodology for the reuse of steel framing elements [11]</u>



The document provided by the CTICM presents a step-by-step guide for assessing the potential of steel structural elements to be reused in a new construction project. It covers the whole process from the audit, performance assessment, testing recommendations to the removal and the reinstallation of the steel elements.

Welded and coated elements are not considered as well as the elements that were reused previously unless their traceability is known.

The guide includes six annexes that provide additional information and tools to support the diagnosis and evaluation methodology.

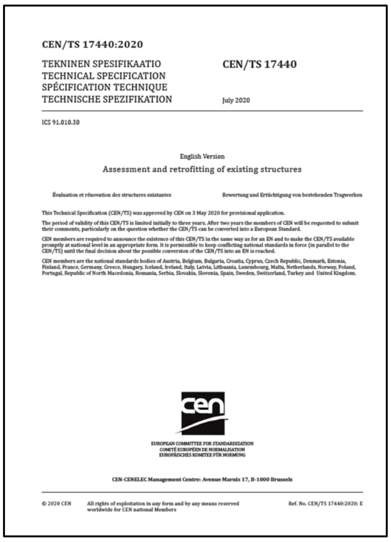
CTICM: Professional recommendations - Reuse of steel structural elements (2024) [12]

These technical specifications provided by the CTICM define a procedure for requalification of reused steel structural elements, making it possible to guarantee that the essential properties of the product are equivalent to the essential characteristics of a new product of the same type.

The requalification methods defined in this standard allow the user of the reuse product to integrate it into a manufacturing process compliant with NF EN 1090-2 and to size it with the methods defined in the corpus of Eurocodes.

The document also gives recommendations relating to the initial diagnosis, deconstruction, and traceability of a reuse element.

CEN/TS 17440 Assessment and retrofitting of existing structures (2020) [13]



CEN/TS 17440:2020

TEKNINEN SPESIFIKAATIO
TECHNICAL SPECIFICATION
SPÉCIFICATION TECHNIQUE
TECHNISCHE SPEZIFIKATION

CEN/TS 17440

July 2020

ICS 91.010.30

English Version

Assessment and retrofitting of existing structures

Évaluation et rénovation des structures existantes

Bewertung und Ertüchtigung von bestehenden Tragwerken

This Technical Specification (CEN/TS) was approved by CEN on 3 May 2020 for provisional application.

The period of validity of this CEN/TS is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the CEN/TS can be converted into a European Standard.

CEN members are required to announce the existence of this CEN/TS in the same way as for an EN and to make the CEN/TS available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the CEN/TS) until the final decision about the possible conversion of the CEN/TS into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

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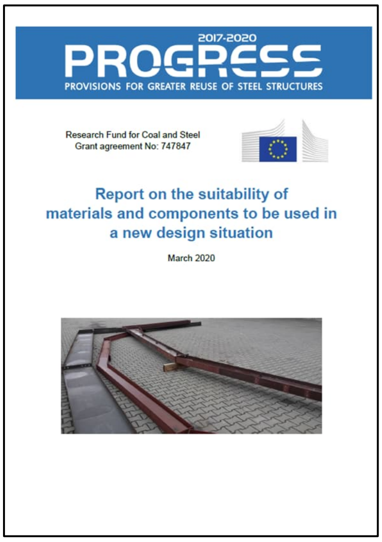
Ref. No. CEN/TS 17440:2020: E

Although the technical specification by CEN/TC250 is not specifically dedicated to reuse of constructional steel, it lays down the basis for further development of the recommendations for the assessment and design according to the new generation of structural Eurocodes.

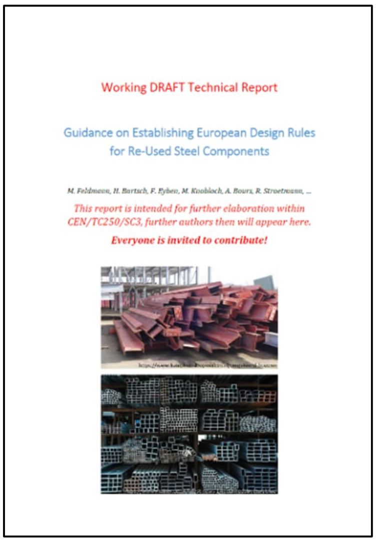
The Technical Committee may then develop dedicated TS for design of reused steel components or a section in a new TS for existing structures and reused components which will be then used in the development of new part of the Eurocode 3 (EN 1993-X or EN 1993-1-X) as described in detail in Section 5.3.3 of this report.

PROGRESS Report on the suitability of materials and components to be used in a new design situation (2020) [14]



Deliverable D2.2 of PROGRESS project summarizes the aspects influencing reusability of structural steel and steel-based components to establish a scientific basis for development of verification and approval procedures. Reusing steel components in a new construction or in the same, but in different design situation compared with the initial one must face the challenge of identification and evaluation of the effects of different deterioration processes such as ageing and weathering, time-varying loadings, and maintenance and repair interventions, among others, all of them inducing uncertainty in characterization of material and geometrical properties and definition of physical models. First, material properties and acceptability criteria (in terms of geometrical imperfections) must be defined to enable or limit the potential reuse of these components. Then, definition and classification of reusing situations is proposed, with associated acceptability criteria for the steel products.

CEN Guidance on Establishing European Design Rules for Re-Used Steel Components (2024) [9]



AHG of CEN/250 SC3 is developing a new technical report describing the need for concepts and rules for the evaluation, reclaiming, storing, distribution, design, and installation of reused constructional steel components. The document will propose Eurocode 3 design rules for reused steel components and action plan to foster reuse in construction across European countries. The scope of the AHG work includes pre-deconstruction audit, assessment of the suitability for reuse, testing protocol, and determination of safety factors and characteristic material values based on the available information. The report proposes “key-routes” for the procedure how assessment and design of reused steel components can be done. The detailed description of the CEN methodology is in Section 5.3.3 of this report.

2.1.4 Qualification of reclaimed steel and testing

This section reviews the existing standards, guides, and technical specifications for the testing and qualification of reclaimed steel and identifies the main barriers and challenges for reuse. It presents the testing protocols developed by the national associations, standardization groups or international research project. The protocols provide specific procedures for non-destructive and destructive testing of reclaimed steel products depending on their material certificate, traceability, and execution class. The section also discusses the recommendations for re-certification and re-fabrication of reclaimed structural steelwork developed by the PROGRESS project. The overview of testing protocols from MVR in Sweden, FCSA in Finland, and CEN/TC135 is included. These protocols are based on the PROGRESS methodology and provide specific guidance for material testing and certification of reused steel components.

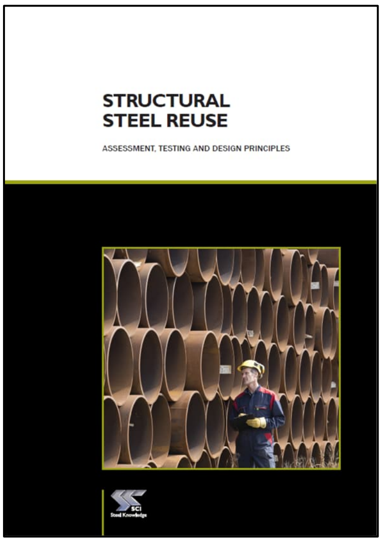
Norwegian Steel Association: Reuse of structural steel and related building materials (2018-2024) [15]

The report by the Norwegian Steel Association (Norsk Stålforbund) called Reuse of structural steel and related building materials analyses the existing European and Norwegian regulations and provides guidance on CE marking of reused steel according to EN 1090-2 [16], reusing coated steel and material testing. The testing protocol describes four procedures:

- Procedure A: Non-destructive testing (spectrometer test and hardness measurement) for products without material certificate and execution class EXC1 (all grades) or EXC2 (<S355)
- Procedure B: Non-destructive and destructive testing (spectrometer, hardness, and tensile testing) for products without material certificate and execution class EXC2 (≥S355) or EXC3 (≥S355)
- Procedure C: Visual inspection of products with material certificate and full traceability
- Procedure D: Spectrometer test of product with material certificate but without full traceability

Version 1.2 of the guidance was published in 2024.

SCI P427: Structural steel reuse, assessment, testing and design principles (2019-2024) [17]



The testing protocol by the Steel Construction Institute recommends data collection, inspection and testing to ensure that reclaimed structural steelwork in UK can be reused with confidence. Certain conservative assumptions about the material characteristics may be made, or testing should be undertaken to determine the properties with greater confidence. The testing protocol includes description on statistical and non-statistical, destructive, and non-destructive testing and the recommended implementation of the results in the Eurocode design. The publication was developed in parallel with the testing protocol published by PROGRESS project Deliverable D2.3 [7]. The second edition of the protocol is currently under development.

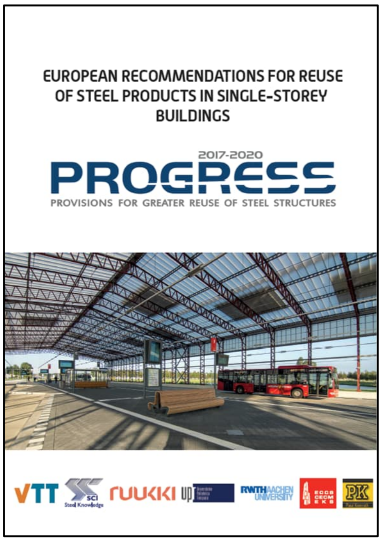
PROGRESS Quality verification protocol (2020) [7]

This protocol recommends data collection, inspection and testing to ensure that reclaimed structural steelwork can be reused with confidence. Certain conservative assumptions about the material characteristics may be made, or testing should be undertaken to determine the properties with greater confidence.

According to this protocol, the reuse of reclaimed structural steel is limited to applications where the reclaimed members were not subjected to fatigue, for example, steelwork from bridges. Reclaimed steel from structures which have experienced extreme loads such as fire or impact are not considered to be suitable for reuse and therefore are not covered by this protocol. Steel used in construction before 1970 is also excluded from these recommendations.

This protocol recommends that steelwork is reclaimed in groups of members that have the same form, size, original function and are from the same source structure. Assembling groups in this way allows certain material properties to be established by testing one or more representative members from the group. Material characteristics declared under CE marking procedures, are designed to ensure that the material is as specified in design. When using reclaimed steel, the design is based on the material properties (either tested or based on conservative assumptions), maintaining the relationship between the design assumptions and material resistance with an adequate level of reliability.

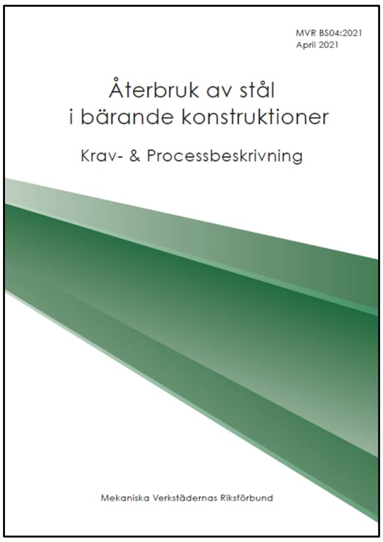
Part 1 of the European recommendations for reuse of steel products in single-storey buildings (2020) [18]



Part 1 of the PROGESS guide provide recommendations for the existing single-storey buildings. It covers steel products produced after 1970 excluding built-up members, fatigue or fire damage or plastic deformations. It focuses on hot-rolled and cold-formed components, and cladding. The testing procedure is in-line with the recommendations of SCI P427 protocol [17] and PROGRESS D2.3 [7].

The guide recommends that re-certified and re-fabricated reclaimed structural steelwork can be CE Marked in accordance with EN 1090-2 [16].

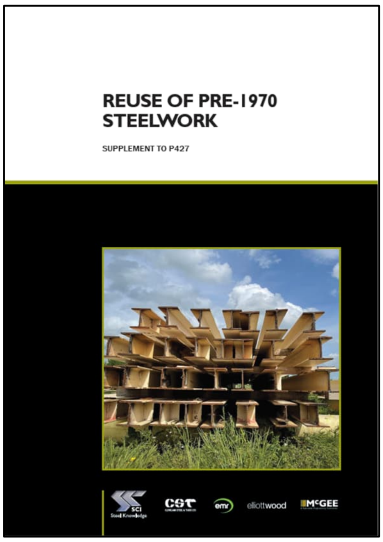
MVR: Reuse of steel in load-bearing structures (2021) [19]



The guidance published by MVR (Mekaniska Verkstädernas Riksförbund) in Sweden covers reuse of steel constituent products produced after 1970 with similar limitations to PROGRESS D6.1 [18] and SCI P427 [17]. The protocol covers execution class EXC1, EXC2 and EXC3 without fatigue and seismic loads or former EX3 reused as a lower class but it is not applicable for cold-formed components and beams with web openings. The testing procedure is divided into four protocols depending on the knowledge about the material properties and its type:

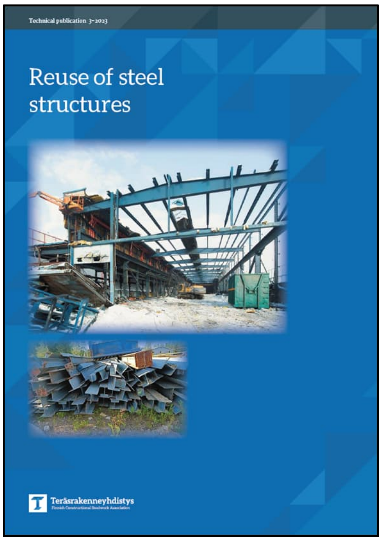
- Protocol A: No testing (only visual inspection) of components having a known provenance, type 1 structural steel with the original inspection documents.
- Protocol B: Testing 1 member of test unit (group) of components having a known provenance, type 1 structural steel without the original inspection documents.
- Protocol C: Testing 3 members of test unit (group) of components having a known provenance.
- Protocol D: Testing all components of steel without any available documentation.

SCI P440: Reuse of pre-1970 steelwork, supplement to P247 (2023) [20]



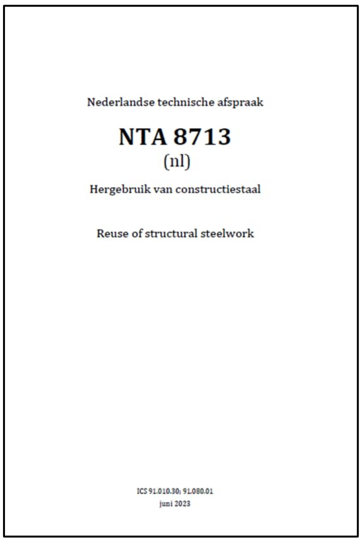
Steel Construction Institute's recommendations of P427 [17] have been extended and modified to cover the verification of pre-1970 steel in accordance with EN 1993-1-1 [21]. The scope of this document is steel used in construction between 1932 and 1970 in UK. The main requirements of P427 still apply unchanged.

FCSA: Reuse of steel structures (2023) [22]



The guide by the Finnish Constructional Steelwork Association (FCSA) is based on the MVR guide [19] and PROGRESS recommendations [7]. It covers topics such as assessment of reusability, planning of deconstruction, material classification and testing, manufacturing aspects, design for reuse or materials passport and circulation platforms. It also presents several case studies.

NTA 8713: Reuse of structural steel (2023) [23]


Nederlandse technische afspraak

NTA 8713

(nl)

Hergebruik van constructiestaal

Reuse of structural steelwork

ICS 91.010.30; 91.080.01

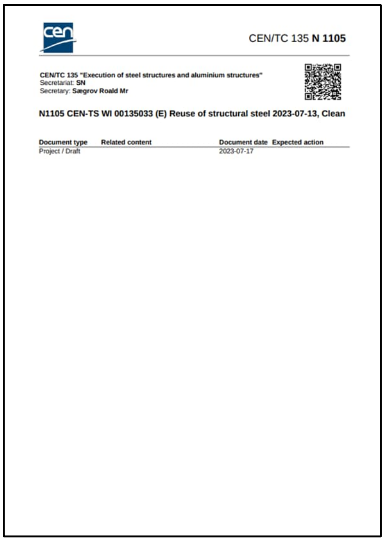
juni 2023

The Dutch technical specification NTA 8713 Hergebruik van constructiestaal describes the procedure to determine the geometric and material properties of steel profiles that are dismantled from a donor building and reused in another structure. The procedure ensures that the suitability of these profiles can be demonstrated with NEN-EN 1993. The purpose is to facilitate the reuse of structural steelwork and reduce the environmental impact of steel structures.

The document specifies the information that needs to be documented before dismantling the steel profiles, such as the original documentation of the building, the inspection documents, the assessment of the tolerances, the visual inspection, and the testing of the material properties and weldability in a building with a certain consequence class.

The specification provides rules and recommendations for the structural design of reused steel profiles, such as the verification of the resistance, stability, and serviceability, and the design of the connections.

CEN/TS WI 135033: Reuse of structural steel (2023) [24]


CEN/TC 135 **N 1105**

CEN/TC 135 "Execution of steel structures and aluminium structures"
Secretariat: SN
Secretary: Sægrov Roald Mr

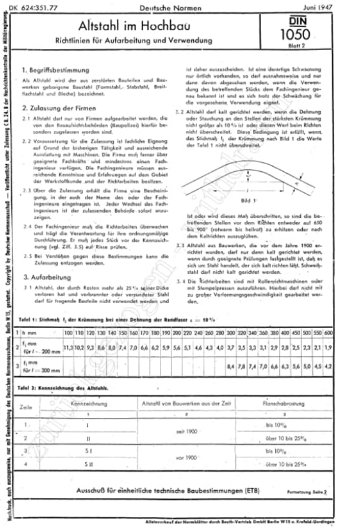
N1105 CEN-TS WI 00135033 (E) Reuse of structural steel 2023-07-13, Clean

Document type	Related content	Document date	Expected action
Project / Draft		2023-07-17	

The Technical Specification was developed by CEN/TC135 to serve as a supplement to EN 1090-2 [16] and provides specific guidance for material testing of constituent products to comply with clause 5.1 of the standard. It is in-line with the general recommendations from PROGRESS project and national guides developed by MVR in Sweden [19] and FCSA in Finland [22]. The detailed description of the testing protocol described in this TS is in Section 5.3.2 of this report.

2.1.5 Labelling and certification of reusable constructional steel

DIN 1050 Sheet 2 Old steel in building construction, guidelines for reconditioning and utilisation (1947) [25]



DK 624:351.77 Deutsche Normen Juni 1947

Altstahl im Hochbau

Richtlinien für Aufarbeitung und Verwendung

DIN 1050 Blatt 2

1. Begriffsbestimmung

Als Altstahl wird der aus zerstörten Bauteilen und Bauwerken geborgene Baustahl (Formstahl, Stabstahl, Breitflachstahl und Bleche) bezeichnet.

2. Zulassung der Firmen

2.1 Altstahl darf nur von Firmen aufgearbeitet werden, die von den Bauaufsichtsbehörden (Baupolizei) hierfür besonders zugelassen worden sind.

2.2 Voraussetzung für die Zulassung ist fachliche Eignung auf Grund der bisherigen Tätigkeit und ausreichende Ausstattung mit Maschinen. Die Firma muß ferner über geeignete Fachkräfte und mindestens einen Fachingenieur verfügen. Die Fachingenieure müssen ausreichende Kenntnisse und Erfahrungen auf dem Gebiet der Werkstoffkunde und der Richtarbeiten besitzen.

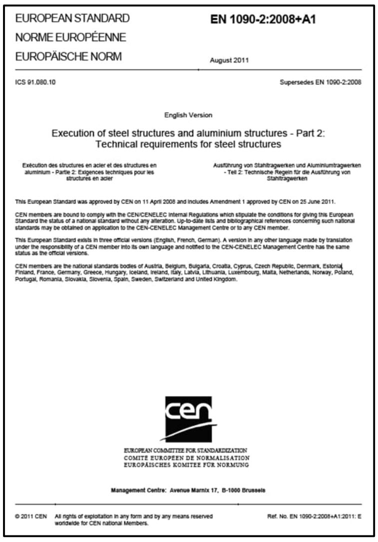
3. Aufarbeitung

Ausschuß für einheitliche technische Baubestimmungen (ETB)

The scarcity of new constructional steel in Germany in 1947 led to the development of the first rules for the assessment and marking of steel components extracted from the destroyed buildings. The steel could be used in buildings with predominantly static loads and must be marked with a certain label. The marking contains information about

- company
- specialist engineer supervising extraction and processing
- steel class depending on the degree of flange rusting (class I with rusting below 10%, class II 10-25% rusting and cross-section resistance reduced to 80%)
- material age (steel older than 1900 was marked with “S” letter)

CEN/EN 1090-2 Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures (2008-2018) [16]



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1090-2:2008+A1

August 2011

ICS 91.080.10

Supersedes EN 1090-2:2008

English Version

Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures

Exécution des structures en acier et des structures en aluminium - Partie 2: Exigences techniques pour les structures en acier

Ausführung von Stahltragwerken und Aluminiumtragwerken - Teil 2: Technische Regeln für die Ausführung von Stahltragwerken

This European Standard was approved by CEN on 11 April 2008 and includes Amendment 1 approved by CEN on 25 June 2011.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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Ref. No. EN 1090-2:2008+A1:2011: E

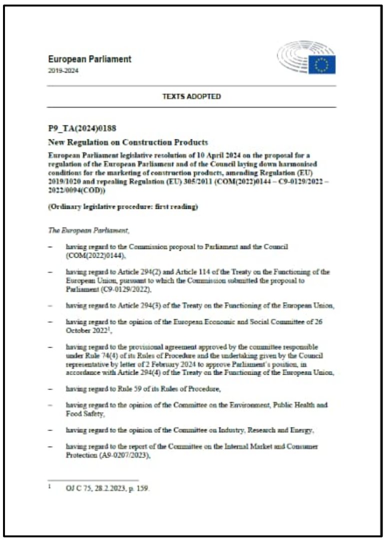
EN 1090 covers structural steel and aluminium products that are installed in a permanent manner. As a harmonised standards it can be used to prove that the products comply with the technical requirements of the relevant EU law, in this case Construction Products Regulation. Therefore, it is used for obtaining CE certification of the constructional steelwork. Part 2 of EN 1090 introduces a possibility to use reused or generally unknown constituent products in the execution of steel structures in Clause 5.1:

“Generally, constituent products to be used for the execution of steel structures shall be selected from the relevant European Standards listed in the following clauses. If constituent products that are not covered by the standards listed are to be used, their properties shall be specified. “

The text was updated in 2018 and the current version of the standard extends the clause with the list of relevant properties to be specified: *strength (yield and tensile), elongation, stress reduction of area requirements (STRA if required), tolerances on dimensions and shape, impact strength or toughness (if required), heat treatment delivery condition, through thickness requirements (Z-quality if required) and limits on internal discontinuities or cracks in zones to be welded (if required)*. Additional information for welds shall be provided such as: *classification in accordance with the materials grouping system defined in CEN ISO/TR 15608 or a maximum limit for the carbon equivalent of the steel, or a declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated.*

CEN/TC135 recently recognized the need for more detailed specification of the testing procedure for reused material and developed TS WI 135033 [24] that is discussed in this section separately.

Construction Products Regulation (2011-2024) [26]



European Parliament
2019-2024

TEXTS ADOPTED

P9_TA(2024)0188

New Regulation on Construction Products

European Parliament legislative resolution of 10 April 2024 on the proposal for a regulation of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011 (COM(2022)0144 – C9-0129/2022 – 2022/0094(COD))

(Ordinary legislative procedure: first reading)

The European Parliament,

– having regard to the Commission proposal to Parliament and the Council (COM(2022)0144),

– having regard to Article 294(2) and Article 114 of the Treaty on the Functioning of the European Union, pursuant to which the Commission submitted the proposal to Parliament (C9-0129/2022),

– having regard to Article 294(3) of the Treaty on the Functioning of the European Union,

– having regard to the opinion of the European Economic and Social Committee of 26 October 2022[1],

– having regard to the provisional agreement approved by the committee responsible under Rule 74(4) of its Rules of Procedure and the undertaking given by the Council representative by letter of 2 February 2024 to approve Parliament's position, in accordance with Article 294(4) of the Treaty on the Functioning of the European Union,

– having regard to Rule 59 of its Rules of Procedure,

– having regard to the opinion of the Committee on the Environment, Public Health and Food Safety,

– having regard to the opinion of the Committee on Industry, Research and Energy,

– having regard to the report of the Committee on the Internal Market and Consumer Protection (A9-0207/2023),

1 OJ C 75, 28.2.2023, p. 159.

Th European Parliament adapted the reviewed text of Regulation (EU) No 305/2011 (Construction Products Regulation, CPR) in April 2024 [27]. The purpose of the regulation is to harmonise conditions for the marketing of construction products and to remove obstacles to trade in construction products between Member States. The new CPR applies to all construction products and kits, including the used and remanufactured ones, according to the following definitions:

- ‘used product’ means a product that is not waste or has ceased to be waste in accordance with Waste Framework Directive [28], and which has been installed at least once into a construction work, and that has not undergone a major alteration affecting its performance,
- 'remanufactured product' means a product that is not waste or has ceased to be waste, which has been installed at least once into a construction work, and that has undergone major alteration affecting its performance.

The standardisation request shall be explicit about whether it covers or excludes used products from the scope of the request. The CE marking of used products shall be followed by the two last digits of the year when the product was de-installed followed by the last two digits of the year in which the CE marking was affixed on the used product.

“In view of enhancing the circularity of construction products, in line with the goals of the Circular Economy Action Plan and the waste hierarchy, product requirements should also be able to improve resource efficiency, prevent waste generation, prioritise repair, reuse and remanufacturing, favour the use of secondary materials and address the recyclability of the product and the production of by-products. Preparing for re-use, reuse, remanufacturing and recycling require certain design, namely by facilitating the separation of products, components and materials at de-installation, deconstruction and demolition and at the later stage of recycling and, when possible, avoiding mixed, blended or intricate materials and substances of concern. As the usual instructions for use and safety information will not necessarily reach the economic operators in charge of preparing for re-use, re-use, remanufacturing and recycling, the necessary information in this regard should be made available in product passports accessible through data carriers and in manufacturer’s websites.”

2.2 Design for future reuse

The aim of the designers should be to provide possibility for as many of the structural components and materials as possible to be either reused or recycled for reuse at a later stage of the building. The buildings shall design to be easily dismantled, with the different components and materials clearly separated, separable and sortable. The reusability can be improved by taking the following measures into account:

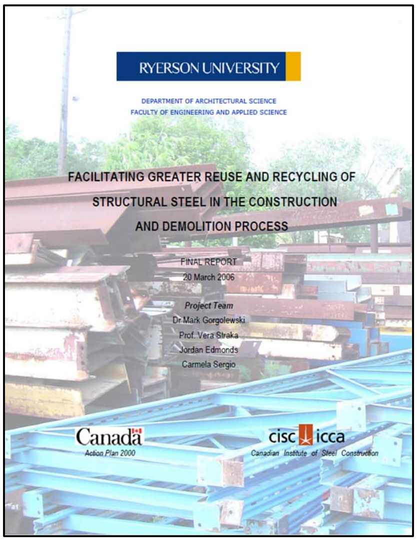
- modularity of the structural system and choice of spans;
- choice of structural components (e.g. material, durability, service life);
- design of the dismantling and reassembly of structural elements joints;
- selection of recyclable materials;
- structural design for long service life (e.g. flexible adaptability, durability, maintainability).

In steel structures, reusability can be further promoted by:

- preference for bolted connections;
- clear and simple structural components and joints;
- the corrosion protection treatment is such that it can be renewed or repaired.

The guides developed by MVR [19], FCSA [22] and PROGRESS project [18] introduced in the previous section provide recommendations for new buildings as well as for the existing steel. In the case of new buildings, the focus is mostly on demonstrating improved reusability through structural detailing and overall considerations about the modularity and repeatability of components and materials used. Documented case studies can guide architects and structural designers through the early stages of project development. Examples of innovative dismountable connectors can inspire steelwork manufacturers or specialised fabricators to introduce solutions suitable for many similar projects.

Facilitating Greater Reuse and Recycling of Structural Steel in the Construction and Demolition Process, final report (2006)



This project developed a greater understanding of the materials flows in the steel construction industry and used this knowledge to provide tools that facilitate greater reuse and recycling of steel components.

The report contains information paper addressing the issues related to design for future reuse. It shows that the ease of deconstruction is affected by the building systems and technologies used, and availability of relevant documentation and information. Appropriate use of technologies and their successful integration into the design process will facilitate an increased reuse of structural steel components.

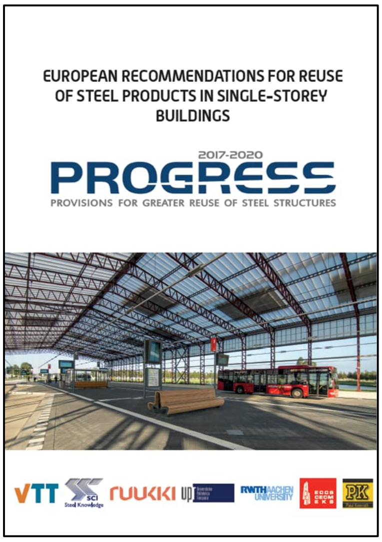
Sustainable building project in steel (SB STEEL) final report (2015) [29]

The decisions leading to the design and development of steel structure optimized for sustainability are mapped in the final report of SB STEEL project.

Two fundamentally different design approaches from the project can be described as ‘the Performance Approach’ and ‘the extended LCA’. Both refer to setting and managing objectives of a building project and to various software tools. In the Performance-based design, the criteria are built up holistically. In the extended LCA, the environmental assessment methodology is the basis to which the performance (‘functionality’) issues are added. Furthermore, they involve requirement of integrated design from the very beginning of a new building project.

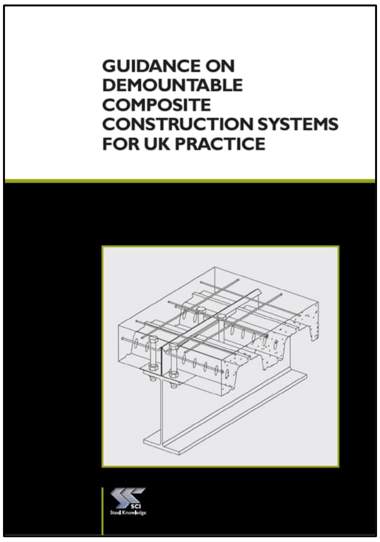
Use of open systems and fast dismountable connections were listed among the key elements of sustainable steel design.

Part 2 of the European recommendations for reuse of steel products in single-storey buildings (2020) [18]



Part 2 of the PROGRESS guide provides recommendations for designing new single-storey steel buildings with the goals of functionality, fabrication cost, demountability and future reuse, and aesthetics. The guide outlines the general principles for design for disassembly and reuse of steelwork, such as using standardised and modular components, minimising the number of connections, choosing reversible and adjustable connections, and documenting the building information. It summarises the recommended design procedures and improvements in construction details that facilitate future reuse, such as avoiding welding and cutting, using bolted cleats and end plates, using open sections or hollow sections with simple geometry, and avoiding composite action with concrete. The guide also discusses the design of the primary structure (framing system, load combinations, stability and robustness requirements, and the design of members and joints) and the design of the secondary structure (purlins, side rails, and cladding systems). The considerations for their reuse potential, such as the durability, thermal performance, and fire resistance are also covered. Finally, the guide addresses the design of the building envelope, including the selection of cladding materials and systems, the thermal and acoustic insulation, the fire protection, and the ventilation and air tightness.

SCI P428: Guidance on demountable composite construction systems for UK practice (2020) [30]



Several more specific guides are already available, such as SCI publication P428, “Guidance on demountable composite construction systems for UK practice”. This document summarizes findings from the RFCS project REDUCE (Reuse and demountability using steel structures and the circular economy) and presents an approach for designing reusable steel-concrete composite structures. It outlines general design requirements for demountable composite construction, a design procedure for composite beams with demountable shear connectors and includes worked examples. The design is based on the principles of Eurocode 4 (BS EN 1994-1-1) and considers the different characteristics of demountable shear connectors regarding their shear resistance, stiffness, ductility, and the requirements to maximize reuse potential. Possible reuse scenarios and alternative demountable shear connection systems are also discussed.

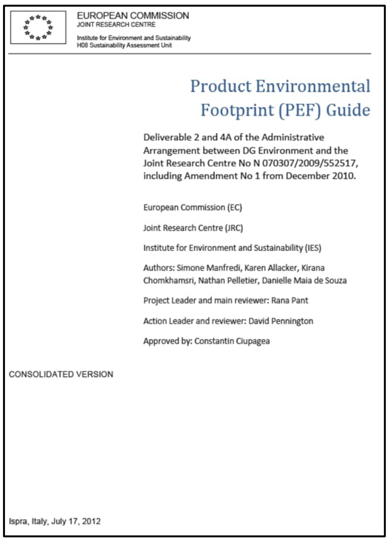
2.3 Sustainability assessment

Reuse of components or entire structures is the most efficient form of material recovery and can be seen as waste prevention or high-level recycling. It offers additional environmental and economic advantages, when compared to other recycling options, but often requires higher initial investment costs. Therefore, to support incentives for reused and reusable steel projects, robust and reliable metrics is needed to declare those impacts. The most common method of assessment of environmental impacts is lifecycle assessment (LCA) following ISO 14044 [33]. The effect of reuse can be then followed in LCA calculations in the product stage in the case of reclaimed steel as the source of material for the assessed building or product or end-of-life stage when the impacts of different actions related to deconstruction and reconditioning of the reusable steelwork are declared. This is typically straightforward process following the well-established LCA practices.

However, the assessment of the benefits of the future reuse is more complex because such benefits do not directly appear in the calculated lifecycle but will be possible afterwards when the reused components may substitute energy intensive steelwork production. The following overview will focus on the calculation methods for expressing the benefits (or loads) of future reuse and selected specific practices for the calculation of impacts of reused elements.

2.3.1 Lifecycle assessment

<u>Product Environmental Footprint (2006) [31]</u>



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Institute for Environment and Sustainability
H08 Sustainability Assessment Unit

Product Environmental Footprint (PEF) Guide

Deliverable 2 and 4A of the Administrative Arrangement between DG Environment and the Joint Research Centre No N 070307/2009/552517, including Amendment No 1 from December 2010.

European Commission (EC)

Joint Research Centre (JRC)

Institute for Environment and Sustainability (IES)

Authors: Simone Manfredi, Karen Allacker, Kirana Chomkhamsri, Nathan Pelletier, Danielle Maia de Souza

Project Leader and main reviewer: Rana Pant

Action Leader and reviewer: David Pennington

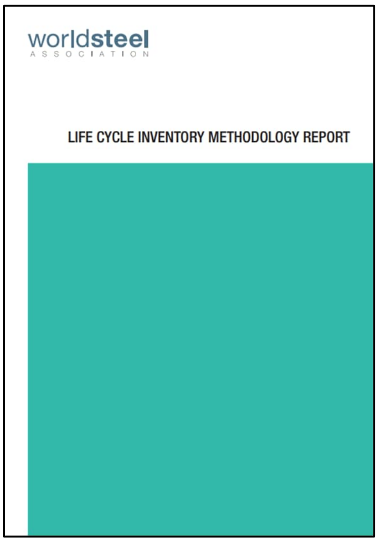
Approved by: Constantin Ciupagea

CONSOLIDATED VERSION

Ispra, Italy, July 17, 2012

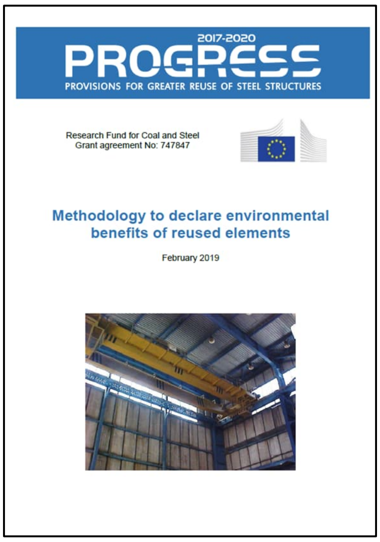
The methodology for declaration of Product Environmental Footprint (PEF) can consider multiple recycling options, and therefore it is suitable for expressing benefits of steel reuse, which is often happening together with recycling of the non-reusable material. The disadvantage of PEF methodology is that the loads and benefits of future recycling and reuse are aggregated together with the impacts of the current lifecycle, and therefore it is difficult or even impossible to distinguish between reuse of existing steel and the design for the future reuse.

World Steel Association's LCI methodology (2008-2017) [32]



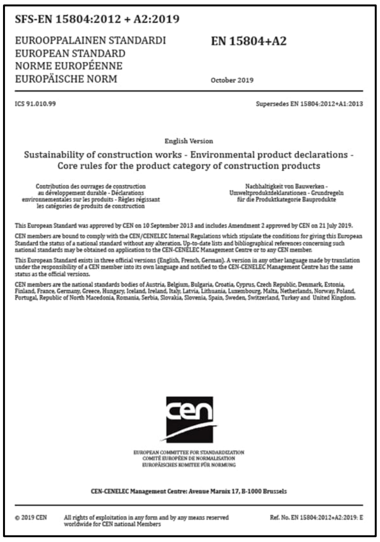
Because of the well-established recycling process for steel products, the World Steel Association provided detailed methodology for declaration of future benefits of recycled steel. This methodology is based on ISO 14044 [33] closed-loop allocation procedure. However, it does not account for component reuse and the revised methodology is being prepared by the World Steel Association.

PROGRESS Methodology to declare environmental benefits of reused elements (2019) [34]



The methodology developed in PROGRESS project extended the World Steel Association's formula [32] by adding the assessment of reuse flow in parallel to the recycling according to the PEF methodology [31]. It was demonstrated that both methods yield the same result. The closed-loop allocation procedure was recommended also for reuse process with the assumption that the material quality does not deteriorate over time and the product can be always refurbished or recycled as scrap.

CEN/EN 15804+A2 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (2019) [35]



SFS-EN 15804:2012 + A2:2019

EUROOPPALAINEN STANDARDI
EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 15804+A2

October 2019

ICS 91.010.99

Supersedes EN 15804:2012+A1:2013

English Version

Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products

Contribution des ouvrages de construction au développement durable - Déclarations environnementales sur les produits - Règles régissant les catégories de produits de construction

Nachhaltigkeit von Bauwerken - Umweltproduktdeklarationen - Grundregeln für die Produktkategorie Bauprodukte

This European Standard was approved by CEN on 10 September 2013 and includes Amendment 2 approved by CEN on 21 July 2019.

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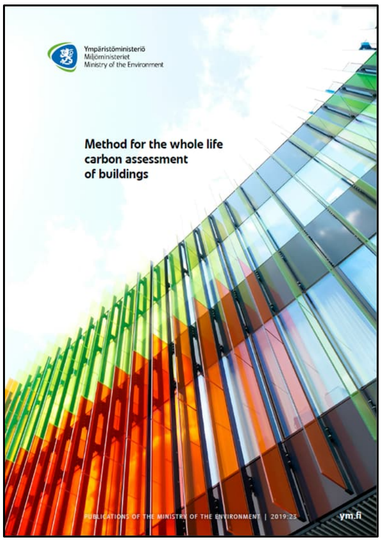
Ref. No. EN 15804:2012+A2:2019: E

Annex D of the standard introduces the calculation of loads and benefits beyond the system boundary (Module D) when more than one recycling or reuse operations are considered at the end of the product's life. This calculation does not consider yield of the recycling process according to the World Steel Association's method, but otherwise it was demonstrated to be compatible with PEF [31] and PROGRESS [34] methodologies.

Finnish Ministry of the Environment: Method for the whole life carbon assessment of buildings (2019) [36]



This publication describes a method employed in Finland for the whole life carbon assessment of buildings based on the European Commission's Level(s) method and European Standards.

A carbon footprint analysis covers a building's entire life cycle including manufacture and transportation of the products, the use and maintenance of the building, its demolition, and recycling. According to the methodology, preparation for reuse or other manufacturing impacts of reused components are excluded from the carbon footprint calculation.

The carbon handprint analysis incorporates the net benefits of climate impact that would not arise if there were no construction project. These are for instance be the benefits gained from the reuse and recycling of the construction products. The calculation of those benefits follows rules from EN 15804+A2 [35].

French environmental regulation RE 2020 (2021) [37]

The French environmental regulation (La réglementation environnementale) RE2020 (Decree of 4 August 2021) stipulate that "*Components (construction products or equipment) resulting from reuse or a reuse operation are considered to have no impact. The impact values for all life cycle modules are therefore zero.*"

CEN/prEN 17662 Execution of steel structures and aluminium structures - Environmental Product Declarations - Product category rules complementary to EN 15804 for Steel, Iron and Aluminium structural products for use in construction works (2023) [38]

Annex F of the proposed standard extends the calculation from Annex D of EN 15804 [35] with the implementation of World Steel Association's yield factor and demonstrates the calculation of simultaneous recycling and reuse. It is in-line with PROGRESS methodology [34], but the recommended allocation procedure for reused products is open-loop. We show in ADVANCE project that both approaches are possible and produce the same results [39].

ADVANCE Environmental assessment of constructional steel reuse (2024) [39]

The report produced in ADVANCE project describes a simple methodology to account reuse, in addition to recycling, in LCA calculations for constructional steel. The method is based on PROGRESS methodology [34] and can be regarded as an extension of the Worldsteel Association's methodology [32] compatible with the CEN/TC 350 standards [35] and PEF Circular Footprint Formula [31]. The methodology is demonstrated in several calculation examples, where the different choices of recycling, reusing and disposal are selected. The method is suitable for individual projects such as buildings specifically designed to be reused. However, it can also highlight the benefits of product categories with substantial rate of reuse, for instance in the Environmental Product Declarations.

2.3.2 Assessment of circularity

The circular economy represents a shift from traditional linear business models, where products are made from raw materials and discarded after their useful life, to circular business models that emphasize smart design. In these models, products and their components are designed for repair, reuse, return, and recycling. To support this, products must be durable, easy to repair, and ultimately recyclable. The costs associated with reusing, repairing, or remanufacturing products need to be competitive to promote these practices. Simply replacing a product with a new one should no longer be the standard approach. Due to a large interest in the assessment and quantification of the circularity, a wide range of circularity indicators has been developed in recent years [41]. The new standard ISO 59020 [42] aims at harmonization of understanding of these metrics. The most relevant indicators for the reuse of constructional steel are presented in detail in this section.

Circularity in construction is based on three main principles:

- Durability: Planning the service life of buildings and their elements to ensure long-lasting structures.
- Adaptability: Extending the overall service life of buildings, reducing waste, and facilitating efficient waste management.
- High-Quality Waste Management: Promoting the future circular use of building elements, components, and parts. This includes minimizing waste and enhancing the potential for reuse or high-quality recycling of major building elements after deconstruction.

Another important aspect is the traceability of elements, crucial element of circularity in the construction industry, allowing for the identification and tracking of materials and products throughout their lifecycle.

The steel construction industry has significant competitive advantages over competing materials. Four keywords define these advantages, i.e. reduce, reuse, remanufacture, recycle.

European Framework for Sustainable Buildings, Level(s) [43]

Level(s) is a framework of core indicators of sustainability and circularity that can be applied to building projects to report on and improve their performance. The Level(s) indicators, related to circularity are:

- Indicator 2.1: Bill of quantities, materials, and lifespans [44]. The idea is to allocate specific lifetimes to each building element, relative to the planned lifetime of the building. Separating components into distinct layers is essential for accommodating the varied life cycles of building systems and materials. This approach contributes to the development of structures that are more technically and socially adaptable and responsible. Steel constructions offer extended durability compared to competing materials. Moreover, steel bring great benefits in hybrid or composite solutions, in conjunction with indicators 2.3 and 2.4.
- Indicator 2.2: Construction and demolition waste [45]. A systematically plan can be developed for the reuse and recovery of materials, through segregated collection during construction, renovation and demolition activities. For the case of steel structures deconstruction and future reuse at different levels (constituent products, elements, whole structure) represent a great benefit.
- Indicator 2.3: Design for adaptability and renovation [46]. It involves designing buildings to be adaptable and flexible to changing markets and occupier needs, thereby extending their useful life. It can help users to achieve significant environmental benefits through extending the useful life of buildings, including their structures and facades, which are associated with the most pronounced environmental impacts. A scoring and weighting system for adaptability design aspects can be developed. Increased span and free height in steel or hybrid/composite steel construction allow for the integration of utilities and services, as well as the use of movable partitions to configure spaces, leading to higher scores.
- Indicator 2.4: Design for deconstruction [47]. From the design stage, Level(s) supports professionals to embed reuse and recycling plans into the building project from the start, for example by defining steps and measures to simplify the separation of materials at each life cycle stage. By circular approaches to the use of materials, they can reduce the construction sector’s embodied life cycle impact and natural resource consumption. In the case of steel structures, easily building materials are reused and recycled in a variety of scenarios. In the case of hybrid or composite systems that follow "Design for Disassembly and Reuse (DfDR)" principles enable reuse or recover of materials when the building reaches its end of life.
  The outcomes that are considered in the indicator 2.4 calculator are generally aligned with the waste hierarchy set out in the Waste Framework Directive and are as follows, in order of best outcome first:
  - Direct reuse (circularity coefficient = 1.00);
  - Preparing for reuse (circularity coefficient = 0.90);
  - Pure stream recycling (circularity coefficient = 0.75);
  - Mixed stream recycling (circularity coefficient = 0.50);
  - Material recovery (circularity coefficient = 0.25);
  - Energy recovery (circularity coefficient = 0.15);
  - Inert or non-hazardous landfill (circularity coefficient = 0.01);
  - Hazardous waste disposal (circularity coefficient = 0.00).

BRE design for deconstruction (DfD) methodology [40]

The methodology developed by Building Research Establishment (BRE) in UK with the support of BRE Trust provides criteria to assess the deconstruction potential of new residential building designs. Besides residential construction, the method was used for office buildings and other types of structures. The method considers four criteria (performance categories) and nine groups of components (see Table 1). The scoring for each element/component and criteria is 0 (not considered), 0.5 (partially considered) or 1 (fully considered in the design) and the elements are weighted according to their embodied CO_2 to achieve the overall score.

Table 1. Basic parameters of BRE methodology

Component groups	Performance criteria	Scoring levels
• Foundations and floors • External walls • Internal walls • Other floors • Roof • Windows and doors • Floor finishes • Building services • Sanitary ware	• Reuse and recycling potential • Connections between the elements and components • Accessibility of elements and components • Deconstruction process	• not considered (0.0) • partially considered (0.5) • fully considered (1.0)

The following observations were made concerning the possible adaptation of BRE assessment method on the steel single-storey buildings:

- The choice of element groups limits the methodology to residential and similar buildings with clearly distinguishable roof and external walls.
- Weighting according to the embodied CO_2 is appropriate for the buildings with a large variety of building materials but requires additional effort for the evaluator to obtain these values. In the case of structural steelwork assessment, it would be sufficient to use masses of the components as the weighting factors.
- The economic value of the recovered elements is also not included, the methodology being focuses on technological aspects of “deconstructability”.

PROGRESS reusability index [48]

A new methodology for assessing constructional steel reusability was proposed in PROGRESS project. The reusability assessment consists of technical and economic indexes, which can be used independently or combined into a single score. The technical part is then combined from results of structural kits, their sub-assemblies and individual components as a weighted average related to their mass and the reusability assessment provided by an expert in the prepared scoring sheet. The methodology is simple and transparent; however, it requires different scoring sheets for different types of products and buildings. Moreover, extension to multi-material components or assemblies will have to be based on some environmental criteria (e.g. embodied CO_2e) instead of their mass.

Material Circularity Indicator (MCI) tool [49]

The Material Circularity Indicator (MCI) tool, part of a broader 'Circular Indicators Project' developed by The Ellen MacArthur Foundation and Granta Design, allows companies to identify additional, circular value from their products and materials, and mitigate risks from material price volatility and material supply. Integrated with the MI:Product Intelligence package, MCI enables users to analyse and evaluate a range of environmental, regulatory, and supply chain risks for their designs and products.

At the product level, the indicators can be used in the design of new products to take circularity into account as a criterion and input for design decisions. The indicators allow for comparing different versions ('what if' scenarios) of a product regarding its circularity at the design level. They could also be used to set minimum circularity criteria for designers. This can apply to new products as well as the further development of products with the aim to make them more circular.

Any product that is manufactured using only virgin feedstock and ends up in landfill at the end of its use phase can be considered a fully 'linear' product. On the other hand, any product that contains no virgin feedstock, is completely collected for recycling or component reuse, and where the recycling efficiency is 100% can be considered a fully 'circular' product. In practice, products will sit somewhere between these two extremes and the MCI measures the level of circularity in the range 0 to 1.

MCI provides an indication of how much a product's materials circulate. It neither considers what these materials are, nor does it provide information on other impacts of the product. As additional support to decision making, this methodology therefore recommends an approach to prioritise product improvements by using the MCI in combination with complementary indicators to identify relevant risks and impacts.

Buildings As Material Banks (BAMB) [50]

Buildings have traditionally been valued based on their floor area, the location and land area they sit on, architectural features and the use that can be made of the building. However, there is also a residual value that is locked into a building via the components and materials it is made of. This locked-in value (often viewed solely as a future demolition and disposal cost) is maximised when these components and materials can be adequately retrieved at the end-of-life of the building for reuse.

This BAMB concept is relevant to all buildings but can be especially incorporated into the design of new buildings or in the definition of major renovation activities. By choosing elements and components that can be disassembled, and by providing clear instructions about their correct disassembly via building material passports, the possibility to reuse that material or element is maximised. The level of information for each product could include the product features, reuse/recycling potential and visual details of the building element or material. This principle can underpin the "circularity" of the whole building as well.

2.3.3 Sustainability certification schemes

BREEAM [51]

The BREEAM (Building Research Establishment Environmental Assessment Method) is considered the oldest method of assessing, rating and certifying the sustainability of buildings. It was first published by the Building Research Establishment in 1990s. The BREEAM scheme rewards the reuse of building components in several ways:

- BREEAM promotes resource efficiency and encourages the reuse and recycling of materials that are already on site. By providing baseline targets, with contractors monitoring and recording waste quantities, the cost in relation to the quantity of materials ordered and waste transfer is minimized.
- Although projects that choose to remove and dispose of reusable or recyclable products will not be penalized by the resulting demolition, transport, processing, and disposal (impacts which belong to the end-of-life of the previous building), reuse is still significantly incentivized by avoiding the A1 to A4 (all or in part) and stage C impacts that would result from using products from other sources.
- BREEAM provides guidance on how to sustainably refurbish a domestic property, which includes the use of sustainable materials, avoidance and management of waste, and energy efficiency measures

LEED [52]

The LEED (Leadership in Energy and Environmental Design) sustainability scheme by U.S. Green Building Council is the most widely used green building rating system in the world. It encourages the reuse of materials and components in several ways:

- It is possible to obtain credits for projects that reuse materials, thereby reducing the demand for new materials and minimizing the amounts of old materials that end up in landfills.
- LEED encourages the preservation and reuse of existing building structures and shells, which can significantly reduce the environmental impact associated with new construction.
- The use of recycled and recyclable materials in construction is promoted, which can help to conserve natural resources.
- LEED rewards innovative strategies that promote sustainability beyond the standard credit categories, which can include unique approaches to design for reuse.

DGNB

The German Sustainable Building Council (DGNB) has several criteria catalogues for assessing the sustainability of buildings. The DGNB Criteria for New Buildings and the DGNB Criteria for Deconstruction are of interest for deconstruction. They are described in detail in Deliverable D4.1 of ADVANCE project [39].

Green Star [53]

The Green Star rating system was established by the Green Building Council of Australia in 2003. The system sets the standard for creating healthy, resilient, and environmentally-friendly buildings and spaces. The Responsible Products credits in Green Star award points for the use of products and materials that are certified by recognized initiatives. This encourages the use of sustainable and reusable materials in construction by several strategies such as prioritizing reuse over recycling, fostering supply and demand, acknowledging unique characteristics of reclaimed material or recognizing extra benefits of reuse.

CASBEE [54]

The Comprehensive Assessment System for Built Environment Efficiency (CASBEE) was developed by a research committee established in 2001 through the collaboration of academia, industry, and national and local governments, which established the Japan Sustainable Building Consortium (JSBC) under the auspice of the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). CASBEE is a method for evaluating and rating the environmental performance of buildings and the built environment.

While the method itself does not explicitly mention the reward for reuse of components, the principle of reducing life-cycle resource use and environmental loads associated with the built environment is inherent in its design. This implies that strategies such as the reuse of components, which contribute to these goals, would be positively evaluated. However, it's important to note that the specific mechanisms for rewarding reuse might vary depending on the implementation of the CASBEE method and the specific criteria used in the assessment.

Nordic Swan Ecolabel [55]

Nordic Swan Ecolabel was founded in the end of 1980's, by the decision of Nordic Minister Council. Products and services using the Swan Ecolabel are fulfilling tight environmental requirements, which are based on life cycle approach. This considers e.g., the origin of raw materials, the energy consumption of production and use of the products, use of chemicals, and waste formation during the whole production and consumption chains. The Nordic board of Swan Ecolabel makes the decisions of which product groups will be covered by this label, and what are the criteria for them.

One of the main topics of the Ecolabel is construction. The criteria ensure the buildings and construction products to be environmentally friendly for the whole life cycle. So far, no steel products seem to be on the list in any Nordic countries. The criteria are very strict and are updated every five years according to the latest research and development.

According to several studies, the costs of certified buildings are not always rising compared to normal buildings. In March 2024, new criteria for Swan Ecolabel regarding repair and renovation of buildings, was published. A proposal for Swan Ecolabel criteria regarding maintenance of buildings, is now (in May 2024) on circulation for comments.

SBToolCZ [56]

SBToolCZ is a national Czech certification tool for expressing the quality level of buildings, in accordance with the principles of sustainable construction. The certification process was officially introduced and put into operation in June 2010. UCEEB was involved in the development of the updated methodology to be published in 2022 and the further development of new variants of the tool.

The tool contains a set of criteria from the field of sustainable construction. Each criterion has a scoring system, which is based on the research and respects local practices and legislation. The evaluation of criteria is supported by a panel of experts, when the resulting quality level is determined based on the number of points received.

CESBA [57]

CESBA stands for Common European Sustainable Building Assessment. It is a collective European initiative that aligns with the objectives of the European Commission. It represents a bottom-up initiative towards promoting a harmonization of sustainable building assessment throughout Europe.

This initiative is designed to make the quality of the built environment comparable and improve the control of the quality of buildings. CESBA is not a new assessment scheme and is not in competition with other certification systems but promotes low-cost, mass-oriented, operable certification processes.

The aim of CESBA is to allow businesses, governments, and users to be more conscious of the opportunities and environmental improvement promises related to sustainable buildings and to reach 100% certified buildings in 2030.

3. Case studies

The following section presents the overview of selected case studies documented in ADVANCE project (see Annex B), several past projects such as PROGRESS [58], Stee-reuse [59] and DISRUPT [60], specialized company websites [61][65] and other literature [62][63][64].

3.1 Relocation of industrial halls and warehouses

The most common single-storey steel buildings are industrial halls and warehouses. Their primary structure typically consists of portal frames (welded or hot-rolled) or girders on columns assembled with bolted connections. Such structures can be easily disassembled and erected in a different place without major structural interventions. Several examples

SEGRO warehouse, Slough, UK

The warehouse building from 2000 was relocated in a different layout in 2015 to enable the construction of a new road bridge. The original brick cladding was replaced by a new composite wall system. [58]

Agrocolumna warehouse, Copăceni, Romania

The building was erected in 2004 in Craiova, consisting of a two-storey office area and a warehouse. In 2012, it was moved to Copăceni (227 km east of Craiova) and one more bay was added to the warehouse [58].

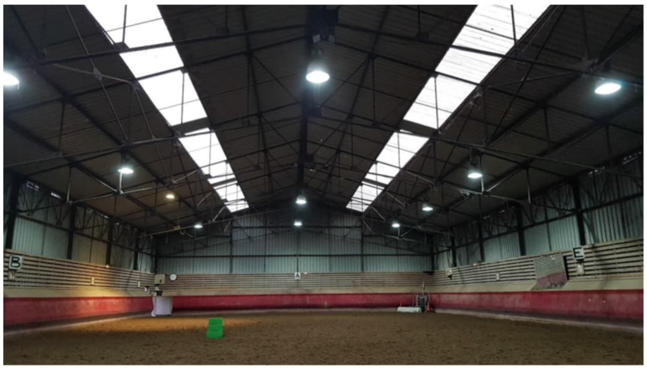
Metis canopy, Otočcu, Croatia

The original structure was erected in Pula and was relocated for reuse in 2011 in Otočcu, 266 km away [58].

Production hall, Argeş county, Romania

The construction was redesigned and built in 2004, in Romania, based on a project and an existing steel structure relocated from the USA. The building is a single-story building with 36.2 m × 43.4 m plan dimensions. The structure is three spans of approx. 12 m each and 6 bays of 6.78 m and 7.62 m and a height of 8.5 m.

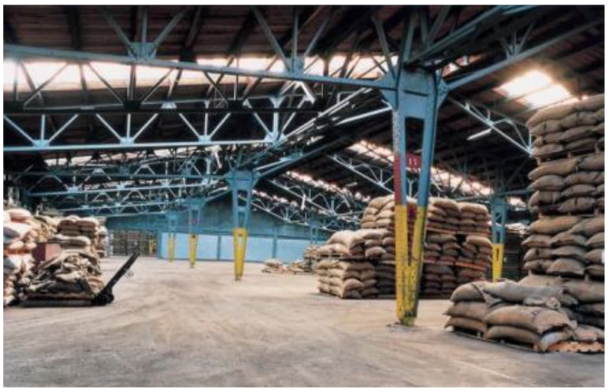
Indoor riding arena, Gennevilier, France



The original building from 1970s was deconstructed and inspected in 2023. Based on the inspection and risk analysis, it was decided that nearly the whole structure can be reused. It will be re-assebled and reused as canopy for a waste sorting centre in Epinal, France (see Annex B).

West harbour, Helsinki, Finland

The od warehouse from the West harbour in Helsinki was relocated without disassembly using cranes because of the short distance. The building was then reused as the terminal building. [61]



Braziliëloods shopping centre, Amsterdam, Netherlands

The steel warehouse was dismantled to its original components in the late 90s after 80 years of service. The structure was recoated and reused. [64]

Honda Warehouse, Swindon, UK

Originally erected on Honda's Swindon site in 2001, this 10,300 sq. ft. steel warehouse building was dismantled in 2004 and put into storage. After 18 months, in September 2005, the structure was re-erected, at a different location on the same Swindon site. All the main frame structural steelwork was re-used including column base plates, as were all the cold rolled items. Unfortunately, changes to various aspects of the building codes, and the change of use for the building, meant that the original cladding system could not be reused. [63]

3.2 Relocation and conversion of old hangars

The extensive use of airships and airplanes during the 20th century wars in Europe means that the large hangar structures were abandoned in the post-war periods and some of them could be converted into civilian use.

Bus station Schiphol – Nord, Amsterdam, Netherlands

The original building was erected in 1958 and was used as a hangar by the Rotterdam Airport until the late nineties. In 2003, the structure was reused as a hangar for seven years by the Rotterdam Detention Center. In 2015, it was reused again as a bus station in Schiphol. [58]

BRE test facility, Cardington, UK

Two sheds in Cardington were converted from hangars for building zeppelins in wartime. No. 2 shed owned by BRE was initially erected in Pulham but was moved to Cardington in 1928. The entire 3270 tonne steel structure was dismantled and reassembled. [62]

3.3 Reuse of other buildings and structures

Hakaniemi Market Hall, Helsinki, Finland

The steel and glass hall in the Hakaniemi Square, Helsinki, operated for 5 years during the renovation of the historical Market Hall. The load-bearing structure of the 2300 m² hall is a steel frame assembled with bolted connections. The facade of the hall consists of glass elements and wood cladding. Deconstruction work was done in nine weeks by Purkupiha. The dismantled parts of hall were carefully protected and transported to Tuuri, a shopping village 350 kilometres to the north of Helsinki. There, the Hakaniemi Glass Hall was given a new life as the village's Fashion Outlet.

S-Market, Urjala, Finland

The owner of the retail stores chain in Finland decided to replace an existing building in Tampere with a new, larger one. At the same time, the need for a new grocery store emerged only 60 km far away creating a perfect opportunity for a relocated reuse. [58]

Sydney Olympics aquatic centre, Sydney, Australia

Temporary seating for the aquatics stadium; deconstructed and re-erected as a permanent grandstand.

3.4 Partial reuse of the primary structure

While relocation and reuse of the entire steelwork is very simple and straightforward process, in many cases, only a certain part of the structure is required in the new design. The following examples show several use cases with reused parts or sub-assemblies of the original primary structure.

NTS building, Thirsk, UK

The original building order was cancelled in 2008 after the fabrication of its steelwork and the elements were stored. Then the fabricated steelwork was divided in four parts and sold in auction. The new building was erected in 2017 by reusing one of the lots from the original building. [58]

Kings Science Academy, Bradford, UK

A new secondary school was built on an existing industrial site on which there were existing portal frame structures. Two portals were retained to create the dining area and kitchen of the new school. Parts of the existing frame needed re-engineering to strengthen it using retaining columns. Although it was a challenging task, by reusing the frame, £10,000 was saved on the project. [63]

Complex of buildings, Sibiu, Romania

A standard kit solution, developed in 2006, in Romania, to build steel structures adaptable for different climatic/seismic conditions and applications, was used in new complex of buildings. The dimensions of the standard kit structure were 6 bays of 6 m, with a single span of 15 m and a height at eaves of 7 m, with the possibility to connect several such kits for longer lengths. Four existing structures of the standard kit, located in various locations were disassembly, re-engineered (some of them including new intermediate floors) and integrated in a new complex of buildings in Sibiu, Romania in 2019. The total value of the economy for the four halls with transverse frames from reused elements was 35000 € (see Annex B).

3.5 Reuse of cladding and secondary structure

The elements of secondary structure and cladding are typically more difficult to reuse, especially if they are not attached to the original primary structure. Examples of such cases are presented in this section.

Mac-Fab Systems department store, Monaghan, Ireland

Steel cladding was reused on a large department store in Monaghan, Ireland. [64]

740 Rue Bel-Air, Montreal, Canada

Roof joists from existing industrial buildings were reused in the construction of a new government building on the same site. [59]

3.6 Reuse of constituent products in multistorey buildings

The structural systems of multistorey residential or commercial buildings are typically not reused in their original layout, but their constituent products (e.g. hot-rolled sections) are separated and reused in the new projects. Reused steel in residential buildings is typical in the UK and other countries with larger share of steel-based multistorey buildings.

Bedzed, London, UK

Temporary works from Brighton railway station, were used in the permanent structure of the mixed-use development in 2002. [59]

55 Great Suffolk Street, London, UK

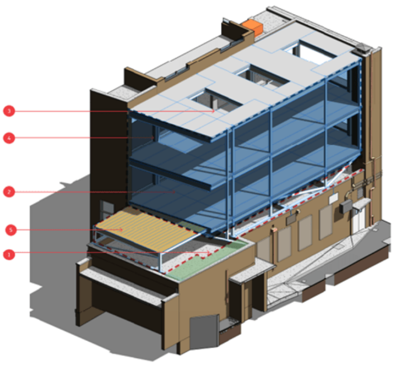
Reclaimed steel from demolition project in the City (1 Broadgate) was purchased to make up the structure for a new external core of the Victorian style historic warehouse in Soutwark. 97% of the steel (over 20 tonnes) will be reused in this project. [60]

Elephant & Castle Town centre redevelopment, London, UK

Three of four new commercial and residential buildings in the emerging new town centre at Elephant and Caste will utilize reclaimed steel. The total amount of steel in buildings E2, E3 and E4 is 372 t, of which 26% (96 tonnes) will be reused. [60]

Holbein Gardens, London, UK

24 tonnes of reclaimed steel (35% of total) was used for the extension of 1980s office building off Sloane Square in Belgravia. [60]



Sloane Square House, London, UK

Two storey extension of 1950s office block built on top of Sloane Square Underground Station achieved 100% sourcing of steel (21 tonnes) obtained from existing buildings across the country. [60]

Refurbishment project, Lichfield, UK

Refurbishment of 1960s two-storey residential house is an example of rising public awareness about the sustainable choices in private construction projects. The homeowner contacted reclaimed steel supplier and received two sections matching the specification, one slightly oversized and one section that required splicing. [60]

3.7 Reuse of constituent products in other projects

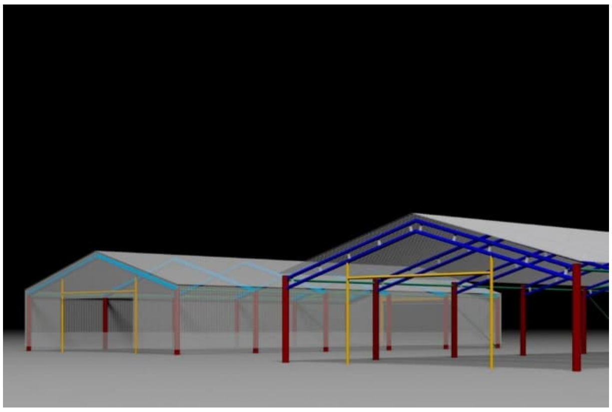
Constituent products from demolitions, renovations or surplus construction materials can be used also in other non-residential projects. Several examples of such buildings are presented in this section.

The London Olympic Stadia, London, UK

2500 tonnes of surplus oil and gas pipeline tube material was used to build major stadia projects including Old Trafford North & South Stands, Emirates Stadium & the Reebok Stadium. [65]

Bent Cross Town Primary Substation, London, UK

Around 45% of the total designed steelwork was reused in this project leading to around 40% carbon savings. Reclaimed steel tubulars were selected for the long columns of the structure, while virgin steel was used for the façade support, where tubes would have been less efficient and clunky for connections. [60]



Agricultural buildings from reused steel tubes, North Yorkshire UK

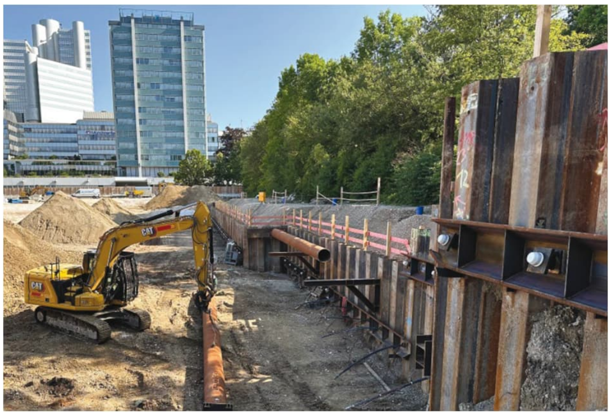
Simple Works is designing agricultural sheds using reclaimed steel supplied by Cleveland Steel and Tubes. The system utilises reclaimed steel tubes to create portal frame structures consisting of pitched welded trusses. [60]

The Entopia Building PV canopy, Cambridge, UK

CISL develops leadership solutions for a sustainable economy, so it needed to lead by example when commissioning its new office base. The project incorporates the reuse of the original structure and material reuse including the reuse of steel for the PV canopy. [60]

BCSA headquarters, Carwood Park, Doncaster, UK

The new steel-framed buildings in Carwood Park were constructed from 82 t of used steel. [63]



Reuse of steel sheet piles

Steel sheet piles are versatile, modular, and reusable. In temporary scenarios, sheet piles are frequently reused multiple times, while acceptance of their reuse in permanent applications is growing. Examples of such applications in “Schwarze Pumpe” brownfield site, Spremberg (Germany), Vienna tube extension (Austria), New Headquarters of the Bayerischen Versorgungskammer (BVK) in Munich (Germany), Gorinchem - Waardenburg dyke (the Netherlands) or Belval train station (Luxembourg) are given in Annex B.

3.8 Conversion of primary structure into a multi-storey building

Large industrial halls can be often converted into schools, commercial or office buildings during the revitalization of large industrial areas. Their primary structure is reused in-situ and reinforced to be able to carry additional floors.

HIDROTIM offices, Timisoara, Romania

The building was erected in the 1960s as a single storey industrial hall of steel structural elements with crane and converted into a five-storey office building in 2004. [58]

RWTH seminar building, Aachen, Germany

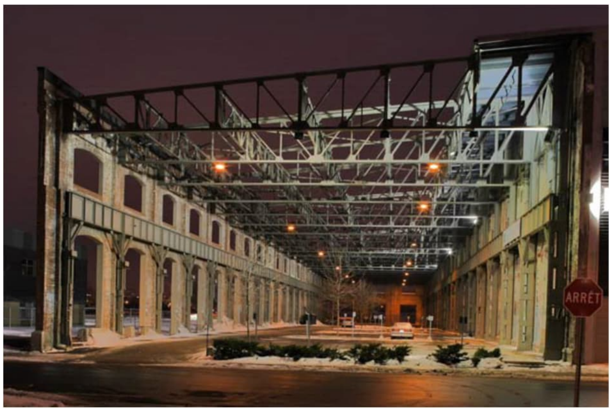
Following the closure of the RWTH heat and power plant in the 1990s, the decision was made to transform it into a seminar building by adapting the structure to meet the new functional requirements. [58]

3.9 Changing the general purpose of the building

Another example of reuse in-situ is the conversion of one building to another purpose without major changes of the primary or secondary structural elements. If the alternative option would be demolition of the old building, we are still considering the process to be case of structural reuse.

Musée d'Orsay, Paris, France

The Orsay railway station was built for the Universal Exhibition of 1900 and converted into museum in 1978. [64]



Angus Technopôle Building, Montréal, Québec

A former locomotive assembly plant used by Canadian Pacific Railway was converted into light industrial workshops and office spaces for community-focused businesses in 1999. [59]

3.10 Major refurbishments

Old structures are often undergoing deep renovation or major refurbishment, when the cladding and secondary structure is removed and the primary structure is repaired, modified or reinforced. One of the reasons can be the requirement of conservation of the historical steel structural elements.

PUT laboratory, Timisoara, Romania
The structure was erected in 1959, consisting of truss elements. Part of the structure was damaged in 2017 by a storm. [58]

Blue Steel Building, Leeds, UK

The existing warehouse was thoroughly refurbished. Its portal frame was raised by 3 m, existing purlins, bracing and rafters were reused and a new office block was added with composite metal decking. [63]

Winterton House, London, UK

Originally built in 1968, stripped back to its original structure and reclad in 1999. [63]

University Technical College, Leeds, UK

The construction company BAM was the main contractor for a University Technical College Leeds building project, involving the renovation of a 1900s historic building with a requirement that the steel structural frame be conserved. [63]

3.11 Buildings designed for reuse

The following section introduced several examples of steel buildings designed for reuse. Although, there are many companies specialized in temporary and modular steel buildings, the selected cases are representing more complex, either designed as permanent or with unique structural system.

MEXX DAY hall, Timisoara, Romania

The structure was designed in 2008 as a standard kit to be adapted for different locations and applications. It was erected in 2009 and relocated for reuse in 2017. [58]

YIT warehouse, UK

The building has been erected several times – first in Finland and then twice in the UK. The building foundations have changed from asphalt to concrete and the cover has been replaced once but the frame structure has remained the same throughout. As YIT’s construction sites have changed, Best-Hall has relocated the building, which is used as a warehouse, from one country to another as required. [61]

Petite Maison, Luxembourg

The building was a demonstration project aimed at promoting the circularity of construction materials and contributing to the European Capital of Culture Esch2022. It was designed in 2021 and deconstructed in 2023, with reclaimed materials and components stored for reuse (see Annex B).

3.12 Unsuccessful reuse cases

Meridian Water 'drumsheds', London, UK

In this project, Enfield Council suggested and wished to investigate the possibility to reuse steel from eight industrial sheds. However, the plan was not successful due to the estimated increased demolition time and related costs. Another setback to steel reuse was that some of the steelwork is pre-1970s and therefore does not comply with steel reuse protocol P427. [60]

Reuse of pre-1970 steel, London, UK

The project involved the demolition of an existing building and the development of a new commercial building on the same site in London. The original intention was to reclaim some steel from the existing building. The plan was rejected due to the steel being encased in concrete, and the building dating back to the 1950s [60]

4. Business models

4.1 Circular economy business models in construction

4.1.1 Buildings as material banks (BAMB)

BAMB represents an EU research initiative comprising 15 partners from seven European countries. Their collective goal is to catalyse a transformative shift in the building sector by championing circular solutions. The dynamics of value creation and distribution within society are evolving, diverging from conventional linear value chain frameworks. Unlike traditional models, which rely on cost-plus value calculations, emerging ecosystem-based models prioritize the 'willingness' to pay for participation in the value network.

Contrary to the rigidity of traditional value chains, circular ecosystems demonstrate heightened flexibility among individual players and the group. The flows within these ecosystems are multidirectional across various dimensions, fostering intensified collaboration and information sharing. Moreover, the complexity of value creation in these ecosystems is more group-oriented, allowing for a more proportional allocation of value to all participants. This shift is attributed to increased data availability and transparency within the system.

A major obstacle to the introduction of circular economy practices in the construction industry is the lack of high-quality shared information. Professionals, including designers, builders, and recyclers, often face limited access to crucial product specifications, conditions, and availability information. This information gap substantially restricts the potential for reuse at different levels. The evolving landscape necessitates new methods of collaboration and data sharing among stakeholders.

While existing approaches and technologies focus on integrating building models through data, such as Building Information Modelling/Management (BIM), they do not adequately address the information gap concerning the current building stock. BIM systems, while powerful, remain complex and are primarily accessed by experts for data management and extraction. Many roles in the construction industry still lack specialized knowledge in utilizing these intricate information systems. Despite this, the application of BIM in new builds, extensive renovation projects, and facility management is on the rise.

Existing methodologies and technologies primarily concentrate on incorporating building models stored in data, such as Building Information Modelling/Management (BIM), to establish foundational information. However, they have yet to effectively address the information gap associated with the current building stock. Additionally, BIM systems, known for their complexity, are predominantly utilized by experts for data management, reworking, and extraction, leaving many professionals in the construction industry without specialized knowledge of these intricate systems. Nevertheless, the utilization of BIM is on the rise in new construction and extensive renovation projects, extending to applications in facility management and maintenance.

Several key drivers are poised to foster the adoption of circular building practices within the European Union, including:

- Urbanization
- Legislative measures
- Resource scarcity

- Land constraints
- Transition to modular construction
- Challenges in a tightly margined industry
- Emphasis on Corporate Social Responsibility
- Advancements in Recycling Technology
- Optimization of construction processes (utilizing technologies like BIM)
- Enhanced Asset Lifecycle Management.

These factors collectively contribute to the momentum of circular building practices, reflecting a broader shift toward sustainable and efficient construction processes in the European context.

4.1.2 ReLondon (Former: The London Waste and Recycling Board (LWARB))

ReLondon emerged as the rebranded identity of The London Waste and Recycling Board (LWARB), reflecting a strategic move to underscore their dedication to fostering a sustainable and resource-efficient urban environment. This transformation aimed to signal a broader commitment to shaping London into a city that prioritizes environmental responsibility. In essence, ReLondon seamlessly carried forward the ongoing initiatives spearheaded by LWARB, placing heightened emphasis on comprehensive waste reduction strategies, advancing recycling efforts, and championing the principles of a circular economy within the metropolitan landscape. Through this evolution, ReLondon continued to serve as a pivotal force in driving positive environmental change and promoting sustainable practices across London's waste management and recycling sectors.

The built environment, given its expansive scope and scale, presents an ideal platform for the integration of circular economy practices, enabling the sector to spearhead transformative shifts in construction methods and building utilization not only in London but also throughout the UK and globally. London's dynamic pace of change provides a unique opportunity to embrace circular economy principles early on, reaping benefits swiftly. Current projections estimate that circular economy initiatives within the built environment could contribute an annual boost of £3 – 5 billion to GDP by 2036, encompassing advantages realized locally in London and those associated with activities originating in the city.

Key areas of impact include:

- <u>Innovation in Modular Construction:</u> Implementation of modular construction techniques and forward-thinking approaches like widespread adoption of 3D printing and additive manufacturing can significantly reduce structural waste and construction time, resulting in an annual benefit exceeding £800 million.
- <u>Optimized Building Utilization:</u> Practices such as peer-to-peer renting, enhanced urban planning, office sharing, and repurposing buildings contribute to increased value for new constructions in London. Doubling the utilization of 20% of buildings by 2036 could lead to annual savings surpassing £600 million.
- <u>Effective Building Disassembly and Material Management:</u> Designing buildings for efficient disassembly, coupled with strategic material management through high-value closed loops, material passports, innovative business models, and reverse logistics ecosystems, has the potential to save over £200 million.

The adoption of circular economy principles in London's built environment not only results in direct cost savings but also opens up new opportunities across interconnected facets. These opportunities span areas such as land restoration programs, adherence to design principles (e.g., energy-neutral buildings), exploration of new materials, collaborative equipment and parking space sharing, and integration of information and communication technologies. In essence, the circular economy not only benefits from but also actively contributes to reshaping the overall economy.

4.1.3 EU circular economy in construction research

Cinderella - New Circular Economy Business Model for More Sustainable Urban Construction

The EU-28 total waste generation in 2014 was 2598M tones, the highest since 2004, 33.5% of which was from the construction sector, being also one of the larger consumers of inorganic raw materials. Construction activities are mainly localized in urban areas where by 2050 about 86% of the developed world is expected to live. CINDERELLA project aims to develop a new Circular Economy Business Model (CEBM) for use of secondary raw materials (SRM) in urban areas, connecting different industries, the construction sector and municipal services, decision makers and the general public with the support of CinderOSS, a “One-Stop-Shop” service, articulated in (i) an on-line ICT platform for tracking and modelling the urban waste-to-product flows, on-line marketing and sharing knowledge and information along the value chain (ii) production and marketing of (SRM) based construction products and (iii) building with SRM based construction products supported by building information modelling (BIM). Different streams of waste will be exploited in the project, i.e. construction and demolition waste, industrial wastes, heavy fraction from municipal solid waste and sewage sludge, mostly of them currently landfilled and/or incinerated. Their suitability for use for building materials will be demonstrated through large scale demonstration activities in Slovenia, Croatia and Spain while the ICT platform will be demonstrated in Slovenia, Croatia, Spain, Poland, Italy and The Netherlands. The project will contribute to 20% reduction of environmental impacts along the value and supply chain, reducing virgin material exploitation and converting wastes to products. Sustainability of CEBM will be proven with the environmental, economic and social assessment through whole life (LCA, LCC and S-LCA). The pre-feasibility analysis of the proposed CEBM indicates an increase of recycling by 30% of CDW, 13% of industrial waste, 100% of heavy fraction and 25% of sewage sludge with a net profit of 18%.

The Project provides deliverables as a result of the project regarding the following topics:

- Policy Recommendations: This deliverable is connected with Task 82 Exploitation of project results Based on implemented pilot demonstrations stakeholders interaction and other activities project consortium will give several propositions of policy legislation and administrative development on local regional national and EU levels which will be communicated with policy and decisionmaking stakeholders This will includes proposal for new GPP procurements guidelines explanatory documents on construction products legislation and EndofWaste protocols use of SRMbased products in other fields eg agriculture and others All recommendation and results on communication with relevant stakeholders ministries regional and local governments will be recorded in report.
- End of waste criteria protocol for recycled waste used as aggregates: This deliverable is connected with Task 5.2 (Preparing End-of-Waste criteria based on the intended use of recycled waste). It will define a proposal of harmonized approach for End-of-Waste protocol (including lab and field tests, parameters to be assessed, limit values, etc.), which will be

based on already existing normative/regulation, the involved stakeholders requirements, and main outputs from the different related tasks of the project.

- "Final Report including ""Sustainability Footprint Declarations"" and Policy Recommendations Paper": This deliverable is connected with Task 74 Development of decision making criteria and positioning of the CinderCEBM according to the SDGs It will include Catalogue of Sustainability Footprints of the new materials together with a list of sustainability criteria that should be considered in procurement public and private of SRM based constructions and guidance on how to use them
- Protocols for the implementation of encouraging practices: Based on evaluated and demonstrated pilots in different environments technical as well as economical this document will gather protocols how to transfer optimized CinderCEBM in different environments in Europe
- Environmental LCA assessment report for each pilot demonstration: This deliverable is connected with Task 71 Environmental assessment and LCA during all phases of the project from materials to demonstrations value chains It will be in the form of a report for the LCA studies applied to each pilot case performed in WP6
- LCA, LCC and S-LCA methodology report: This deliverable is connected with Task 7.2 (Socio-economic assessment, including LCC and S-LCA) but will follow up the framework set in Task 7.1 (Environmental assessment and LCA during all phases of the project (from materials to demonstrations, value chains)). The report will describe the methodology that will be applied in order to assess all the aspects of sustainability in the project: environmental (by meand of LCA techniques), economic (by means of LCC techniques) and social (by means of a S-LCA approach).
- Blueprint for a resource-efficient secondary raw material based urban and peri-urban construction sector: This deliverable is connected with Task 3.4 (Setting up a new framework for SRM based urban and peri-urban construction). The blueprint will include the study of needs, conditions, potentials, and obstacles (technological, legislative, administrative, socio-economic, and environmental) across Europe for implementation of SRM in urban construction sector. Report will be prepared based on literature survey and stakeholders' interactions, including initial conference / workshop carried out in WP8.
- Report on the valorisation of existing end-of-life scenarios and alternative value chain: This deliverable is linked with Task 3.3 (Value chain assessment and assessment of actors along the value and supply chains). Report will be prepared on evaluation of the potential new value chains as well as existing (waste to landfill/incineration) that connect together multiple sectors within urban and peri-urban areas. This deliverable is important for follow up activities in Task 3.4 and beyond
- Flow maps and data based for selected urban areas: This deliverable is connected with Task 3.1 (Flow map of urban and peri-urban areas).It will provide the urban metabolism analyses of the studied regions, i.e. Maribor region (Slovenia), selected county in Croatia, Madrid (Spain), Trento (Italy), Amsterdam (The Netherlands) and Silesia region (Poland).
- Report on impact of disruptive construction technologies on CinderCEBM: This deliverable is connected with Task 43 CinderCEBM optimisation more specifically subtask 432 It will include benchmark study on beyondstateofart innovativeness of wastetorecourse solutions as well as further development of circular business ecosystem thinking methodology and innovative circular business ecosystem in connection with new emerging technologies in construction sectors such as additive manufacturing 3D printing advanced robotics and peopleless construction prefabrication and modular construction and others

HOUSEFUL Innovation circular solutions and services for new business opportunities in the EU housing sector

The housing sector is a major contributor to current global problems of resource depletion and climate change, representing one of the most important consuming sectors at EU level: 50% of all extracted materials, 40% of final energy consumption, 33% of water consumption and 33% of all produced waste. The lock-in to the linear business models of today is causing many environmental problems and is one of the major barriers in transition towards a circular economy. HOUSEFUL project proposes an innovative paradigm shift towards a circular economy for the housing sector by demonstrating the feasibility of an integrated systemic service composed of 11 circular solutions. HOUSEFUL will introduce solutions to become more resource efficient throughout the lifecycle of a building, taking into account an integrated circular approach where energy, materials, waste and water aspects are considered. This approach fosters new forms of co-creation, increasing the collaboration among stakeholders of the housing value chain to develop new circular solutions and services. HOUSEFUL concept will be large scale demonstrated at 4 demo-sites in Austria and Spain, adapting the concept to different scenarios, including in social housing buildings. HOUSEFUL solutions will be evaluated from an environmental (Life Cycle Assessment), economic (Life Cycle Cost) and social (Social Assessment) point of view. The results obtained will be used to define an integrated HOUSEFUL service which will be driven and promoted through a SaaS (Software as a Service). The SaaS will integrate a Circularity Tool to quantify the circularity level of buildings and will include different circular solutions to be offered as services, encouraging the housing value chain to redesign traditional business models towards circular ones. 10 EU Follower buildings will be engaged with the support of a Collaborative Community of Housing Experts to replicate HOUSEFUL results and maximise the impact of the project. The results are documented in 20 deliverables regarding among others the following topics:

- Social conditions for the co-creation of all HOUSEFUL services and co-created materials
- Social perceptions and beliefs in circular economy at building scale (version I)
- Report on end-users' requirements and CEBO on residential buildings
- Social assessment
- Existing market circularity solutions and product

4.2 Circular economy business models in the steel construction

4.2.1 Hire or leasing of Products

In this business model, the products, which can be buildings or construction components, are leased rather than sold. Leasing of buildings is common practice throughout the property sector. Generally, rented buildings are permanent structures however, there are many examples of companies that lease temporary, relocatable buildings. These include temporary events structures and seating, temporary office, education, industrial and medical buildings, etc. Most of these buildings are of a modular form and the structural steel used is most often cold-rolled, hot-dipped galvanised coil sections. Benefits of temporary, relocatable buildings include:

- No capital outlay
- Generally, no maintenance costs
- Flexible terms i.e. can be hired over different time-frames according the users requirements.

At the product level, there are many existing examples of temporary works, steel products that are commonly hired. These include:

- Piles, particularly sheet piles
- Road plates
- Scaffolding
- Props and formwork.

Steel props vary from large, generally tubular sections used in large construction projects to more domestic scale props.

When constructing cofferdams, shoring, support structures and large infrastructure projects like railroads, road construction, and excavations, many alternate construction methods exist to retain soil or water, whether temporary or permanent. Steel sheet piles are particularly well-suited because they are relatively light and easy to handle, can be supplied in long lengths, can be extended or cut, easy to retrieve after use, and can be reused serval times.

ArcelorMittal has implemented a rental and buy-back business model; new and used steel products such as steel sheet piles, tubes, etc. can be rented or purchased with a buy-back contract. Steel sheet piles can be used up to 10 times with proper handling and repair. With a buy-back option for purchase, after the execution of a project (temporary applications), customers can either choose to keep the sheet piles for reuse in other projects or sell them as second-hand or return them to ArcelorMittal at a price negotiated before the sale, provided the piles are in good shape. Upon return of the buy-back, the sheet piles are either sold as second-hand for reuse or added to the stocks for rental. Reused sheet piles are inspected, jet-washed, and trimmed and can be re-used several times in temporary applications or applied in permanent applications. At the end of life, sheet piles are recycled for new products.

ArcelorMittal has been continuously improving the steel sheet pile range by more sophisticated steel grades and optimizing the shape's geometry, which enable lighter, wider, more resistant steel sheet pile solutions. ArcelorMittal's stock and service facilities in France, Germany, and the UK stock a wide range and large quantity of sheet piles for fast supply for both sales and rental, and offer services such as interlock sealant application, drilling, cutting, welding, pairing, etc. Additionally, upon the return of rental or buy-back, the service centre also takes care of cleaning, reconditioning, grinding if necessary, and repair welding. ArcelorMittal begun transitioning its sheet pile rental stocks to the EcoSheetPile™ Plus range, produced in Luxembourg from ca. 100% scrap through the electric arc furnace route with a guaranteed 100% renewable electricity supply, which further reduces the environmental impact.

The added value of reusing steel sheet piles is that:

- The buy-back & rental business model contributes to a circular economy: higher up in the waste hierarchy, it switches volumes from new production or from recycling into reuse; thus, reduces the environmental impact.
- The physical inventories at construction companies are reduced – these are now held by the rental business rather than the construction companies and can be put to much more intensive use. Storage on the project site is also minimized.
- Better soil and land quality – as steel sheet piles are completely removed from the ground when they are no longer needed.
- Logistics: ensuring a fast response & delivery to the construction site.

The main challenges regarding the rental business are related to:

- Financial: working capital required for ensuring that a large variety of sections is readily available from stock to satisfy customer demand.
- Technical: when piles are returned damaged, they must be repaired or sent for premature recycling. Traceability, sorting, cleaning, and ensuring that the material is fit-for-purpose requires a team of professionals.
- Regulatory: lacking incentives to support the rental business model by recognition of environmental performance, e.g., in Green Public Procurement.

4.2.2 Product as a service or servitisation

Servitisation is the innovation of an organisation's capabilities and processes in order to create value by shifting from selling products to selling product-service systems. A product-service system is an integrated product and service offering that provides added value when used. It should be noted that most servitisation has been developed primarily in the manufacturing industry.

The idea of the "service economy", developed by Walter Stahel in the 1970s, focuses on the importance of selling services rather than products. This method allows manufacturers to retain greater control over the products they produce and the energy and materials they contain, enabling better maintenance, recycling and recovery. Customers also benefit, as they only pay for the service they need and use, and often receive a better service as the manufacturer has a greater interest in delivering a long-lasting product.

Product-as-a-Service (PaaS) is a business model that allows customers to purchase a desired outcome rather than the equipment that delivers that outcome. In the context of construction, where the end product is a physical building that must safely withstand forces, provide a comfortable and safe indoor environment, etc., it is not immediately obvious how these functions could be servitised. In contrast, building management is a good example of servitisation that is relevant to the property sector and has been around for a long time.

The product as a service is comparable to a rental or leasing model but is based on a service rather than a product. For example, the structural support for a building over a period of time or the provision of a safe, watertight and thermally efficient envelope for a building over a period of time.

The challenges associated with servitisation business models include

- Understanding what value means for customers and consumers (not producers and suppliers)
- Developing the ability to design and deliver services rather than products
- Developing a service culture
- Embedding all these aspects into a service organisation.

4.2.3 Take back/buy-back model

A take-back scheme is an initiative, usually set up by a manufacturer or industry, to collect used products or materials from consumers (usually at the end of a product's life) and return them to the original processing and manufacturing cycle. A buy-back scheme is the same as a take-back scheme, except that the manufacturer pays the consumer to return the product.

Take-back schemes are increasingly being introduced in many sectors to improve waste management and resource efficiency. This is most prevalent in the retail sector and for electrical and electronic equipment (and batteries) under the WEEE Directive. More recently, take-back schemes for plastic waste have been introduced in response to the increasing problems associated with discarded plastic waste. Companies appear to be increasingly recognising the public relations benefits of take-back and buy-back schemes. Examples of take-back schemes in the construction industry are less common, but there are some examples in the UK and Europe, including:

- Steel sheet piles
- Rockwool offer a recycling scheme where they accept uncontaminated, packaged Rockwool stone wool insulation for recycling at their manufacturing facility.
- Plasterboard manufacturers offer recycling programmes, but these are limited to new build waste and offcuts from new products, i.e. they do not include demolition waste.
- Insus: buy back system for polyurethane core material for sandwich panels

It should be noted that the few construction-specific schemes that have been identified relate only to construction and not demolition waste. One exception is the Europe-wide PVC recycling initiative Reconvinyl, which covers both construction and demolition waste streams. Another example from the UK is Armstrong Ceiling Tiles, which takes back (for recycling) mineral fibre, glass wool and rock wool ceiling tiles manufactured after the year 2000. Steel products have the advantage over many competing non-metallic building products in that their scrap value has always been high enough to ensure that steel is recovered from construction and demolition waste streams for recycling. This has meant that steel manufacturers have not been obliged (or have chosen voluntarily) to introduce take-back schemes to improve recovery and recycling rates. One exception is the deposit systems for drinks packaging, which include steel cans. Some manufacturers of construction products have introduced take-back schemes, but these are currently limited to buying back waste generated during the construction phase and not demolition waste at the end of its life. Again, it is the longevity of construction products that limits the feasibility of take-back/buy-back programmes to construction rather than demolition waste streams. Extended Producer Responsibility (EPR) is a policy concept whereby producers are made significantly responsible - financially and/or physically - for the treatment or disposal of post-consumer products. Assigning such responsibility can, in principle, incentivise the prevention of waste at source, promote environmentally sound product design and support the achievement of public objectives in the areas of recycling and materials management. In the European Union, extended producer responsibility is mandatory under the WEEE, Batteries and ELV Directives, which make producers responsible for financing the collection, recycling and responsible disposal of waste electrical and electronic equipment, batteries, accumulators and vehicles. The Packaging Directive also indirectly refers to the EPR principle by requiring Member States (MS) to take the necessary measures to ensure that systems are set up for the collection and recycling of packaging waste. Other waste streams for which producer responsibility organisations have been identified most frequently in the European Union include tyres, waste oil, paper and cardboard, and construction and demolition waste. Despite being the largest waste stream in the EU, an end-of-life directive has never been developed for both construction and demolition waste.

5. Policies and regulations

While re-use is the most efficient end of life (EoL) option and shortest path to carbon neutral constructions, its uptake into policies is being slow.

5.1 Taxonomy

First Taxonomy draft included ambitious reuse targets in its substantial contribution to "Transition to a Circular Economy" environmental objective:

"The asset comprises at least 50% (either by weight or by surface area of building elements including facades, roofs and internal walls and floors) from a combination of re-used components, recycled content, or responsibly-sourced renewable materials. The 50% should be reached with the following criteria:

- *Minimum 15% comes from re-used components.*
- *Minimum 15% comes from recycled content.*
- *The remaining 20% may be met by either re-used or recycled content or by responsibly sourced, renewable materials or any combination of these three" .*

However, the final version does not set building level but material level targets and the requirements are limited to secondary material use. In D4.1 a critical review of the Taxonomy "Transition to a Circular Economy" technical screening criteria was made highlighting that , very few projects will comply with the "Transition to a Circular Economy" substantial contribution criteria and the technical screening criteria are clearly in favour of the use of mineral secondary materials and constrain the use of metals an responsibly sourced materials.

5.2 Waste Framework Directive

The directive [28] sets the by 2020, the preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70 % by weight.

The inclusion on backfilling as EoL option and the different level of achievement in the different member states have generated hesitates on the Waste Framework Directive implementation.

Latest amendments are limited to the textiles and food waste and despite it was expected that a new revision with ambitious high-quality recycling and reuse target should entry into force in a short term, this revision is not in place.

5.3 CEN TC General approach

CEN technical committees TC 350, 250 and 135 started to intensively work in reuse in recent years. While TC 350 addresses reuse aspects for all construction materials developing an horizontal standard on reuse a design for reuse, CEN TC135 is developing a specific methodology for the assessment of steel structural elements and CEN TC 250 is working on the design with reused elements.

5.3.1 CEN TC 350 SC1

Reuse has been selected as one of the work topics in CEN TC 350 SC1. Two of five Task Groups in CEN TC SC1 WG1 were devoted to reuse.

- Task Group 4: Horizontal Standard/Technical Report on reuse.
- Task Group 5: Horizontal deliverables for design for circularity at all levels for construction

Both Task Groups have resulted in new Working Groups under CEN TC 350 SC1:

- WG6 “Reuse of construction products” with the scope to develop and horizontal standard for re-use of construction products, being Markus Beckman, Sweden the convenor. A PWI for a European Standard entitled "Circular Economy in the Construction Sector – Horizontal requirements for reuse of construction products" subject to approval by CEN/TC 350 has been registered.
- WG7 "Circular economy in the construction sector" with the scope “To develop guidance and horizontal standards for circular design of construction products and constructions in all parts of the construction sector" being Evert Schut the convenor. Two different PWI have been registered:
  - European Standard "Circular Economy in the Construction Sector – Horizontal requirements for circular design of construction works and construction products" subject to approval by CEN/TC 350.
  - Technical Report entitled "Circular Economy in the Construction Sector – Guidance for the implementation of circular design of construction products and construction works" subject to approval by CEN/TC 350.

5.3.2 CEN TC 135 WG2

CEN TC 135 WG2 developed CEN/TS WI 135033 “Reuse of structural steel that covers the assessment protocols for reused steel structural elements” [24], which gives complementary provisions to EN 1090-2 [16] for the use of reclaimed structural components for the execution of steel structures to EXC1, EXC2 and EXC3 according to EN 1090-2. The provisions apply to products used in structures to be designed according to EN 1993-1-1 [21] for quasi-static loading and not subject to fatigue loading.

Protocols are limited to constituent products, while fabricated products assessment is only provided as an informative Annex C. The Technical Specification does not apply to cold-formed structural steel sections and sheeting according to EN 1090-4 or mechanical fasteners.

Data collection:

The following information about the structural components to be reused should be collected, analysed and recorded, if available:

- Date and place of construction of the original building;
- Information on fabricator, erector, designer, architect and other actors;
- Drawings, models, photographic evidence, etc. for the as built structure;
- Inspection documents, e.g. according to EN 10204 or similar standard in use at the time;
- Information about the design such as calculation notes, loading history, etc.;
- Building Owner's manual;
- Operation and maintenance manual
- Inspection and maintenance records;
- Records of interventions (e.g. expansions, modifications, etc.); j) Records from any possible incident (e.g. fire, earthquake, etc.).

At least the following information shall be recorded and included in the inspection and test record:

- A description of the donor structure including its use and geographical location;
- The age of the donor structure which may be obtained from records (e.g. building permit) or local/anecdotal information;
- A listing of the structural components including their location and function;
- Condition evaluation.

Condition evaluation is limited to visual inspection to identify:

- Global deformations indicating plastification;
- Signs of direct exposure to high temperatures (e.g. soot, burnt or blistered paint), or;
- Local damages, inclusive plastic deformations, and reduced cross sections (e.g. through holes, openings, cracks or excessive corrosion).

Quality Assessment

The material properties to be assessed as well as the testing methodologies depend on the available certificates if steel has been produced after 1970 and certificates are available, a simple checking of properties according to Annex A of EN ISO 18265 is allowed. However for steel produced before the 1970 and unavailable certificates destructive testing for all components is requested: Tensile testing (EN ISO 6892-1), Impact testing: Impact testing (Charpy) If not specified, the testing temperature shall be assumed to be room temperature, i.e. 20°C and analysis of chemical composition methods among those listed in CEN/TR 10261.

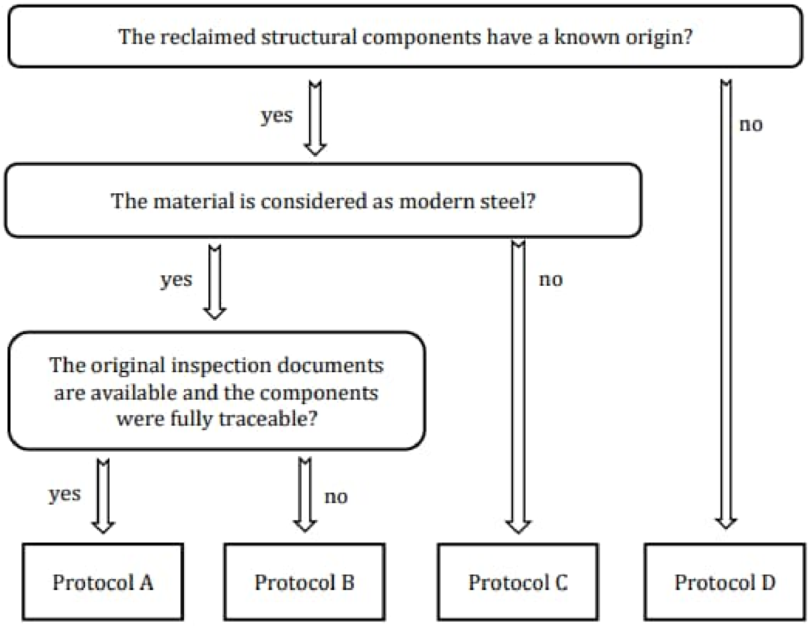


Figure 2. Flowchart for the choice of testing protocol.

The characteristic values of yield and tensile strength shall be derived with the method in Annex D of EN 1990. In addition, the material shall also satisfy the ductility requirements (elongation at failure and ratio Rm/ReH) in part 5.2.2 of EN 1993-1-1. An example of protocols to be implemented is provided in Table 2

Table 2. Example of testing protocols for different reused steels based on MVR.

Property	**Protocol A**	**Protocol B**	**Protocol C**	**Protocol D**
Yield Strength	Estimated*	Non-statistical**	Statistical***	All members****
Tensile Strength	N/A	Non-statistical**	Statistical***	All members****
Impact Testing	N/A	Non-statistical**	Statistical***	All members****
Chemical Composition	N/A	Non-statistical**	Statistical***	All members****

** Member with the lowest hardness value submitted to destructive testing.
*** the member with the lowest hardness value, the member with the highest hardness value, and at least one additional and randomly chosen member.
**** Each structural component shall be submitted to destructive testing.

All destructive testing shall be performed by an independent and accredited party. The results shall be documented in a test certificate equivalent to a control certificate 3.1 according to EN 10204. The test certificate shall be issued by the independent party that performed the tests.

- Protocol A is applied to steel produced after 1970 with available certificates.
- Protocol B is applied to steel produced after 1970 with no-available certificates.
- Protocol C is applied to steel produced before 1970 with available certificates.
- Protocol D is applied to steel produced before 1970 with no available certificates.

5.3.3 CEN TC 250 SC3

CEN TC 250 has started to work in a technical standard that will consider design with re-used products. Its approach to design with re-used products is explained on "Establishing European design rules for re-used steel components (wiley.com)".

The Working Group has been already created and will start working in autumn 2024. CEN TC 250 SC3 brings a coherent and realistic approach to the overall steel re-use topic and provides a complete process supply chain analysis. An prEN 1090-x for re-used steel and a Eurocode. Annex are expected integrating execution and design components. Understanding the design of re-used construction components involves the consideration from two perspectives:

- as a task for the design of new components and structures being particularly suited for re-use of components in future – 'design for re-use of components.
- as a task for the design of new structures using used components – 'design of re-used components.

Despite most approaches to qualification of re-used products, including TC 135 TS, assume that they should be considered in design as a building product after installation in a new structural context with the same safety and reliability as a new building product, this may be contrary to retrofitting of existing structures where the old structural context remains.,

As for existing structures, where according to EN 1990-1 and CEN/TS 17440, respectively, the target safety index β can be different compared to a new structure; for re-used components, the design target safety index should be equal to that of design with virgin components, in general for, e. g., CC2: β = 3.8, however an structure that has been designed with a lower safety level for the load-bearing capacity (e. g., that of serviceability with pf,1a = 10) will drop very drastically in safety, year after year.

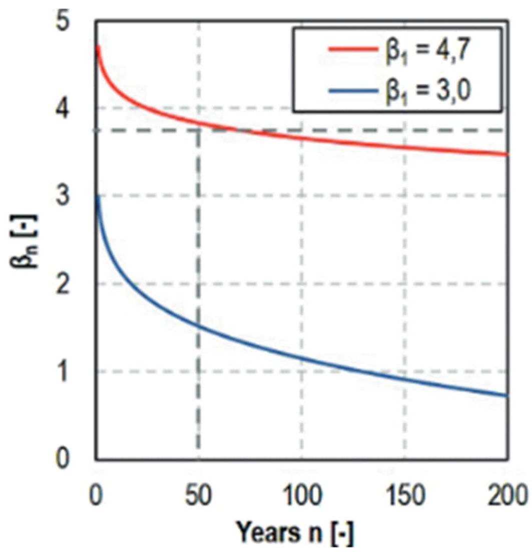


Figure 3 Reliability index β over the years for two different cases

TC 250 SC3 is working in the definition of a complete process chain that may be at least as reference for all structural components in the Horizontal standard to be developed by TC 350 SC1 WG6. The process chain proposed by TC 250 SC3 is provided in Figure 4.

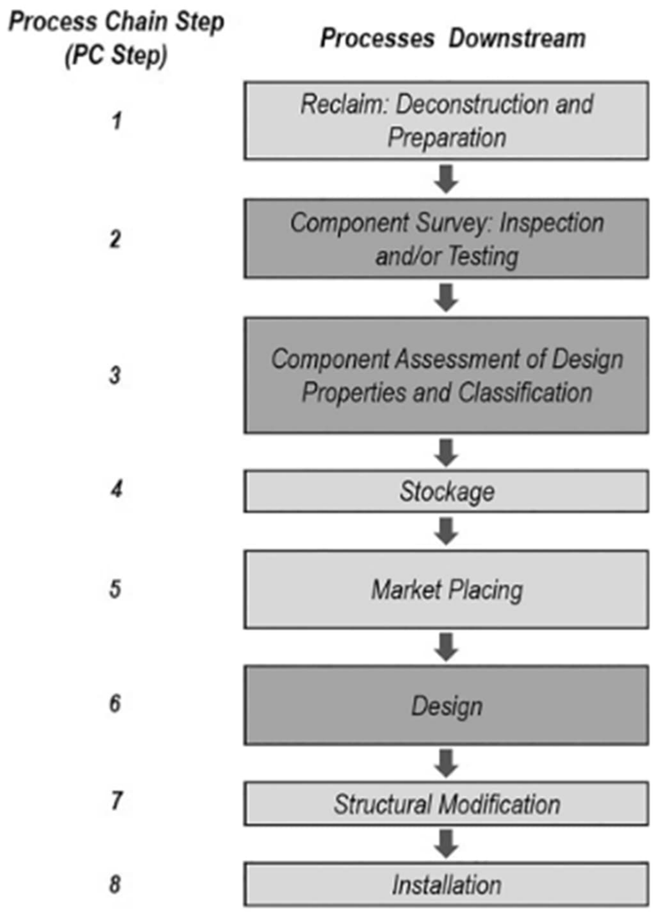


Figure 4. TC 250 SC3 Process chain.

<u>PC Step 1: 'Reclaim: deconstruction and preparation'</u>

In the initial PC Step 1, the procedure of reclaiming of the steel component from an old structure is addressed, where deconstruction techniques are in focus. Demolition methods or deconstruction techniques with the least potential for damage should be used. Reference to rules of prEN 1090-x should be made in the design document on re-used components. PC Step 1 may also include any reprocessing or preparation work on the component if necessary.

<u>PC Step 2: 'Component survey: inspection and testing'</u>

During PC Step 2, the removed steel component is subject to inspection and/or additional examination. The degree of examination or inspection depends:

- On the age of the construction,
- The function of the component in the structure
- The kind and extent of the preliminary information.

Performing data sampling, structuring of information needs to be done in such a way that an assignment to classes can be enabled. The consideration of the function of the component in the structure and the classes assignment are not considered by TC 135. The data may be of general and specific type:

General data

- typical (nominal) material properties
- typical (nominal) geometrical properties
- provenance of production corresponding particularities of products
- historic periods of production and corresponding particularities of products
- original codes and practices of product, design, detailing, fabrication and erection

Specific data

- real material properties
- real geometrical properties
- original documents on production
- original documents on design and detailing
- original documents on fabrication, erection and service
- actual state of component (surface, corrosion, detailing, cuts, holes, plastification, etc.)

Welds need to be treated in a special way. As there were no detailed workmanship quality specifications, such as EN ISO 5817, in the past, it is anticipated that re-used components may exhibit more welding defects than new components. But often welds not complying with the quality levels of EN ISO 5817 (connected with execution classes EXC 1, 2 or 3 of EN 1090-2 exhibit sufficient resistance. A special assessment route to appropriately classify 'old' welds in EXC is sought and as mentioned below CEN TC 135 TS only contains and informative Annex.

PC Step 3: 'Component assessment of design properties and classification'

Step 3 constitutes the actual evaluation of the steel component determining the assumed resistance in the design. Groundwork for the assessment is the specific data of the inspection and testing routines from PC Step 2 as well as the general and specific theoretical preliminary information on the component. The assessment should be carried out according to the rules of CEN/TS 17440 [13] and EN 1990-2 [16], respectively. Based on this, a classification of the component in view of 'design classes' can be done.

The" design classes" classification to be done should consider:

- which calculation theory – elastic or plastic – is used, which buckling curve is taken,
- which jointing technique is allowed under which conditions,
- which safety factors are to be used, etc.

Information on the components' condition, e.g., state of surface and plastification, needs to be included.

Before a structural component to be re-used is placed on the market for installation in a new structure, its properties and resistances must be assessed with regard to the limit states to be verified to enable a design. As the rules of CEN/TS 17440 are intended for the assessment of existing structures, rules on the re-use of existing components to be re-installed in new structures may differ in detail. Although 'assessment based on past performance' and "assessment by calculation" are considered as an option the "assessment based on load testing of the components " is considered the preferred approach, The ‘assessment based on load testing of the component’ involves updating the failure probability of a component using data obtained from a load test. This should be the usual assessment for re-used steel components in the frame of its further design.

Updating procedures are provided in the main text and in Annex B of CEN/TS 17440. The Informative Annex covers procedures for:

- updating of probability distributions, mean values, characteristic values or assessment values of basic variables and
- updating of the probability of structural failure by using results from testing or information about the past performance.

For relevant basic variables, the statistical properties of the yield strength f_y are considered here, which have a direct influence on the value of the partial safety factor γ_m.

- Case 1: No specific information is given, and assessment must be based on assumptions from the literature.
- Case 2: Prior data are given: Material properties are known based on certificates of components. Here, Annex D of EN 1990-1 has to be regarded.
- Case 3: Sample data are given: the yield strength has been investigated experimentally on 20 samples. No prior data of any material certificates or similar are known.
- Case 4: Prior data and sample data are given: Case 2 and Case 3 data are available.

Table 3 Assumptions for yield strength values and partial safety factors: Case 1

Value	**a) JCSS probabilistic model code [39]**	**b) Investigations of the literature, e.g., [40]**
Mean value	$\mu_X = f_{y,sp} \cdot \alpha \cdot e^{(-u)\cdot v} - C$ $f_{y,sp}$: nominal value for f_y α: 1.0 for plates u: fractile of the distribution C: constant reducing the yield strength Assumption: $\mu_X = 355 \cdot 1 \cdot e^{1.6 \cdot 0.07} - 0 = 397$ MPa	$\mu_X = 402$ Mpa
Standard deviation	$\sigma_X = v \cdot \mu_X = 0.07 \cdot 397 = 28$ Mpa	$\sigma_X = 37$ Mpa
Design value for the yield strength (log-normal)	$f_{y,d} = e^{\mu - \beta \cdot \alpha_R \cdot \sigma}$ μ, σ: mean value and standard deviation transformed to log-normal distribution α_R: weighting factor for the resistance	
	$f_{y,d} = e^{5.98 - 3.8 \cdot 0.8 \cdot 0.07} = 320$ Mpa	$f_{y,d} = e^{5.99 - 3.8 \cdot 0.8 \cdot 0.09} = 303$ Mpa
Partial safety factor	$\gamma_M = f_{y,sp}/f_{y,d}$	
	$\gamma_M = 355/320 = 1.11$	$\gamma_M = 355/303 = 1.17$

Table 4. Calculations of yield strength values and partial safety factors: Case 2, Case 3 and Case 4.

Value	Prior (Case 2)	Sample (Case 3)	Posterior (updated, Case 4)
Mean value	$m' = 365$ Mpa	$m = 385$ Mpa	$m'' = 382$ Mpa
Standard deviation	$s' = 20$ Mpa	$s = 20$ Mpa	$s'' = 21$ Mpa
Samples	$n' = 3$	$n = 20$	$n'' = 23$
Degrees of freedom	$\nu' = 3$ (assumption)	$\nu = 3$	$\nu'' = 23$
Factor $k_{d,n}$ (ULS design [30])	$k_{d,n} = 3.56$	$k_{d,n} = 3.16$	$k_{d,n} = 3.151$
Design value for the yield strength (log-normal)	$f_{y,d} = e^{\mu - k_{d,n} \cdot \sigma}$		
	$f_{y,d} = e^{5.90 - 3.56 \cdot 0.05} = 300$ Mpa	$f_{y,d} = e^{5.95 - 3.16 \cdot 0.05} = 326$ Mpa	$f_{y,d} = e^{5.94 - 3.151 \cdot 0.05} = 322$ Mpa
Partial safety factor	$\gamma_M = f_{y,sp}/f_{y,d}$		
	$\gamma_M = 355/300 = 1.18$	$\gamma_M = 355/326 = 1.09$	$\gamma_M = 355/322 = 1.10$

PC Step 4: 'Stockage'

PC Step 4 refers to the storage of the steel construction components to be re-used. This PC step will include the information and classification system of PC Step 3 (according to digital passports) and the ensuring that no degradation of essential properties takes place and in the exceptional situation of taking place the incidences are recorded.

PC Step 5: 'Market placing'

Here, it is important that the information and classification from Step 3 continue to be used so that the product to be re-used can be traded with these essential properties, especially about its mechanical safety.

PC Step 6: 'Design'

Re-used structural steel components are treated as new structural steel components including modifications. The safety elements and characteristic values may be different, depending on the production and condition of the component as seen in PC Step 3. In some cases, not all EN 1993 rules will be applicable. Depending on production and condition, they must be used with modifications.

The structural modelling should consider all relevant static and kinematic boundary conditions when relevant, including those relating to:

- support conditions,
- fixed connections,
- freedom of movement within joints,
- load transfer mechanisms and interaction between the structure and the ground.

Care should be taken to check whether the constraints and deformations occurring due to the conceptual layout, the boundary conditions and the actions comply with the performance of the component assessed in PC Step 3. The structural analysis for assessment is to be carried out in accordance with the basic principles given in EN 1990-1. The structural analysis methodology applied to a re-used component in the new structural context provides required outputs for the design verification (e. g., effects of actions at cross sections), considering the type of structure, material, actions and other relevant information including deterioration and damage.

Plastic redistribution may be considered for assessment at the ultimate limit state (ULS) if the component and the structure can be shown to have sufficient ductility. This holds in case of steel components for:

- Local plastification, e. g., in the vicinity of connections.
- Plastification distributed over the cross section for utilization of the plastic resistance of a cross section.
- Plastification distributed over the cross section for utilization of global plastic resistance of the structure

For the design of a structure using re-used components, it shall be verified that no limit state is exceeded in any applicable design situation using the partial factor method. Currently two alternative classifications for re-used elements are being considered depending on the period in which steel were produced (Table 5)

Table 5 Possible production periods (examples)

Alternative 1		Alternative 2	
Period	**Decades**	**Period**	**Decades**
1	1XXX–1959	1	1XXX–1959
2	1960–1969	2	1960–1989
3	1970–1999	3	1990–today/future
4	2000–today/future		

Design of old steel products may be covered by EN 1993(CovEx) or not (NonCovEx). CovEX can be divided into two scenarios, when the design is fully covered by EN 1993 and when some modifications are to be applied. NonCovEx consider also the scenarios in which background for additional rules is available and those in which background is to be researched. Table 6 provides the prioritization of the cases.

Table 6 Prioritised CovEx cases

CovEx Case 1	Components to be re-used, design fully covered by EN 1993	Priority 1
CovEx Case 2	Components to be re-used, design covered by EN 1993 but with modifications	Priority 1
NonCovEx Case 1	Components to be re-used, design not covered by EN 1993 but background for additional rules available	Priority 2
NonCovEx Case 2	Components to be re-used, design not covered by EN 1993 background for additional rules to be researched	Priority 3

Table 7 provides an estimation on the safety provision changes. This estimation defines a realistic, conservative but compatible with an increased adoption of reuse and preferred EoL option. For any steel produced after 1970 slight or no-change of safety provisions will apply if documents and technical information is available.

Table 7 Anticipated safety provision changes for re-used components

		Level of technical information on component		
		Low	**Medium**	**High**
Production period of component according to Alternative 1 of Tab. 6	1	CovEx Case 2 or NonCovEx Case 1/2 No safety provisions can be specified	Drastic change of safety provisions	Significant change of safety provisions
	2	CovEx Case 2 or NonCovEx Case 1 Drastic change of safety provisions	Significant change of safety provisions	Slight change of safety provisions
	3	CovEx Case 1 or CovEx Case 2 Significant change of safety provisions	Slight change of safety provisions	No change of safety provisions
	4	CovEx Case 1 Slight change of safety provisions	No change of safety provisions	

PC Step 7: 'Structural modification'

PC Step 7 is necessary if structural modifications are to be made to the component (e. g., by welding or bolting). The design must be done according to EN 1993 [3] and its future additions for re-used components as well as the execution should follow prEN 1090-x [15] for re-used steel components.

PC Step 8: 'Installation':

Finally, in PC Step 8, the used component is installed in a new structure. Here, EN 1090-2 (see section 2.1.4) is the governing rule,

5.4 Consistency of Actions

Steel industry is currently being a major contributor to the development of a framework to promote the re-use of construction product. While CPR and the CEN TC 350 SC1 are currently working in the general description of the re-use process, steel industry is working in a consolidated process from reclamation to installation of re-use structural components. Main challenges are related to the definition of efficient reclamation methodologies and the need and welds assessment.

While some limitation may be found for the reused of steel produced before 1970, particularly when not enough information is available, the re-use of steel components produced after 1970 is feasible resulting into safety factors in the 1.1 range, what is not a barrier. The scenario is particularly advantageous for future construction when information is integrated in digital passports.

6. Roadmap for the future development of steel reuse

This section provides analysis of possibilities for scaling up the outcomes of the background projects beyond their original focus area and an overview of the future technological and other trends affecting the constructional steel reuse. The assessment of past project outcomes was drafted by the partners participating in the projects and then reviewed by the ADVANCE consortium. The projects assessed in Section 6.1 are:

- PROGRESS (RFCS Grant Agreement 747847), "Provisions for a Greater Reuse of Steel Structures", 1.6.2017 - 31.5.2020.
- SB STEEL (RFSR-CT-2010-00027), "Sustainable building project in steel", 1.10.2010 - 30.6.2013.
- LVS3 (RFS2-CT-2013-00016), "Large Valorisation on Sustainability of Steel Structures" 1.7.2013 - 31.12.2014.
- REDUCE (RFCS Grant Agreement 710040), "Reuse and Demountability using Steel Structures and the Circular Economy", 1.7.2016 - 31.12.2019.

The outcomes of the project were assessed according to the following criteria:

- Applicability to all constructional steel (see the definition in Annex A)
- Applicability beyond constructional steel (e.g. to other materials or products)

The results of the assessment in Tables 8-10 are expressed as:

- 🔴 Not applicable (No): The outcome is not required outside of its original scope, or it would need to be completely different.
- 🟠 Applicable with major modifications: The outcome can serve as a basis for the development of the similar outcome in a different scope.
- 🟡 Applicable with (unspecified) modifications: The outcome can be modified or extended to be applicable in a wider scope, but the extent of the modifications was not possible to assess.
- 🟢 Applicable with minor modifications: The outcome can be updated to be applicable in a wider scope.
- 🟢 Applicable (Yes): The outcome of the project was developed to be used in the given scope or the change of the scope does not affect the applicability of the outcome.

The future trends affecting circular economy for steel-based building components are summarized in Section 6.2. This section identifies several technological and other factors that will influence the circular economy practices for steel-based building components, such as digitalization of the circular value chain, decarbonization of the building stock, industrial IoT in construction and deconstruction, smart circular buildings, extreme weather events, human migration patterns shift and demography change.

6.1 Upscaling recent research outputs

6.1.1 PROGRESS

The PROGRESS project [66] approached the most important aspect of the circular economy in steel construction, the reuse of components, across the whole lifecycle of the constructional steel products. Both, existing and future buildings were studied equally in the project to be able to provide continuity in the implementation of the sustainability goals. The methodologies, protocols and models were developed for the single-storey, steel framed buildings because of their relatively simple reusability, short service life and already emerging business models for their reuse or for the reuse of their components. The solutions for primary structure, secondary lightweight structure and envelope were developed in the project's Work Packages with the particular focus on their scalability and applicability beyond the single-storey steel buildings. It can be concluded that the project forms a solid framework for the future development of circular economy in steel construction.

Table 8. The most relevant outcomes of PROGRESS project

Outcome	**Scope**	**Applicable to all reusable constr. steel?**	**Applicable to other materials or products?**
European Recommendations for reuse of steel products in single-storey steel buildings	Single-storey steel buildings	🟢 The modifications will be done in ADVANCE project.	🔴 No
Lifecycle assessment methodology	Any reusable materials with closed-loop recycling	🟢 Yes	🟢 With minor modifications
Reusability assessment methodology	Steelwork, envelopes	🟢 Yes	🟡 With modifications
Pre-deconstruction audit protocol	Steelwork, envelopes	🟢 Yes	🟡 With modifications
Deconstruction protocol	Single-storey steel buildings	🟢 With minor modifications	🟠 With major modifications
Material qualification protocol	Hot-rolled sections	🟢 With minor modifications	🟠 With major modifications

6.1.2 SB STEEL

The main outcome of the SB Steel project [29] was a pilot software for decision-making to support selection of steel-intensive solutions in the early phases of a building project that are known to be most crucial for the success of the construction work and for the performance and value of the completed building. The early design stages were defined as phases of conceptual design and pre-design that are characterized by a lack of precise data and drawings. The piloting web-based service was made available to various operators of the steel construction sector by the European Convention of Constructional Steelwork ECCS. The project produced two printed publications concerning design methods and processes of sustainable steel-framed and steel-intensive buildings. It organised four workshops in four European countries. The R&D tasks of the project supported the development of approaches to steel-intensive new building and renovation and establishing of software:

- to build up a sustainability assessment methodology for a new or renovation building project
- to select a relevant set of key indicators and macro-components applicable for early stages of a building project
- to develop multi-criteria assessment method suitable for an early phase of a building project
- to develop a decision-making platform that supports selection of steel-intensive solutions
- to develop a pilot version of the software based on the combination of key indicators, macro-
- components and decision-making methodology.

Table 9. The most relevant outcomes of SB STEEL project

Outcome	**Scope**	**Applicable to all reusable constr. steel?**	**Applicable to other materials or products?**
Environmental Software Tool	Commercial, industrial, residential and office buildings, only Recycling in Module D. New buildings and renovations	🟡 With modifications	🟠 With major modifications
Key indicators and macro-components for early stages of design	Commercial, industrial, residential and office buildings, only Recycling in Module D. New buildings and renovations	🟠 With modifications	🔴 No
Databank of macro-components	Commercial, industrial, residential and office buildings, only Recycling in Module D. New buildings and renovations	🟠 With major modifications	🟠 With major modifications
Assessment methods focusing on deep structural renovations and functional upgrading	In-situ reuse / renovation	🟡 With modifications	🟡 With modifications
Background documents		🟠 With major modifications	🔴 No

6.1.3 LVS3

The main goal of LVS3 project [67] was to disseminate the knowledge acquired in the recent years about the environmental impact assessment of steel and composite buildings. During the previous decade, a lot of research projects have been funded to develop methodologies, systems and products aiming at improving the thermal efficiency as well as the global environmental footprint of steel buildings. The new standard EN 15804 intended for environmental calculation of buildings considered the fact that steel is a recyclable material (Module D). Therefore, the objective of this project was to summarise all this acquired knowledge into different documents (Background, Design guide, leaflet, User-friendly Software), to translate all these training and teaching support into the different European languages and finally to disseminate amongst Europe by the organisation of workshops.

Table 10. The most relevant outcomes of LVS3 project

Outcome	**Scope**	**Applicable to all reusable constr. steel?**	**Applicable to other materials or products?**
Mobile LCA app	Commercial, residential and office buildings, only Recycling in Module D.	🟢 Reuse and industrial buildings will be included in ADVANCE project.	🔴 No
AMECO software	Commercial, residential and office buildings, only Recycling in Module D.	🟠 With major modifications	🔴 No
Presentation materials		🟢 With minor modifications	🟠 With major modifications
Background document		🟠 With major modifications	🔴 No
Design guide		🟠 With major modifications	🔴 No

6.1.4 REDUCE

The overall objective of REDUCE was to provide practical tools and steel-based technologies to be able to design steel and composite structures for deconstruction and reuse. One objective was to develop and test demountable and reusable composite, steel-based flooring systems. This led to the use of demountable shear connector systems which were investigated in the project. The project investigated applications of the developed systems in commercial and residential buildings and explored options for greater standardisation. In the context of demountable composite construction systems, the shear connector systems with the greatest potential were tested and analysed using numerical modelling. The objective was to retain material efficiency through composite action while enabling future deconstruction and subsequent reuse.

Table 11. The most relevant outcomes of REDUCE project

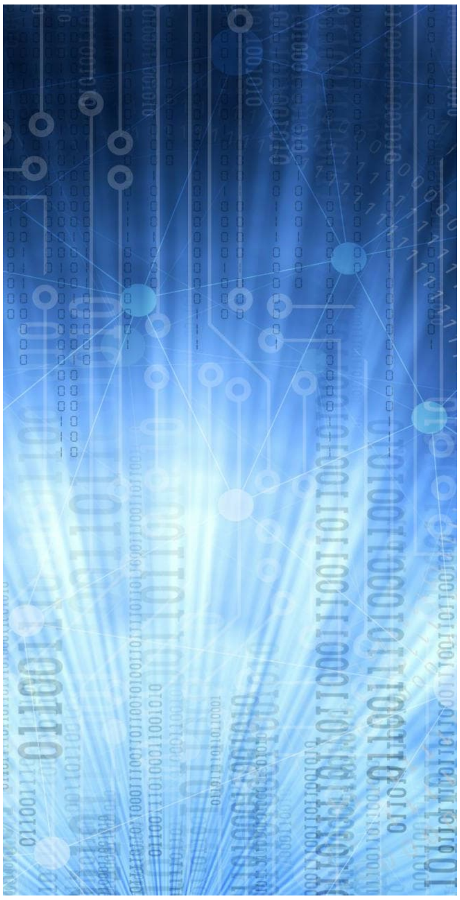
Outcome	**Scope**	**Applicable to all reusable const. steel?**	**Applicable to other materials or products?**
Guidance on design for re-use	Demountable composite construction systems; adaptability; BIM; LCA	With major modifications	With major modifications
Technical solutions	Steel /composite construction (composite beam/flooring; steel connections between elements or modules)	With major modifications	With major modifications (steel-timber)
LCA analyses considering reuse and application of BIM	Any reusable materials with closed-loop recycling	Yes	With minor modifications
Background document and presentation materials		With major modifications	With major modifications

6.2 Addressing the future trends

This section provides a detailed exploration of the technological and other trends affecting circular economy for steel-based building components, emphasizing the integration of advanced technologies and sustainable practices. It presents a comprehensive view of the upcoming opportunities and barriers and highlighting the importance of innovation and sustainability in the construction sector.

6.2.1 Digitalization of the circular value chain

Construction industry is rapidly developing the capabilities of processing building information models (BIMs) with the use of open data standards and open APIs for automatic information exchange. Several new concepts are emerging in this area:



Digital passports and logbooks

The introduction of digital material/product passports [69] and building logbook will bring a standardized description of the data structures and ontologies necessary to facilitate information delivery and exchange during the reuse process.

BIM in online marketplaces

Material exchange platforms will gradually start offering BIM objects [70] to decrease data modelling needs for the new buildings. Pre-selling of components from existing buildings will be much easier.

Machine readable standards and regulations

Conversion of regulatory documents to machine readable format will allow fast and accurate automatic compliance checks. This will increase safety of the works and decrease time needed to obtain permits and other certifications [71].

Blockchains

Blockchains will be gradually implemented to secure contractual and design data between different stakeholders in the reuse process. They will help streamlining the complicated supply chains [72].

6.2.2 Advanced computing in structural reuse

The role of computing and simulations will grow beyond of the traditional domain of structural engineering and thermal modelling. For instance, implementation of generative AI in the construction sector may bring advancement in several areas, especially in the design and reconstruction of existing and obsolete information sources.

3D models from flat images

Efficient reuse of structural elements should be based on accurate information of their shape and spatial configuration. Therefore, 3D representation of components and structures is important and may be obtained from 2D drawings [73] or even aerial photos with the help of generative AI.

Structural design and detailing

Designing a new building with elements with unique shape or alterations made during its previous life may be difficult task in a common architectural practice. However, generative algorithms may easily overcome this obstacle by providing solutions to optimal layout and detailing of connections between reused components in the new design [74][75].

Probabilistic programming

The introduction of probabilistic programming languages will allow faster development of applications for the assessment of reused products or for the verification of their structural integrity and stability [76].

Quantum computing

The future quantum computers will play important role especially in material modelling, automated design logic and complex optimization tasks [77].

6.2.3 Decarbonization of the building stock

This section focuses on the technological advancements and challenges in the construction practices driven by the need to decarbonize the building stock.

Decarbonization of steelmaking

Use of (green) hydrogen and biochar in steelmaking will reduce further the environmental impact of recycling [78] [79]. However, component reuse will be still more efficient option in most cases in the future.

Green tech integration

The future buildings will require new types of components, especially for energy production (solar panels, energy harvesting piles), storage (batteries) and distribution (charging stations). The components from existing buildings will need to be adapted or integrated in the new design process.

New carbon efficient materials

Introduction of new low-carbon materials (such as carbonated concrete [81]) may affect the choices of future designers, and therefore it may be necessary to look for the alternative uses of the current constructional steel components.

6.2.4 Reuse of additive manufactured products

The use of 3D printed custom components [82] does not seem to be corresponding with the basic idea of reusable construction, which requires standardization of shapes and modularity. However, in combination with AI-assisted design tools, reuse of such components might be as simple as in the case of traditional modular construction. Standardization will then focus on connections and interfaces and structural typologies instead of prescribed sizes and shapes of the products. This will allow greater advancement of mass customization of constructional steelwork [83].

6.2.5 Industrial IoT in construction and deconstruction

This section explores how IoT technologies can facilitate circular economy practices.

Off-site manufacturing

The general trend in the construction sector is to prepare most of the components in the workshops and assemble them on site [84]. On-site drilling, cutting and welding will be reduced. Building modules may be assembled in the automatic assembly lines.

5G technology

The use of private 5G networks in manufacturing and on-site operations allows precise positioning, and bandwidth sufficient for video streams from multiple sources [85].

Robots and drones on site

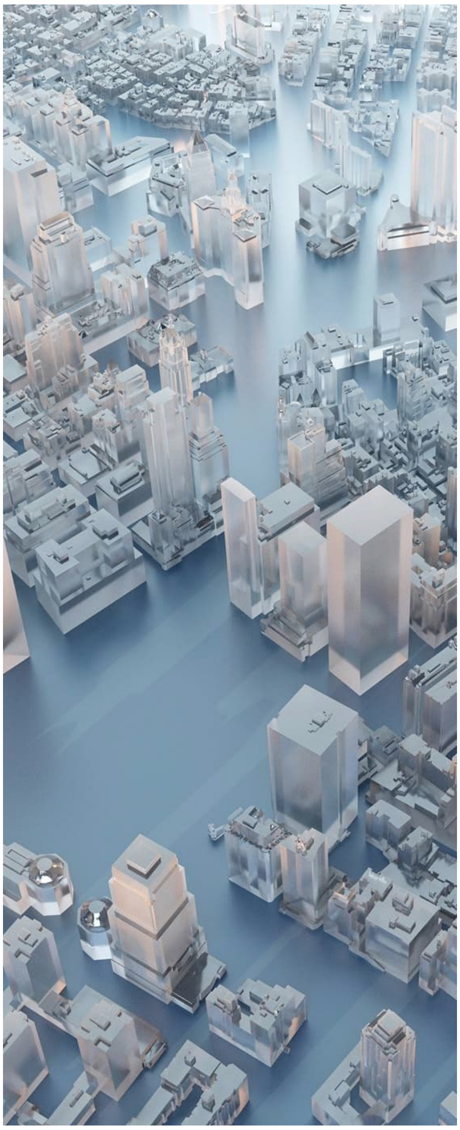
Robots and drones will be able to reach beyond visual line of sight or to access hazardous environments. They may also have cognitive skills and collaborative abilities [86]. They may be provided as service for the specific construction or deconstruction project.

Proximity, material and object recognition

Advances in the remote scanning e.g. with the use of Active Hyperspectral Sensing, Muon detection, Ground Penetration Radar with Eddi Current measurement will Improve material handling and accuracy of inspections of existing buildings [87].

6.2.6 Smart circular buildings

Technologies and innovations linked to smart buildings and infrastructures are the focus of section 6.2.6, where they are applied to streamline disassembly, reuse and re-designing process.



Digital twins and cognitive twins

The adoption of digital twins is increasing in construction industry. With the integration of AI to simulate assets, machines and processes in real-time they become powerful tools in planning and operation of new buildings [88].

Mixed reality, virtual reality, augmented reality

Augmented Reality (AR) and Virtual Reality (VR) are gaining more prominence in the development of digital twins. These technologies are also used in structural steel reuse projects, such as the RWTH seminar building in Aachen [58].

Hybrid human-computer vision analysis

Sensor fusion and spatial computing technologies can be further enhancing the AR/VR experience during on-site operations, deconstruction and inspection works. They can provide real-time sensor data visualization, equipment tracking, and evaluation of the material and product suitability for reuse.

Decentralized content platforms

The utilization of big data, digital passports and complex ontologies in the construction sector create a shift towards decentralized digital and data-driven practices. However, it's important to note that the adoption of these technologies also comes with challenges, such as ensuring data security, privacy, interoperability, and the scalability of decentralized data storage [89].

6.2.7 Other relevant factors affecting future structural steel reuse

The external factors relevant that could influence the future of structural steel reuse are presented in the following overview.

Extreme weather events

The increasing number of storms, draughts and fires, floods and landslides, heatwaves and other climate-related effects [90] will require future structures to be robust and able to resist such events. Reused steelwork might need to be reinforced or otherwise adjusted to fulfil the future design criteria.

Human migration patterns shift

Global events have been causing several large migration waves in recent years. [91] This effect relates to the need of temporary housing and services where reusable lightweight construction systems might be a suitable solution.

Demography change

The ageing population in Europe [92] and worldwide will require significant changes in the building construction and operation patterns. Selection of durable materials and robust systems without demanding maintenance needs will be preferred.

7. Summary

Circular economy is a rapidly developing area with the ambition to mitigate negative impacts of climate change and scarcity of natural resources. Construction sector plays an essential role in the implementation of circular economy principle because it is responsible for a large share of carbon emissions and waste. Although reuse of constructional steel components seems to be a very small part of the circular construction, its importance reaches far beyond the direct environmental impact of the currently reused elements because of the following reasons:

- Constructional steel is becoming the first building material with the fully developed set of European technical standards supporting its deconstruction and reuse. Reuse concept will be implemented in the execution standards [24] and the Eurocodes [9], and the Product Category Rules (PCR) for the steel components are under development [38]. The whole process is then supported by a large number of industry guides and national standards, especially in the area of material qualification [11][12][15][17][19][20][22][23] and environmental assessment [32][34][36]; many of those existing documents being already implemented by the industries. We assume that the process of closing the “standardization loop” will be followed by other materials in the upcoming years.

- Deconstruction and reuse of construction products from other materials will largely depend on steel-based solutions. Bolted and clamped connections made of steel will be more widely used to join prefabricated concrete [93] and timber [94] elements to enable easy and efficient separation at the building’s end-of-life. Therefore, the innovations in this area will have large indirect impact on the circularity of the whole building sector.

- According to the numerous case studies and interviews conducted in the previous projects, it is obvious that reuse of constructional steel elements can be profitable and desirable solution in a wide range of situations. We have carefully mapped and categorized successful case studies and highlighted the main reasons, benefits and bottlenecks during their execution.

- Structural steel has highly developed and efficient distribution and collection chain across the Europe. Almost 100% of the end-of-life steel scrap is recovered and recycled, and therefore the adaptation to cover collection and re-distribution of reusable building elements will be easier than in the case of other materials without similar infrastructure.

- Reused constructional steel components will be able to serve well in the changing environment during the following decades and centuries. They are suitable for the modern construction and inspection techniques and the reused material itself does not need any alterations or modifications to reach the demanding sustainability targets.

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Annex A: Terms and definitions

This section presents hierarchical glossary of terms and definitions used in ADVANCE project. This glossary will be used for the development of steel reuse ontology in order to be able to process information about circular steel use cases in machine-readable format.

Activity is action, process or operation performed on construction, product or waste during its life cycle.

> **Alteration** is a transformative process of a product or component.
>
> > **Minor alteration** means transformation caused by checking, cleaning and repairing, which results in a product or component that retains most of its original material (by weight) and does not change its major dimensions by more than 10%.[1]
> >
> > **Major alteration** is going beyond checking, cleaning or repairing recovery operations by which the product or components of products are prepared.[2]
>
> **Audit** (or pre-development audit) is qualitative and quantitative assessment of materials and products prior to deconstruction, demolition or renovation of buildings and infrastructures. It includes demolition and refurbishment assessments of what can be reused from deconstruction and stripped out, respectively. It informs the potential to reuse products and materials in subsequent construction and/or fit out (of refurbishment) [3] [4]
>
> > **Reclamation audit** is the pre-development audit focusing specifically on building products before refurbishment or deconstruction, their characterisation and planning of their reuse. It results in the reclamation inventory.[5]
> >
> > > **Pre-deconstruction audit** is the reclamation audit before building deconstruction. Its main purpose is to prevent the reusable products becoming waste.[1]
> >
> > **Material audit** (or resource audit) is the audit focusing on the materials, their characterisation, recycling and recovery. Such audit is typically performed before traditional demolition and can be also called **pre-demolition audit**.[1]
> >
> > > **Waste audit** is the material audit focusing on different waste streams, their characterisation and management.[3]

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[1] Based on PROGRESS project, Deliverable D9.1 Comprehensive Overview of the Project
[2] Based on the adapted text of the new Construction Products Regulation (CPR)
[3] Based on the European Commission's Waste Audit Guidelines
[4] Based on BAMB project https://www.bamb2020.eu/wp-content/uploads/2017/07/Reuse-of-building-products-and-materials-barriers-and-opportunities.pdf
[5] Based on FCRBE project https://opalis.eu/sites/default/files/2022-02/FCRBE-Reclamation_Audit-v12.pdf

Deconstruction (or disassembly) is the selective dismantlement of building components, specifically for reuse, repurposing, recycling, and waste management. It differs from demolition where a site is cleared of its building by the most expedient means.[1]

Decontamination is reduction or removal of hazardous materials.[1]

Deep renovation is a renovation, which focuses on essential building elements, and which transforms a building or building unit into a zero-emission building.[6]

Demolition is the tearing down of buildings and other structures typically resulting in their destruction. It contrasts with deconstruction, which involves taking a building apart while carefully preserving valuable components for reuse purposes.[1]

> **Selective demolition** is the demolition focused on specific waste materials that are treated separately from the mixed waste. It results in higher quality materials for recycling. It is often combined with deconstruction of selected reusable components.[1]

Destruction is the intentional damaging or discarding of a product as waste with the exception of discarding for the only purpose of delivering a product for preparing for re-use or remanufacturing operations.[7]

Distance selling is offer for sale, hire or hire purchase of products, online or through other means of distance sales, whereby the potential customer cannot physically access the product displayed.[7]

Execution means all activities carried out for the physical completion of the construction works including procurement, the inspection and documentation, such as work on site or fabrication of components off site and their subsequent erection on site.[8] [9]

Maintenance is an action (or series of actions) carried out during the working life of the structure or product to retain it in a condition where it can function as specified. It includes set of activities to enable it to fulfil the requirements for reliability.[2] [7] [8]

Manufacturing is an activity required to produce and deliver the component, which may encompass fabrication, welding, mechanical fastenings, assembly, testing and documentation of the performance characteristics declared.[9] [10]

Preparing for assembly is an activity performed on the constituent products to produce the parts ready for assembly and inclusion in components, such as identification, handling and storage, cutting, shaping and holing.[9]

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[6] Based on the Energy Performance of Buildings Directive (EPBD)
[7] Based on the Ecodesign for Sustainable Products Regulation (ESPR)
[8] Based on EN 1990 (Eurocode 0)
[9] Based on EN 1090-2
[10] Based on EN 1090-1

Preparing for reuse means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.[11]

Recycling is a process where the waste materials are collected, broken down and processed to be converted into raw materials for new products. The process is typically energy intensive, requires a special facility and differs from reuse where the components do not enter the material stage.[11]

Closed-loop recycling is a process in which products are recycled into materials aimed to manufacturing products with the same function. An example of closed-loop recycling is recycling steel into steel by re-melting.[1]

Open loop recycling is a process where the material gained from recycling is used in a different product system than the original product. It comprises both upcycling and downcycling.[1]

Downcycling is a recycling process when the product created from recycled material is of lower commercial value, quality or functionality than the original product. One example is the crushing of concrete for use as road fill or aggregate.[1]

Upcycling is a recycling process when resulting product or material is of a higher commercial value, quality or functionality than the original item.[1]

Refurbishment means preparing or modifying an object that is waste or a product to restore its performance or functionality within the intended use, range of performance and maintenance originally conceived at the design stage, or to meet applicable technical standards or regulatory requirements, with the result of making a fully functional product.[7]

Remanufacturing is an industrial process in which a product is produced from objects that are waste, products or components and in which at least one change is made to the product that affects the safety, performance, purpose or type of the product typically placed on the market with a commercial guarantee.[7]

Repair means returning a defective product or structure (fixing or replacing its defective components) to a condition where it fulfils its intended use. This activity falls outside the definition of maintenance.[2 7 8]

Repurposing is any operation that changes the function or purpose of a component.[1]

Reuse is any operation by which the building components are used again. They may be reused for the original function (a conventional reuse scenario), or repurposed, but the components will only have minor alterations, retaining a similar (or the same) form. The operation includes checking, cleaning or repairing, by which the components are prepared so they can be used without any other pre-processing. Components can be reused in closed-

[11] Based on the Waste Framework Directive (WFD)

loop without repurposing or open-loop resulting in lower or higher value of the reused products.[1 11]

Adaptive reuse (of buildings or building sites) is the process when the buildings or sites are repurposed for use other than the original design. Adaptive reuse is not the focus of the ADVANCE project.[1]

In-situ reuse means that the component is reused locally in the same or neighbouring building site without the need to organize its transport.[1]

Relocated reuse requires transport of the component over longer distances.[1]

Upgrading means enhancing the functionality, performance, capacity or aesthetics of a product.[7]

Waste management is the collection, transport, recovery (including sorting), and disposal of waste, including the supervision of such operations and the aftercare of disposal sites, and including actions taken as a dealer or broker.[11]

Waste prevention means measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including through the re-use of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of hazardous substances in materials and products.[11]

Waste recovery is any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations.[11]

Waste treatment means recovery or disposal operations, including preparation prior to recovery or disposal.[11]

Actor is a natural or legal person/organisation responsible for carrying out any activity or in possession of the materials, products or components at any stage of the building's life cycle.

Constructor is any natural or legal person executing the construction works.[9]

Contractor is any natural or legal person acting on behalf of the owner of the construction, products, material or waste with the responsibilities specified in the contract.

Dealer is a retailer or any other natural or legal person who offers products for sale, hire or hire purchase, or displays products to customers in the course of a commercial activity, whether or not in return for payment.[7]

Distributor is any natural or legal person in the supply chain, other than the manufacturer or the importer, who makes a product available on the market, including by offering products for sale, hire or hire purchase, or displaying products to customers or installers during a commercial activity, and including through distance selling, whether or not in return for payment.[2 7]

Economic operator is the manufacturer, the authorised representative, the importer, the distributor, the fulfilment service provider or any other natural or legal person in relation to the manufacturing or remanufacturing of products, including reused products, or to making those products available on the market in accordance with CPR.[2 7]

End user is any natural or legal person, to whom a product has been made available either as a consumer outside of any trade, business, craft or profession or as a professional end user during its industrial or professional activities.[12]

Manufacturer is any natural or legal person who manufactures a product or who has such a product designed or manufactured and markets that product under its name or trademark or, in the absence of such person or an importer, any natural or legal person who places on the market or puts into service a product.[5 12]

Service provider is any natural or legal person providing a service to a manufacturer or to a supplier of a key part, provided that the service is relevant for the manufacturing of products, including to their design, or to their deinstallation in the case of reused products.[2]

Supplier is any natural or legal person providing raw materials, interim products, or used products to manufacturers or to other persons providing raw materials, interim products, or used products to manufacturers.[2]

Waste holder means the waste producer or the natural or legal person who is in possession of the waste.[11]

Waste producer is anyone whose activities produce waste or anyone who carries out pre-processing, mixing or other operations resulting in a change in the nature or composition of this waste.[11]

Building element is a technical building system or an element of the building envelope.[6]

Building envelope means the integrated elements of a building which separate its interior from the outdoor environment.[6]

CE marking is a marking by which the manufacturer indicates that the relevant product is in conformity with the applicable requirements set out in Union harmonisation legislation providing for its affixing.[7]

Circular Economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible. In this way, the life cycle of the products is extended.[13]

[12] Based on the European Regulation (EU) 2019/1020.
[13] Based on European Parliament's definition https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits

Construction (or construction works) is everything that is constructed or results from construction operations whether over or in the ground or water. This term covers both building and civil engineering works comprising both structural and non-structural components. [2 8 9 14]

> **Building** is a roofed construction having walls, that provide shelter for its occupants or contents as one of its main purposes, usually partially or totally enclosed and designed to stay in one place permanently.[6 14]
>
> **Civil engineering works** means construction works including, but not limited to roads, bridges, tunnels, pylons and other facilities for transport of electricity, communication cables, pipelines, aqueducts, dams, airports, ports, waterways, and installations which is the bases for the rails of railways.
>
> **Structural steelwork** means steel structures or manufactured steel components used in construction works.[9]

Degradation is loss of item performance due to changes in its material, geometry or connection to the system.

Design strategy is a set of rules and requirements for the design process to achieve optimal solution with respect to the specific set of goals.

> **Design for deconstruction** (design for disassembly, DfD) is a design strategy considering how a building can be taken apart allowing for effective recovery of building materials and components.[1]
>
> **Design for end-of-life** (DfEOL) is a design strategy considering one or more end-of-life scenarios including the communication of the relevant design information to the end-of-life industry.[1]
>
> > **Design for reuse** is a specific DfEOL approach considering deconstruction and reuse of building components as one of the basic requirements. The design documentation should take into account also reuse process.[1]

Design life (or design working life) is assumed period for which the component or structure is to be used for its intended purpose with anticipated maintenance but without major repair being necessary.[10]

Digital passport is a repository of machine-readable information about a physical entity or process in open data format according to the dedicated specification. The data may be open or with restricted access.

> **Building logbook** (or Digital Building Logbook, DBL) is a common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, as well as data related to the life cycle GWP, which facilitates informed decision making and information sharing within

[14] Based on ISO 6707-1:2017

the construction sector, and among building owners and occupants, financial institutions and public bodies.[6]

Material passport (or Digital Material Passport, DMP)

Product passport (or Digital Product Passport, DPP) is a set of data specific to a product that includes the information specified in the applicable delegated act adopted pursuant to Article 4 of ESPR and that is accessible via electronic means through a data carrier in accordance with Chapter III of ESPR.[7]

Construction Product passport is the Digital Product Passport of construction products according to the new Construction Products Regulation.[2]

Renovation passport is a tailored roadmap for the deep renovation of a specific building in a maximum number of steps that will significantly improve its energy performance.[6]

Environmental impact means any change to the environment, whether adverse or beneficial, wholly or partially resulting from a product system during its life cycle or beyond the system boundary directly related to the product.[7]

Environmental footprint is a quantification of a product's environmental impacts, whether in relation to a single environmental impact category or an aggregated set of impact categories occurring in one or more life cycle stages.[7]

Carbon footprint is the sum of greenhouse gas emissions and their removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change.[7]

Whole-life-cycle greenhouse gas emissions are greenhouse gas emissions that occur over the whole life cycle of a building, including the production and transport of construction products, construction-site activities, the use of energy in the building and replacement of construction products, as well as demolition, transport and management of waste materials and their reuse, recycling and final disposal.[6]

Life-cycle global warming potential is an indicator which quantifies the global warming potential contributions of a building along its full life cycle.[6]

Essential characteristics are those characteristics of the product which relate to the basic requirements for construction works set out in Annex I of CPR, and those which are listed as predetermined environmental essential characteristics in Annex II of CPR.[2]

Kit is a product placed on the market by a single economic operator as a set of at least two separate items, none of which needs to be a product itself, intended to be incorporated together in construction works.[2]

Structural kit means set of structural components to be assembled and installed on site.[10]

Life cycle means the consecutive and interlinked stages of a product's life, from raw material acquisition or generation from natural resources, or in the case of products which have previously been incorporated in a construction work, from the latest de-installation from the construction work to final disposal.[2 7]

End-of-life is the life cycle stage that begins when a product is discarded and ends when the product is returned to nature as a waste product or enters another product's life cycle.[7]

Material (e.g. steel) means any substance, excluding waste, with specific properties that is embedded in the products in a permanent manner.

Constructional material (e.g. constructional steel) is a material used in the construction works.

Structural material (e.g. structural steel) is a constructional material used in the load bearing (structural) components.

Obsolescence is loss of product performance due to changes in the performance requirements.[15]

Performance is the degree to which a product has certain scalable characteristics.[2]

Adaptability is the possibility to change or modify a product, system or module to make it suitable for a particular purpose.[13]

Durability is the ability of a product to function as required, under specified conditions of use, maintenance and repair, until a limiting event prevents its functioning.[7]

Load bearing capacity is value or set of values for the loads that can be carried by the component referring respectively to either a single type and direction of loading or to a set of loads in various directions and referring to a defined level of resistance in accordance with EN 1990 and the relevant parts of EN 1993, EN 1994 or EN 1999. For kits the load bearing capacity refers to loads and load combinations the kit can carry that are relevant to the structure for its intended purpose.[10]

Recyclability is the susceptibility of a material or product to be effectively and efficiently separated, collected, sorted and aggregated in specific waste streams for the purpose of being recycled into secondary raw materials while minimising the loss of quality or functionality compared to the relevant primary raw material.[2]

Reliability is the ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed the probability that a product functions as required under given conditions for a given duration without a limiting event. It covers safety, serviceability and durability of a structure.[5 10]

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[15] Based on ISO 15686-1:2011.

Reusability is the ability of a product, component or system to be used in its original form more than once and maintain its value and functional qualities during recovery to accommodate reapplication for the same or any purpose.[16]

Weldability is quality of a material for which a qualified welding procedure can be developed.[10]

Product is formed or formless physical item or a kit that is placed on the market or put into service.[7]

Component is a product manufactured as a distinct unit to serve a specific function or functions and intended to be incorporated into another product or structure, which may itself be an assembly of several smaller components.[7 9 13]

Structural component is a component to be used as load-bearing parts of works designed to provide required performance which can be used directly as delivered or can be incorporated into a construction work.[9 10]

Constituent product is a product used in manufacturing with properties which enter structural calculations or otherwise relate to the mechanical resistance and stability of construction works.[9 10]

Construction product is a product that is placed on the market, including by means of supply to the construction site, for incorporation in a permanent manner into construction works or parts thereof with the exception of items that need first to be integrated into a kit or another construction product prior to being incorporated in a permanent manner into construction works.[2]

Custom-made product is a product that, due to the specifications of the client, has a variation in terms of size or material when compared with all other products produced for other clients by the economic operator in question.[2]

Intermediate product is a product that requires further manufacturing or transformation such as mixing, coating or assembling to make it suitable for end-users.[7]

Permanent product is a product intended to remain in the construction work, or in parts thereof, after the completion of the construction or renovation process.[2]

Remanufactured product is a product that is not waste or has ceased to be waste in accordance with Directive 2008/98/EC, which has been installed at least once into a construction work, and that has been subject to major alteration which is qualified as essential to the product's performance.[2]

Used product is a product that is not waste or has ceased to be waste in accordance with WFD, and which has been installed at least once into a construction work, and that: (a) has not undergone major alteration so that it can be used for construction purposes without any

[16] Based on Level(s) https://ec.europa.eu/jrc/en/publication/levels-common-eu-framework-core-sustainability-indicators-office-and-residential-buildings-part-3

other pre-processing; or (b) has been subject to a major alteration which, according to the applicable harmonised technical specification, is qualified as non-essential to the product's performance.[2]

Reused product is a used product installed for at least second time into a construction work.

Service life is the cumulative time during which the component is in use.[1]

Estimated service life (ESL) is the estimated service life of a component.[17]

Reference service life (RSL) is a service life of a component, which is known to be expected under a particular set (e.g. a reference set) of in-use conditions and which may form the basis of estimating the service life under other in-use conditions.[17]

Structure (or structural assembly) is the assembled and organised system of connected structural components designed to carry loads and provide adequate rigidity.[8] [10]

Structural member is physically distinguishable part of a structure, e.g. a column, a beam, a slab, a foundation pile.[8]

Structural system is load-bearing members of a building or civil engineering works and the way in which these members function together.[8]

Use

Intended use is the purpose of a product as set out in the applicable harmonised technical specifications or European assessment documents.[2]

Declared use is the use intended by the manufacturer, including the conditions for usage, as laid out in technical documentation, on labels, in instructions for use, in safety information, or in publicity material.[2]

Waste (e.g. steel scrap) means any substance or object which the waste holder discards or intends or is required to discard.[11]

Construction and demolition waste (CDW) is waste generated by construction and demolition activities.[11]

Hazardous waste is waste that poses substantial or potential threats to public health or the environment. Waste classification is based on the European List of Waste or based on its hazardous properties.[11]

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[17] Based on EN 15804

Annex B: ADVANCE case studies

The consortium of ADVANCE project agreed on developing several additional factsheets to the collection of case studies by PROGRESS project. The factsheets prepared in the first year of the project are presented in this Annex. The complete set of case studies will be then published on the project webpage https://www.steelconstruct.com/eu-projects/advance/ after the project ending date.

Reuse of Steel Case Study no. 12

Design for circularity – Petite Maison, Luxembourg

Project summary

Client: University of Luxembourg (UL)
Subsidized by: Esch2022 and frEsch.asbl
Contractors: Annen, CDCL, Gardula, Schreinerei Hoffmann, Mabilux, Prefalux, Reckinger
Architects: Carole Schmit (UL), Dragos Ghioca (UL)
Structural engineers: András Kozma (DESA), Christoph Odenbreit (UL)
Steel fabricator: ArcelorMittal
Engineering: Betic Ingénieurs-Conseils, BIM-Y, Fire Group SECO, DESA Ingénieurs-Conseils, Geri Securite Sante, Icone, Mersch Ingénieurs-paysagistes, Metrico, Paul Wurth – Geprolux, Polaris Architects, Schroeder & Associés
Construction cost (including demolition): N/A

Description of the new building

The Petite Maison building[1], located in Esch-Belval, Luxembourg, was initiated as an architectural project in January 2021 to promote the circularity of construction materials and contribute to the European Capital of Culture Esch2022. The project comprised design, construction, use and deconstruction phases. The structure was specifically designed for disassembling/deconstruction and reuse, incorporating the latest advancements from the European project REDUCE[2] on demountability and reuse of composite structures.

The main part of the building structure consisted of:

- a steel frame, measuring 10.8 meters (m) × 8.1 m, following a structural grid of 1.35 m,
- modular and prefabricated structural kits[3] in standard sizes, including concrete slabs (1.35 m × 5.4 m) with bolted shear connections, adaptable steel connections,
- diagonal bracing systems (roof and wall),
- a timber roof with steel profiled cladding sheets, supported by steel posts,
- timber wall panels, partitions, cladding, and
- prefabricated concrete foundations.

During the use phase, the building was open for guided public visists, workshops, lectures, a cafeteria by Restopolis. A mobile exhibition on deconstruction, designed by Rotor in Brussels, as part of an INTERREG project called FCRBE was hosted in Petite Maison as well and was open to public visit from December 2022 until January 2023.

In August 2023, the deconstruction of the Petite Maison building commenced. QR codes were attached to reusable building components, linking them to a virtual database to facilitate future reuse. Reclaimed materials and components are presently stored at ArcelorMittal's premises near the building site. Ongoing efforts are underway to transfer these materials to the City of Esch-sur-Alzette with the objective of giving these construction materials a second life.

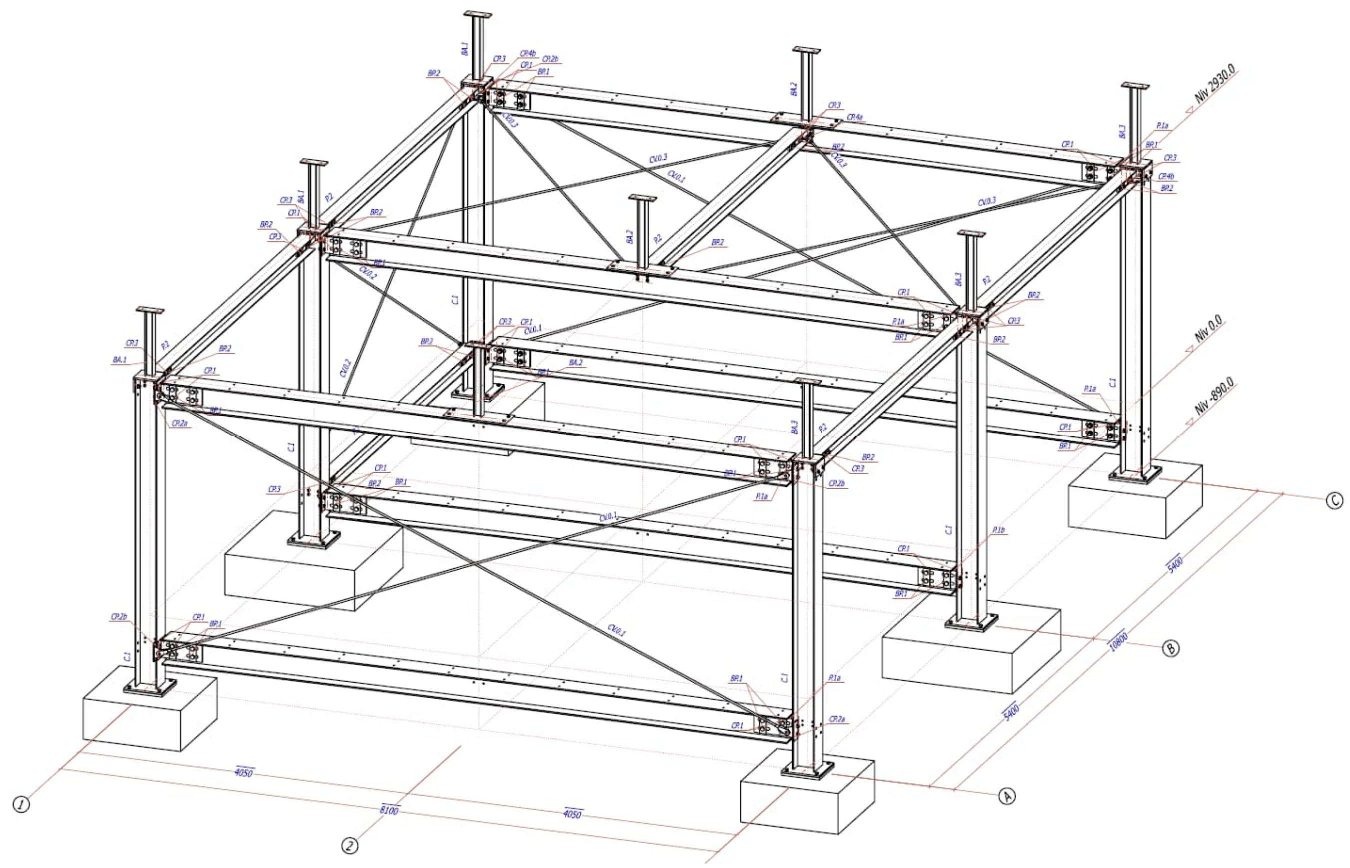
Design process

Several key considerations have been integrated into the design process to enhance sustainability and circularity:

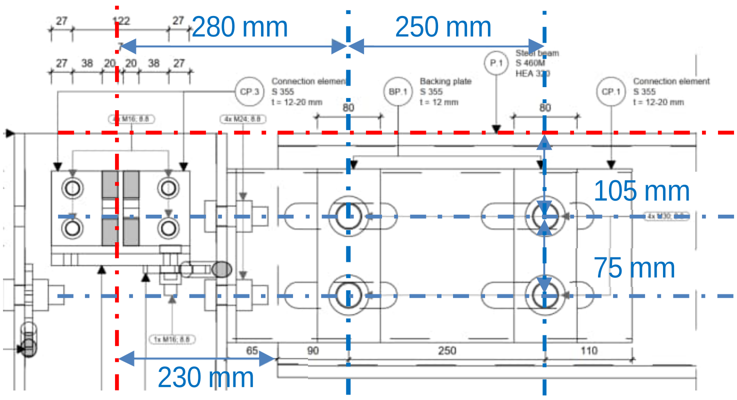
- Carbon optimization:
  During the initial design phase, grade S355 steel was chosen for the frame. In the final design, grade S460 steel was adopted to optimize the frame's weight and minimized embodied carbon footprint, which resulted in 24% reduction in weight, decreasing from 17.39 tons to 13.25 tons.
  Precambering was applied to equalize deflections. The level of necessary precambering was determined using a model with semi-rigid joints considering the real joint stiffness.
- Prioritization of modular prefabricated elements with standardized details:
  Prefabricated concrete slabs have been standardized to conform to a uniform size, while all beams have been standardized in length, aligned with a structural grid of 1.35 meters.
  The number of different elements has been minimized. Uniform sections, including identical bolt hole layouts, were used for columns and primary beams. All additional connected members (for example bracing, roof structure, etc.) used the existing pre-drilled holes in beams and columns.
  Adaptable steel connections were utilized, featuring standardized midi grids for bolts in endplates and fin plates: the first row of bolts in the fin plate and endplate was 105 mm off the edge of the top flange of the beam, followed by 75 mm spacing for the other rows; the first column of bolts in the fin plate was 280 mm off the centreline of the column, followed by 250 mm for the other columns of bolts.
  Concrete foundations are prefabricated, and are designed to be removable and potentially reusable.
- Consideration of member adaptability:
  Adaptable steel connections enable secondary beams to connect with primary beams as well as columns of various sizes within the same structural grid, enhancing the adaptability of these beams.
- Designing for disassembly using bolted connections:
  Bolted connections have been favored within the structure: demountable shear connections between beam and slab, connections for beams, columns, bracings, and foundations, allowing for easier disassembly compared to welded connections. Welding was kept to an absolute minimum (only the base plate is welded to the column, nothing else).
- Responsible sourcing of materials:
  Main building components are new materials with low environment impact inputs where possible, while non-loadbearing timber panels are reused materials; all are sourced from nearby suppliers, thereby minimizing environmental impact.

The design loads and design codes are summarized in the following table (steel structure):

Load (Design code)	Characteristic values (kN/m²)	
Permanent load (EN 1991-1-1)	Cladding - roof	0.25
	Cladding - wall	0.85
	Technical installations	0.50
Snow (EN 1991-1-3)	Snow load on the ground, s_k	0.60
Wind (EN 1991-1-4)	Peak velocity pressure: q_p	0.75
Imposed load (EN1991-1-1)	Imposed load on slabs (Cat. C3)	5.00
	Imposed load on roof (Cat. H)	0.40



Drawing of the structure.



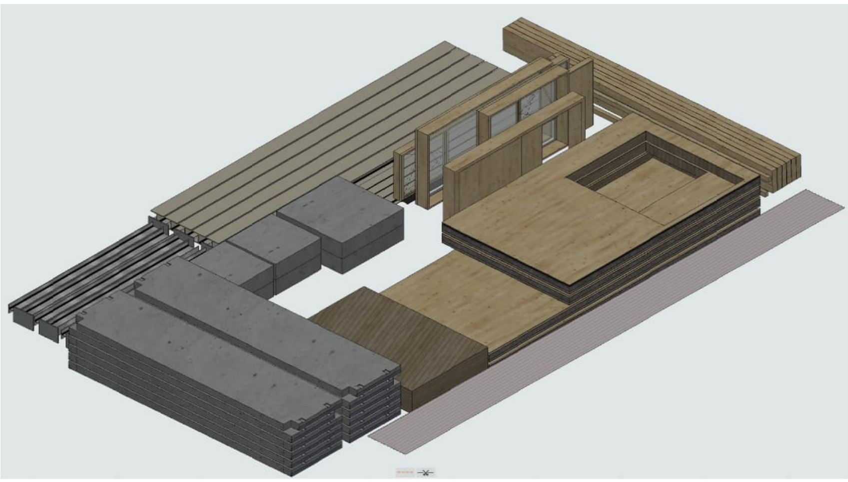
Details of a complex joint where multiple members meet[3]; *Standardized midi grids for bolts in endplates and fin plates*[3].

Construction and deconstruction processes

Both digital and printed inventory catalogues are easily accessible. Each construction element underwent after BIM-modelling by the architects, scanning and inventorying, with QR codes attached, linking to a deconstruction platform jointly developed by LIST and BIM-Y. This platform provides detailed information on geometry, technical properties, and manufacturers.

Steel skeleton with prefabricated concrete slabs[1].

The same contractors are responsible for the construction and deconstruction of the building. The deconstruction process closely mirrored the original construction sequence. A deconstruction procedure[4] and storage plan, devised by Uni.Lu, facilitated efficient handling and organization throughout the deconstruction process.



Storage space measuring 13.5 m × 6 m, estimated by Dragos Ghioca, Uni.Lu.

Schroeder & Associés conducted site visits and surveys to evaluate material and component damage during deconstruction and their potential for reuse. According to their reports and the authors' visit to the storage site:

- Steel sheets were unscrewed from the timber roof frame without any loss, but minor damages were observed in the timber frame at the screw level.
- The elements within the steel frame, including prefabricated concrete slabs and foundations, are well separated and in good condition: there is no visible degradation of galvanization, no signs of rust, and no visible deformation of the profiles. However, local damages have been observed in the concrete foundation blocks. Additionally, the edges of the concrete slabs near the shear connection were protected by steel angles, and no damage could be observed.
- Dismantling the timber frame and partitions revealed challenges with connections between different elements: while the elements remained sufficiently rigid during handling, the screws were deeply embedded, it was necessary to cut notches to access the screw heads.
- Several timber cladding boards were damaged due to nailing fixation; the use of stainless-steel screws would have been more suitable.

- Salvaged elements were labelled by the contractors after deconstruction.
- Due to the size of the timber partitions, they were temporarily stored at PREFALUX.
- The L plates in the adaptable steel connections with the bolts have been reattached to the beams.
- Bolts, threaded rods, and nuts have been recovered.
- Other salvaged materials included major part of the insulation elements, plastic covering films, etc.

Photo taken during deconstruction © Schroeder & Associés; Timber panels with notches for accessing screw heads during deconstruction.

Reclaimed materials are stored at ArcelorMittal's Differdange site, with steel connections reassembled, and QR codes and labels attached to the main structure components. Local damages to the concrete foundation blocks have been observed.

Future reuse scenarios

Future reuse scenarios are under consideration for the materials reclaimed from the Petite Maison project:

- Relocation: the plan involves relocating and reconstructing the Petite Maison building using the same materials and components from within the project itself.
- Extension: this approach involves accommodating reclaimed materials and components in the same layout of the original Petite Maison building, with extensions constructed using reclaimed materials sourced from other buildings or projects.
- Adaptation to new layout: the possibility to design a one-family house on an existing empty plot in the city of Esch integrating the reclaimed materials has been studied. More similar elements are needed to complete the design.

Conclusions

The Petite Maison stands as a pioneering demonstration project, illustrating the potential of new building construction to champion material circularity via a system that is de-constructable, modular, and reusable. Following deconstruction, a valuable stock of reusable building elements is generated, with high potential for future reuse. Deconstruction of buildings and salvaging their components are technically feasible, key aspects to this success are:

- Early engagement during the design phase,
- The incorporation of demountable systems alongside prefabricated and standardized elements and details,
- Comprehensive inventory documentation,
- Contractor familiarity with the building's structure,
- Well-structured deconstruction procedure and storage plans.

Acknowledgement

The Petite Maison project was led and coordinated by architect Prof. Carole Schmit, with support from R&D specialist Dragos Ghioca, and in collaboration with Prof. Dr. Christoph Odenbreit at the University of Luxembourg.

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[4] J. Diéguez, S. Sayyareh, C. Odenbreit, *Key aspects of the deconstruction process for Petite Maison: a comprehensive overview*, University of Luxembourg, Luxembourg. (Internal report)

This case study was prepared by Jie Yang, José Humberto Matias de Paula Filho from ArcelorMittal, with the support of Christoph Odenbreit, Shahin Sayyareh, András Kozma, and Carole Schmit.

The authors are grateful for the information and images provided by Schroeder & Associés regarding deconstruction.

Funded by the European Union

Reuse of Steel Case Study no. 13

Reuse of steel sheet piles

Project summary

Project: Remediation of “Schwarze Pumpe” brownfield site, Spremberg, Germany
Project owner: LMBV GmbH
Design: Arge, CDM Smith
Contractors: Arge Lobbe / Bauer
Steel product: Sheet pile PU 22^{-1} 14.0 m – 23.0 m S 355 GP 2,000 t
Steel manufacturer: ArcelorMittal
Construction cost: N/A

Reuse of steel sheet piles

Sheet piles can be applied in many fields, such as water transport solutions like quay walls, hazard protection solutions such as dams, mobility infrastructure solutions like rail and road bridges, tunnels, underground car parks, and environmental protection solutions such as polluted soil remediation. The modularity of steel sheet piles facilitates their reuse; they can be extracted from the ground at the end of their service life. In temporary applications, steel sheet piles are often reused multiple times in the same project or for subsequent projects. Steel sheet piles are top choice in temporary scenarios for example, cofferdams in water, linear excavations, water retention, complicated utilities installation and repairs, and limitation of settlement in nearby structures and services.

Temporary applications, such as excavation pits, have shorter life cycles, often under 2 years. Contractors commonly employ sheet piles for such purposes, with sections sometimes reused up to 10 times. Symmetric U-sections are particularly suitable for reuse due to their compactness and high stiffness. After each use, a portion (≤ 50 cm) is typically removed if deformations or damages from the installation process are observed at the head or toe. In addition, it is becoming increasingly accepted by project owners to install used sheet piles in permanent applications. After long service lives, the sheet piles can still be extracted from the soil, being recycled and serve as input for the newly produced steel. This establishes a perfect cycle for the infinite use of steel, without any degradation of material properties.

Reuse of steel sheet piles in temporary applications

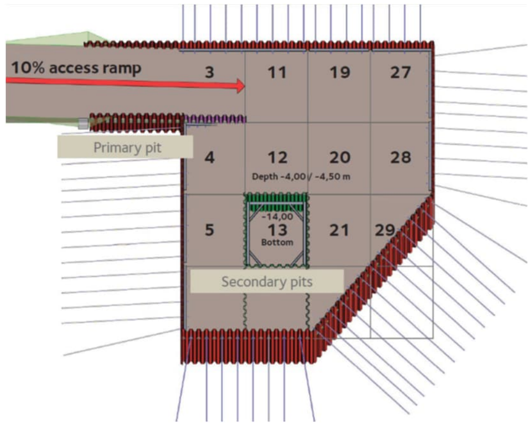
Decontamination of polluted soils:
Soil decontamination projects involve enclosing contaminated areas with steel sheet pile walls. The procedure typically includes surrounding the area with an impervious sheet pile wall, excavating contaminated soil, treating

it off-site or on-site, returning treated soil, and removing and reusing the sheet pile wall. This process can be done in one phase or in smaller sequential cells, the latter allowing for multiple reuses of the sheet piles. Once removed, no waste remains on-site.

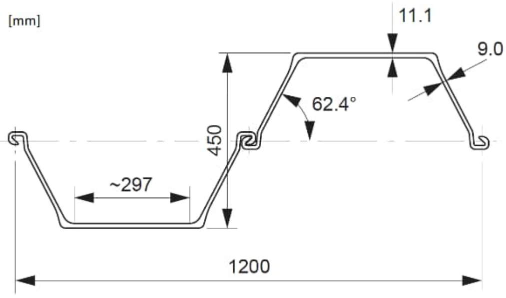
Remediation of "Schwarze Pumpe" brownfield site, Spremberg, Germany[1]

Established in 1955 as the VEB Gaskombinat Schwarze Pumpe, the Schwarze Pumpe Industrial Park initially focused on brown coal energy and briquette production. By 1992, modernization efforts aligned with environmental standards led to the dismantling of old facilities and the construction of new power plants. Remediation efforts began in 2017, processing 430,000 tonnes of contaminated soil using soil treatment processes to purify segments contaminated with benzene and phenols. Heavily polluted areas were excavated, thermally treated, and restored, with an on-site soil cleaning plant constructed to reduce transport requirements.

The adoption of a sheet pile solution was motivated by its modularity and potential for multiple reuses on-site. The primary pit enclosure was first executed with anchored sheet piles. Secondary pits were then executed within the enclosed areas. Specifically, PU 22^{-1} profile was selected for its robustness and reusability. The profile was rolled with a 1 mm reduced thickness compared to the standard profile (PU 22) to optimize the total weight of piles while maintaining sufficient bearing capacity for the project needs. Sheet pile lengths were optimized to suit various application areas, ranging from 14.0 m to 23.0 m, with considerations for length reduction due to repeated use already factored into the determination process. After each use, the sheet piles were cleaned, decontaminated, and they were stored for reuse in future secondary pits.



Plan view of the pits[1]



PU 22^{-1} profile

Cofferdams in water:

Steel sheet piles can have good watertightness as well as high resistance to hydraulic pressures, and are reclaimable after use. In scenarios like constructing bridge piers within a river, sheet piles can serve as formwork, with some left in position within the cofferdam to protect the concrete foundation.

Steel sheet pile wall, Vienna tube extension

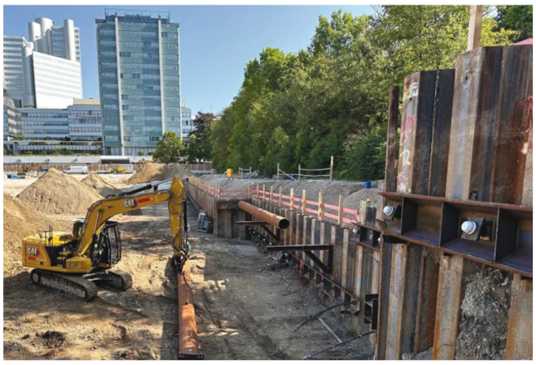
A 4.6 km extension at the northern end of the Vienna U-Bahn line U1 was opened in 2006, serving a population of more than 90,000 people and easing traffic congestion in the city. The U1/3 Großfeldsiedlung section near the end of the extension is 1.76 km long, with 1.3 km designed as a cost-effective cut-and-cover tunnel, 10 m deep, and 5 m underwater. A watertight cast-in-situ concrete box section, constructed inside temporary sheetpiling cofferdams, was selected for the tunnel. The works were split into short sections approximately 70 m long, and the cofferdam was relocated as the works advanced. The cofferdam sidewalls were AU 20 double piles, with double PU 25s for the transverse walls; they were held back by a layer of struts. AU 20 sheet piles were chosen as the most cost-effective solution because (i) they can be reused several times with good driving performance suitable for

Sheet pile wall with struts

the compact gravel of the Danube valley, (ii) compared to the 600 mm wide PU piles, there was a 10% saving on the volume of steel, and in addition, the number of interlocks was reduced, resulting in improved watertightness. Before reuse, the piles were inspected to ensure they were in good condition (the piles were not significantly deformed despite being driven into compact soils); the interlocks were then cleaned and filled with fresh sealant. This procedure was especially economical for the 750 mm wide AU 20 piles, as it minimized the number of piles being driven, extracted, and inspected, as well as the number of interlocks requiring treatment.

Steel sheet pile wall, New Headquarters of the Bayerischen Versorgungskammer (BVK) in Munich[1]

The new BVK headquarters is under construction at the former Siemens site on Richard-Strauss-Strasse 76 (RS76) in Munich. Züblin Spezialtiefbau GmbH was commissioned for the excavation pit project. A total of 188,300 m^3 of soil will be excavated. Temporary sheet pile constructions were erected on the south and east sides of the construction site for excavation support in 2023. The contractor chose EcoSheetPile™ Plus Series Sheet Piles, produced in Luxembourg with 100% recycled steel and 100% renewable electricity (solar and wind). The installed sheet piles were in profile PU 28^{-1}, S 355 GP, range in length from 15.20 to 22.20 meters, totalling 798 tonnes and a sheet pile surface area of 4,850 m^2. The RS76 excavation project has been awarded a certificate for "Sustainable Building Site" by the German Sustainable Building Council, DGNB. In addition to initiatives such as extensive noise protection, further use of demolition material, and tree protection, sustainability contributions from the sheet pile construction are twofold: the sheet piles are XCarb® recycled and renewably produced, and they are rented and returned to ArcelorMittal's rental warehouse for future reuse after this project. ArcelorMittal Träger und Spundwand GmbH has begun transitioning all sheet pile warehouses' rental stock to EcoSheetPile™ Plus Series in the fourth quarter of 2022.



Sheet pile wall shoring of the excavation pit
© Züblin Spezialtiefbau

Reuse of steel sheet piles in permanent applications

Reinforcing the Gorinchem - Waardenburg dyke with steel sheet piles, the Netherlands[2]

While used steel sheet piles are often employed in temporary applications, they are less commonly reused in permanent structures such as dyke reinforcement. However, for the project alliance Graaf Reinald Alliantie, they proved to be the ideal solution for over 6 km of the 23 km dyke project, offering crucial support and reinforcement against hydraulic failure by piping. With Dutch tendering procedures now incorporating environmental impact considerations, Graaf Reinald Alliantie deliberately opted for used sheet piles to minimize environmental effects. To safeguard the dyke against piping, the length of the seepage path must be extended to prevent the occurrence of the phenomenon. A sheet pile wall perfectly fulfils this function, and in this application, a used sheet pile section performs just as effectively as a new one. The reinforcement of the Gorinchem-Waardenburg dyke has a theoretical lifespan of 100 years. Given the minimal corrosion of sheet piles embedded in the dyke body, they can be extracted at the end of the dyke's life. Some removed sheet piles may be reused or repurposed in other projects, while others may be directly recycled in an Electric Arc Furnace for new products.

Dyke reinforcement in Wolferen-Sprok NL[2]

Business models

Given the reusability and modularity of steel sheet piles, there are several business models:

- rental for a short period,
- purchase and re-sale after use,
- purchase with a buy-back option at the end of the project, or
- purchase followed by storage for future works.

Widening of the railway tracks at the Belval train station, Luxembourg

The Luxembourgish railway company CFL rehabilitated the train station at ‘Belval – Mill’ in Luxembourg (2008-2009), choosing steel sheet piles for the new quay structure. Despite compact marl in the soil, installation proceeded smoothly due to careful selection of the sheet pile sections and the driving method. The PU 18^{-1} section, selected for its high stiffness, allowed for deeper driving and minimal wall deflection. The existing sheet piles, in excellent condition, could be easily extracted and the reclaimed sheet piles were kept by the contractors for future projects.

Conclusions

Steel sheet piles are versatile, modular, and reusable. In temporary scenarios, sheet piles are frequently reused multiple times, while acceptance of their reuse in permanent applications is growing. The reuse of steel sheet piles emphasizes cost-effectiveness and sustainability in construction projects.

Further information

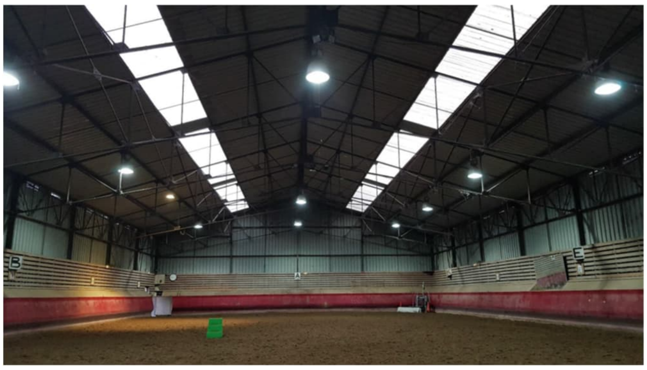
[1]F. Fohl, *Neue Zentrale der Bayerischen Versorgungskammer in München – Fokus Spundwandverbau*. Geotechnik, 2023, vol. 46, no. 3, pp. A16-17.
[2]F. Fohl, O. Hechler, *Reuse of Steel Sheet Piles – Best Practice*. In: L. Bragança, M. Cvetkovska, R. Askar, V. Ungureanu (eds) Creating a Roadmap Towards Circularity in the Built Environment, Springer Tracts in Civil Engineering, 2024. Springer, Cham. https://doi.org/10.1007/978-3-031-45980-1_3.

This case study was prepared by Jie Yang, José Humberto Matias de Paula Filho from ArcelorMittal, with the support of François Fohl, Cécile Prüm and João Martins.

Funded by the European Union

Reuse of Steel Case Study no. 14

The deconstruction and reassembly of a hall with truss structure



Project summary

Client:	SYTEVOM
Contractor:	VIRY – FAYAT GROUP
Architect:	ER ARCHITECTURE
Structural engineers:	ALBYR, ICS BOIS
Steel fabricator:	VIRY – FAYAT GROUP
Original steelwork:	1970s

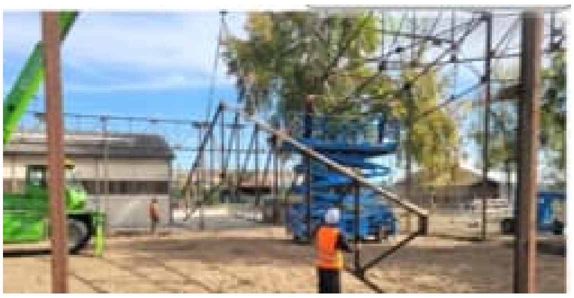
Description of the existing building

The original building was situated in Gennevilliers in the north of Paris. The building served as indoor riding ring. It is has been designed as a frame structure with hot rolled IPE sections used for the columns and truss girders. The truss girder was composed of equal leg angle sections of different sizes: L50x5 used for the upper chord, L60x6 used for the lower chord, L40x4 used for the uprights and diagonals in the centre of the truss and again L50x5 used for the truss elements near the columns. The connection between truss elements and upper and lower chord may be seen as specific feature as these connections are welded.

In total nine frames form the hall.

During the initial inspection of the existing building several members were observed to have suffered from buckling. These trusses were not re-usable and therefore they had been separated from trusses planned to be reused. Nonetheless, these trusses were kept in order to be used for the reassessment of material properties of the structural steel elements.

Deconstruction and Construction processes



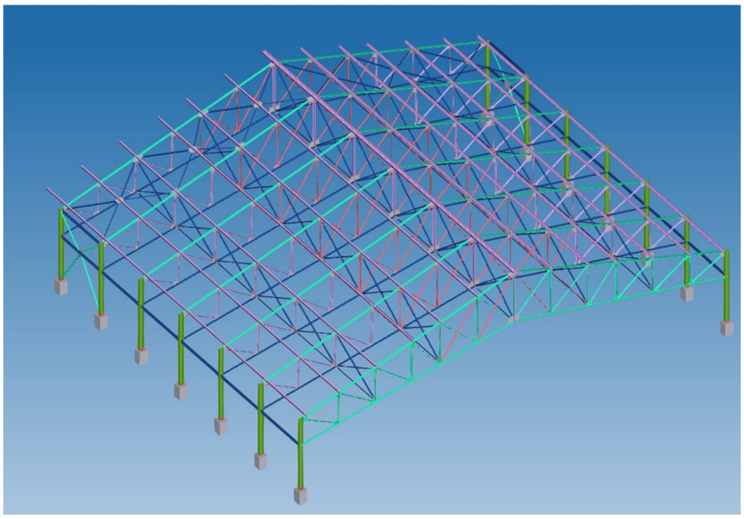
Before the deconstruction, the steel structure has been initially inspected in order to identify elements that are not suitable for re-use and to identify main features as the connections between the elements.
Then truss guirder were deconnected from the columns and moved to ground with a mobile crane. For transporting, the truss girders had to be seperated in two halfs. As the truss elements were welded this had to be done by grinding (mechanical cutting). Finally, all elements were transported to the plant of steel construction company VIRY situated in the vicinity of the new structure to be erected.

Reassessment of existing elements

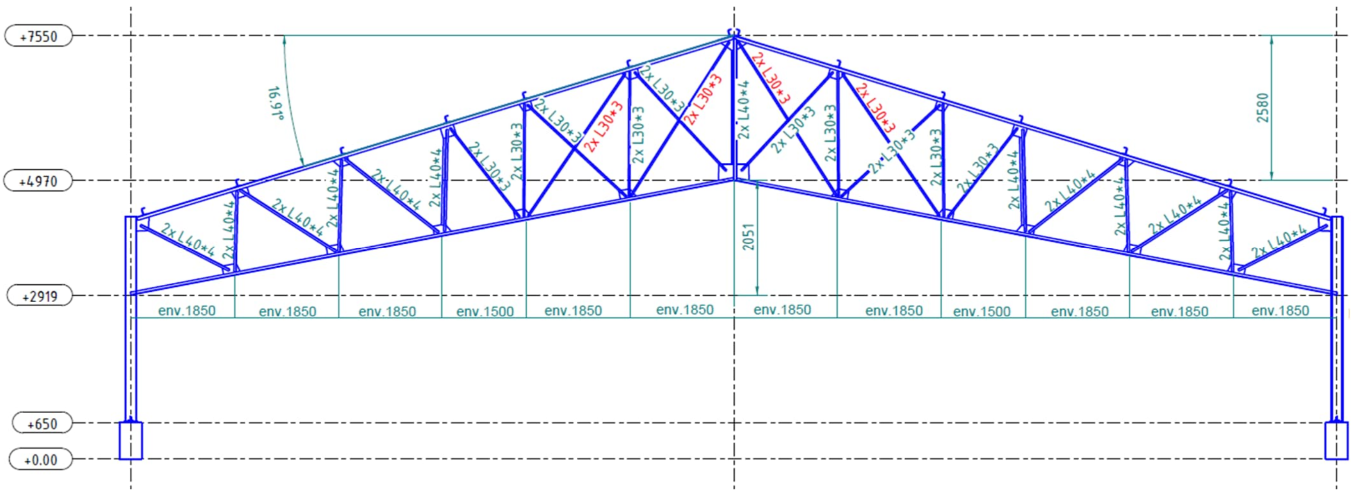
In order to limit the amount of destructive testing, testing groups have been created with the help of surface hardness measurements. After having confirmed the testing groups, several tensile tests and tests for the determination of the chemical composition have been performed. The specimens were extracted from the trusses that could not been re-used due to exessive deformation of some elements. The results of the destructive tests showed homogenous results for the testing groups.
For IPE sections, a safe estimation of the yield strength has been done based on product standards applicable at the time of erection of the existing structure.
The welds have been assessed by visual inspection only, because there were exposed to limited stresses in the orignial building and they will also be exposed to limited stresses in the future structure.

Design of the new building

The hall has been desconstructed and will be reused as canopy for a waste sorting centre situated in Epinal in the eastern of France. Due to increased loads it became necessary to redesign the structure. As a result, it was decided to reduce the distance between the frames. Additionnally, during the inspection of the existing building several members were observed to have suffered from buckling. These trusses were not re-usable and therefore they had been clearley indentified and seperated from the elements to be re-used.
A 3D image of the new structure and the design of the frame is shown in the next Figures.



The overall design of the new structure is identical with donnor structre: The frame is constituted of the reclaimed hot-rolled section columns and a truss rafter. Additionnaly, to the reduction of the distance between the frames, it was necessary to add aditional diagonals in the centre of the truss in order to account to the increased loading. These elements are indicated in red in the Figure below.



Conclusions

The following key aspects of the process have been identified:

- Nearly the whole structure could be re-used including truss elements that have not been separated to their constituent sections.
- A rigorous planning of the deconstruction process is necessary to ensure limit problems and delays. In particular, the aspect of joints with mechanical fasteners may give indications on the ease of loosening of the bolts. In the present project, during the deconstruction it had to be decided to cut some connection because it was to difficulty to loosen the bolts.
- Weld assessment is of importance. Based on a risk analysis, visual inspection has been estimated as sufficient in the present project, but for more critical connection with higher stress state more detailed non destructive testing will be necessary.

This case study was prepared by André Beyer and Amor Benlarbi, CTICM, with the support of Emile Seta, VIRY.

Funded by the European Union

Reuse of Steel Case Study no. 15

Deconstruction and relocation of four standard kit modules in a new complex of buildings in Râmnicu Vâlcea, Romania

Project summary

Client: S.C. CCS IMOB CONSTRUCT S.R.L.
Structural engineers: S.C. BON STEEL S.R.L.

Description of the existing building

A standard kit solution was developed in 2006 to build steel structures adaptable for different locations (climatic/seismic conditions) and applications, in different locations in Romania. The structure of standard kit was designed as 6 bays of 6.0 m, with a single span of 15.0 m and a height at eaves of 7m, with the possibility to connect several such kits for longer lengths.
Buildings from four construction sites, implemented between 2008 and 2010 in Baia Mare (A), Râmnicu-Vâlcea (B), Târgu Mureş (C), and Cluj-Napoca (D) were disassembly, relocated and integrated in a new complex in Sibiu, Romania in 2019. The secondary structure consists of cold-formed steel purlins and side rails. The 3D views of the relocated structures are presented in Figure 1.

Baia Mare | Râmnicu Vâlcea | Târgu Mureş | Cluj-Napoca

Fig. 1. 3D view of the initial structure (structural model)

Fig. 2. Components of the existing structures

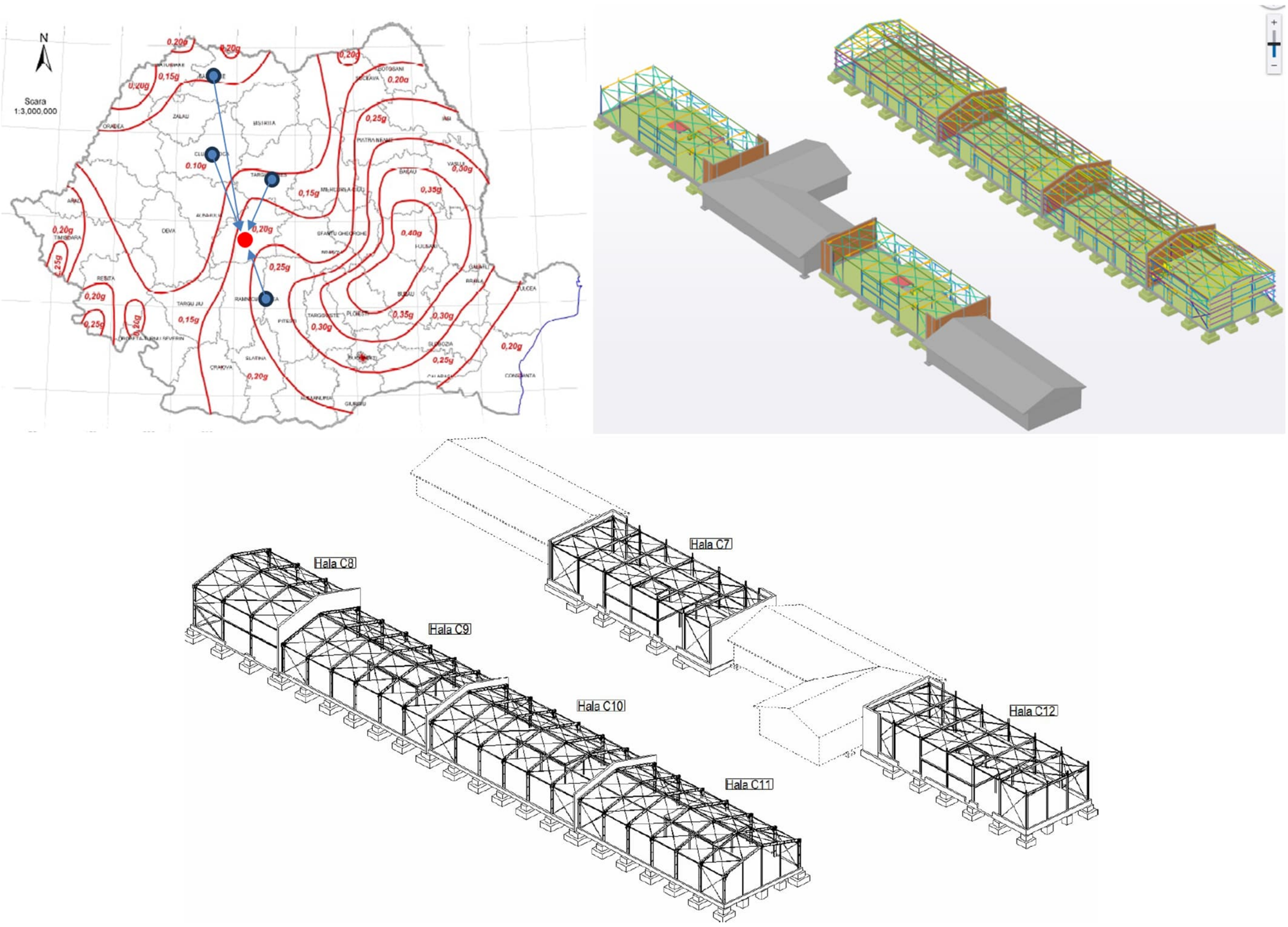


Fig. 2. Seismic map and the location of the new structure + 3D view of the new complex (structural model)

A new complex of buildings made from standard kit modules was implemented by the client. The industrial complex consists of two existing masonry structure buildings and six steel structure buildings. Four of these were deconstructed and relocated to Sibiu (buildings C8 - C9 - C10 - C11), while the other two steel structures are new.

Design process

The new building had to be redesigned with the idea of partially employing the elements recovered from the old buildings and adding a new floor for building C8 and partial floor for building C10.
The most important aspects for designing the new structure were:
- change of location, which imply new loading conditions (snow, wind, seismic actions);
- evolution of design codes (from 2006 to 2019)

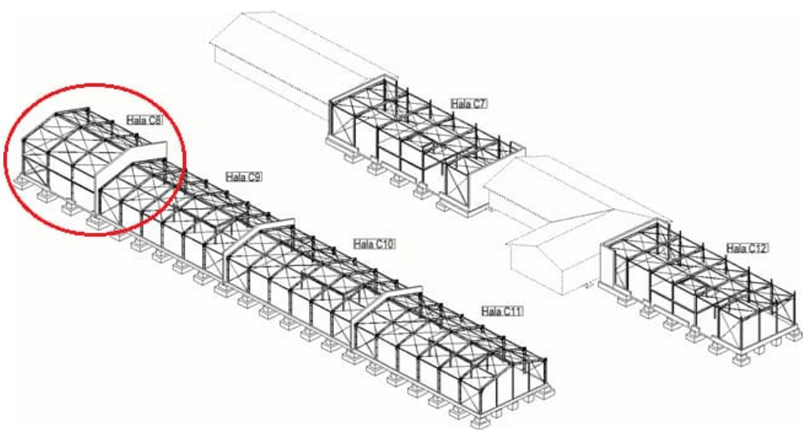
Loads Characteristic values	Characteristic values 2007 Design Codes				Characteristic values 2019 Design Code	max %
	Baia Mare	Cluj-Napoca	Târgu Mureş	Râmnicu Vâlcea	NEW SIBIU	
Snow load, $s_{0,k}$ kN/m^2	2.0	1.5	1.5	2.0	1.5	--
Wind pressure, q kN/m^2	0.5	0.4	0.4	0.4	0.6	↑25% - 50%
Peak ground acceleration for seismic action, a_g	0.12g	0.08g	0.12g	0.20g	0.20g	↑167% - 250%

Deconstruction and Construction processes

The project was divided into three contractual phases:

(1) inspection of the existing structure and identification of available documentation; deconstruction process; inspection of the elements from the deconstruction of the existing building to assess their potential for reuse; experimental investigation of the mechanical properties of the steel components;
(2) preparation of the new site and other groundworks;
(3) new construction.

C8 structure



For this structure, an intermediate floor was introduced. In such conditions, the new loads lead to over-stresses in some elements, which required interventions to strengthen them. Some elements such as the longitudinal beams and vertical braces were not reused. Figure 3 presents the initial structure model and the new, indicating in red and blue the positions of the element and the strengthening.

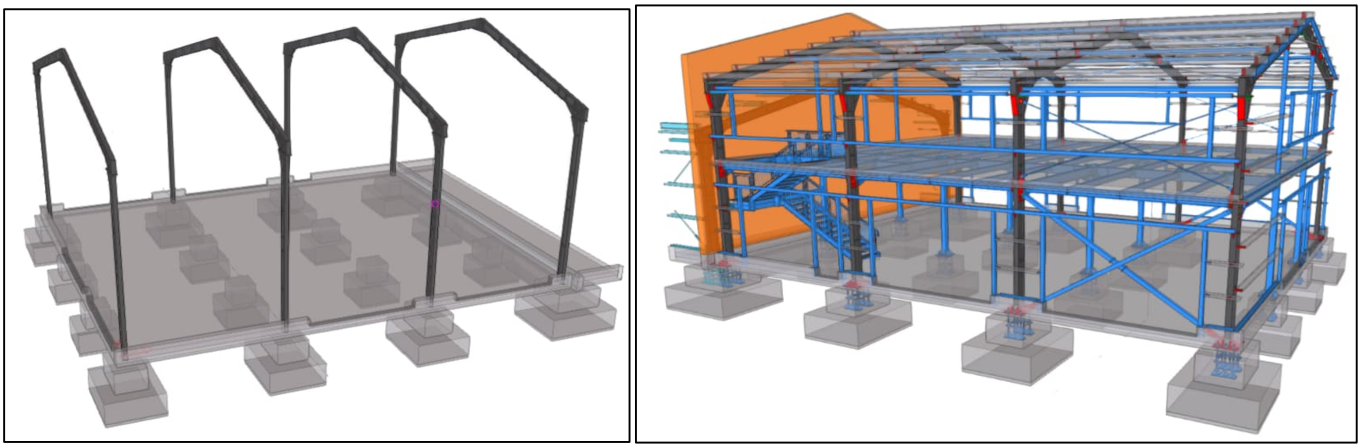


Fig. 3.

The pinned column base connection was changed into a rigid connection. The connection strengthening was done using a larger base plate, vertical stiffeners and 6 anchoring bars of 36 mm in diameter.

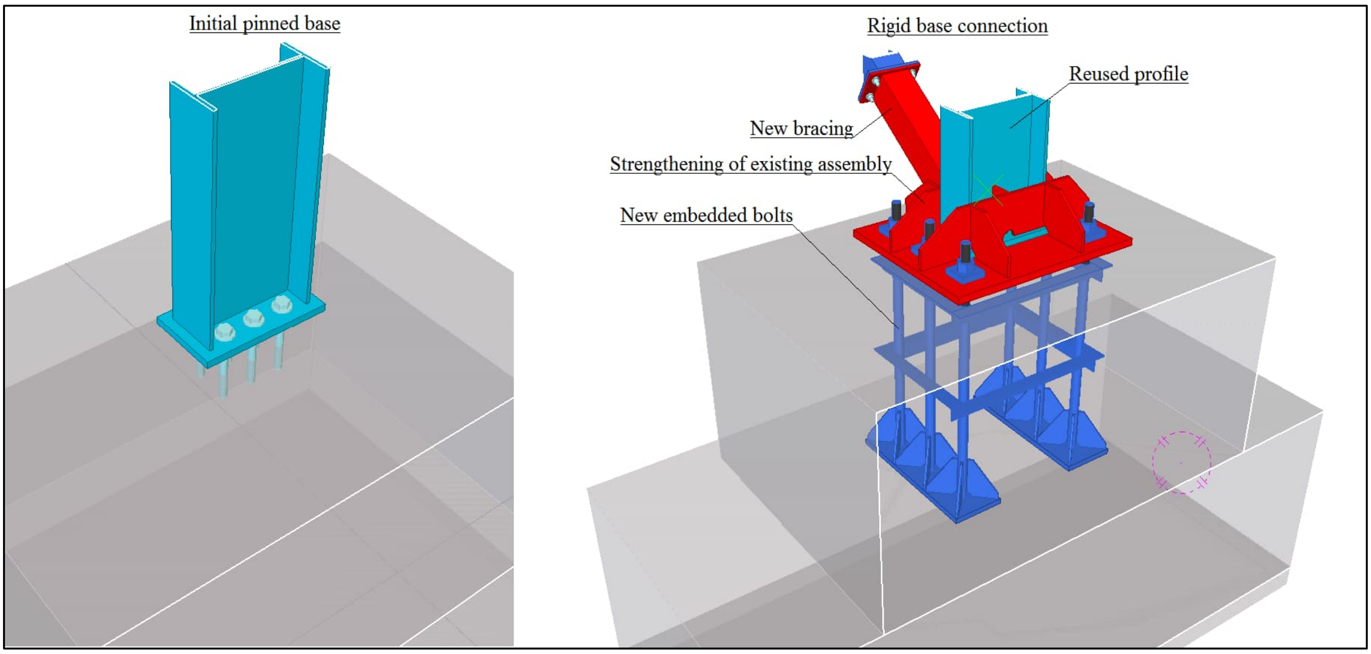


Fig. 4.

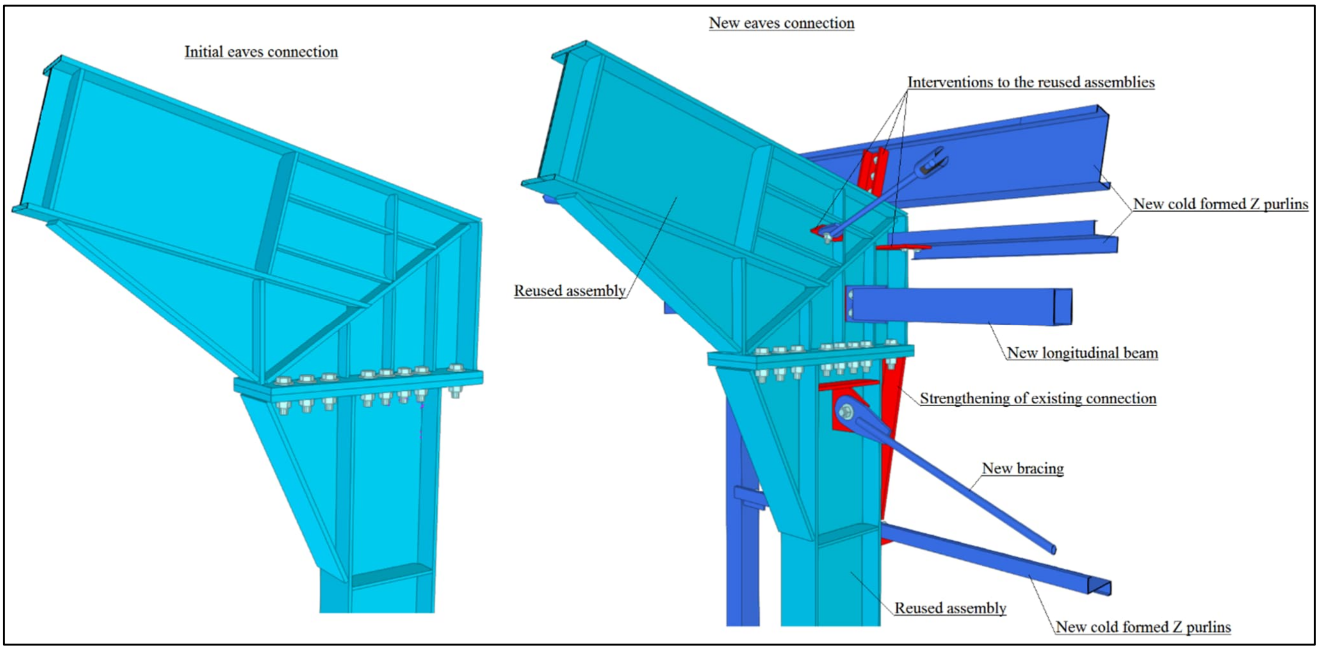

Initial eaves connection
New eaves connection
Interventions to the reused assemblies
New cold formed Z purlins
Reused assembly
New longitudinal beam
Strengthening of existing connection
New bracing
Reused assembly
New cold formed Z purlins

Fig. 5.

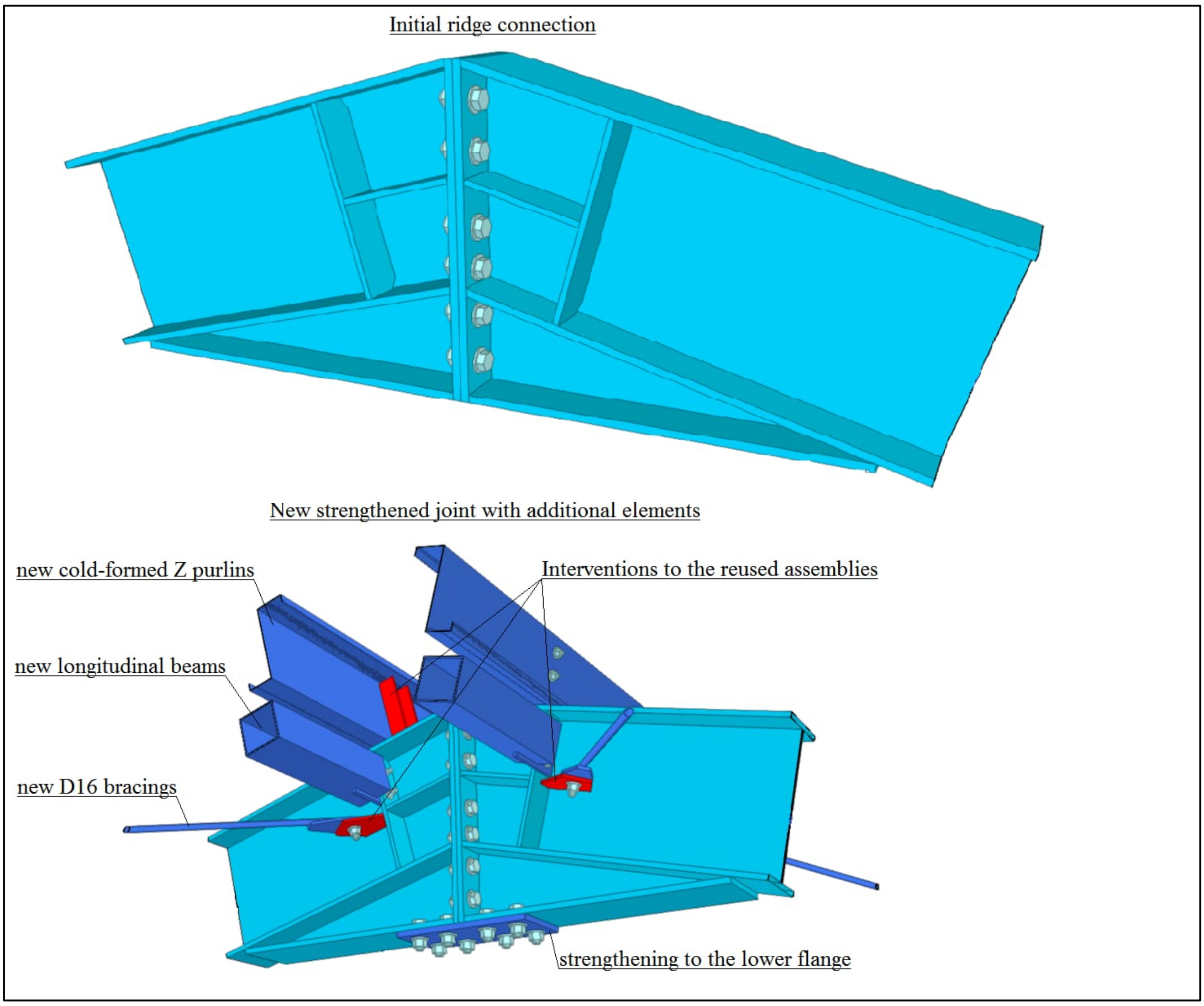

Initial ridge connection
New strengthened joint with additional elements
new cold-formed Z purlins
Interventions to the reused assemblies
new longitudinal beams
new D16 bracings
strengthening to the lower flange

Fig. 6.

In order to accommodate the new floor, additional plates welded on the web of the columns at the intermediate beams were introduced.

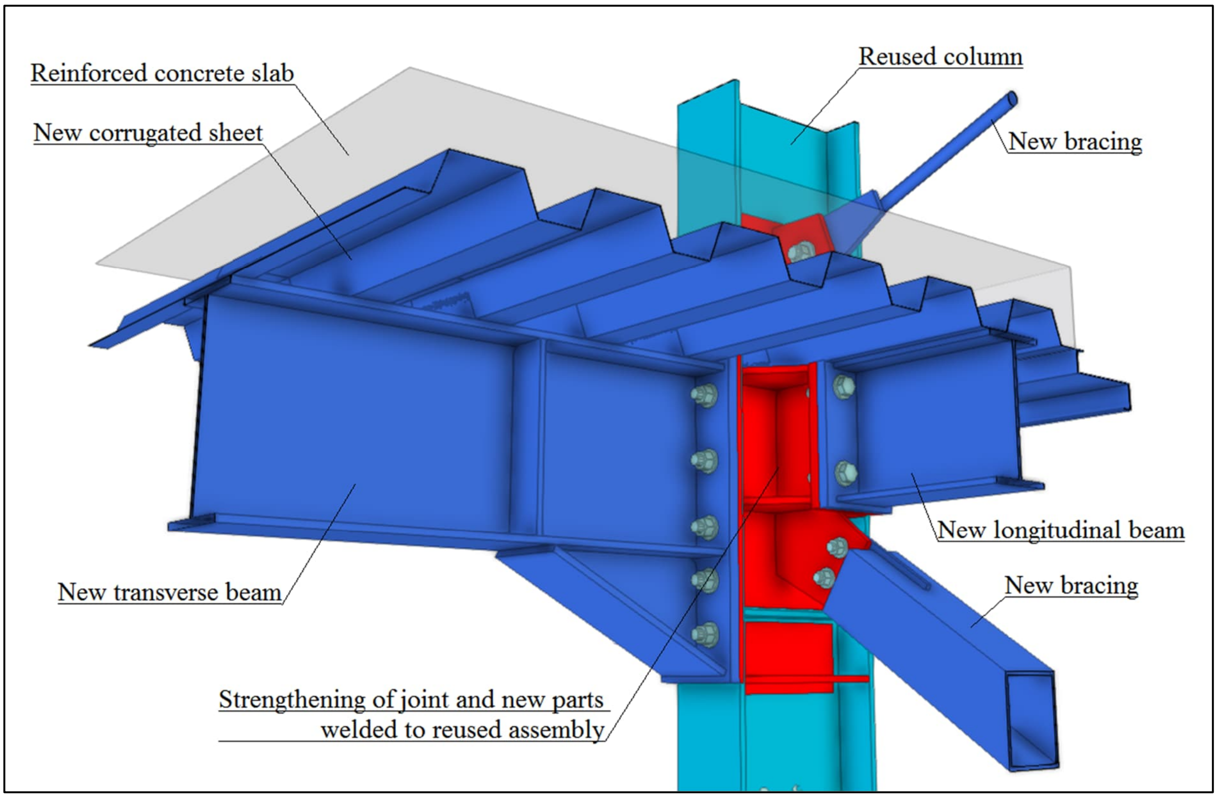
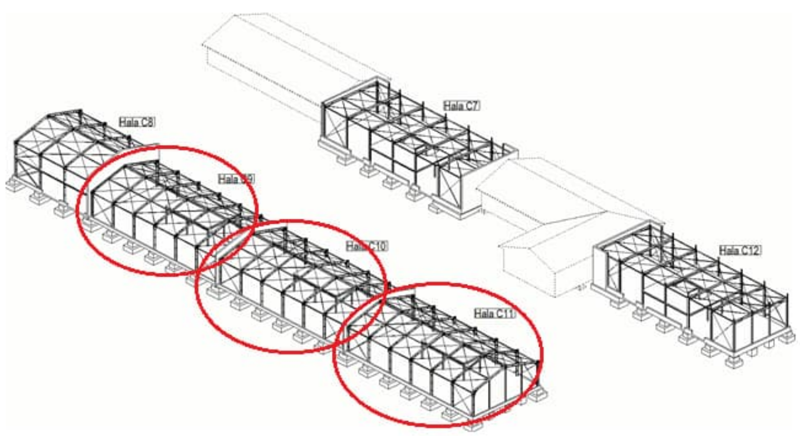


Fig. 7.

C9, C10, and C11 structures



The solution for a minimum intervention to the structure is based on the reduction of the initial bay from 6.0 m to 5.1 m. In this case, the longitudinal elements cannot be reused in a convenient manner. In addition, the decision was to change the column base from a pinned support to a fixed support, similar to the intervention presented for structure C8.

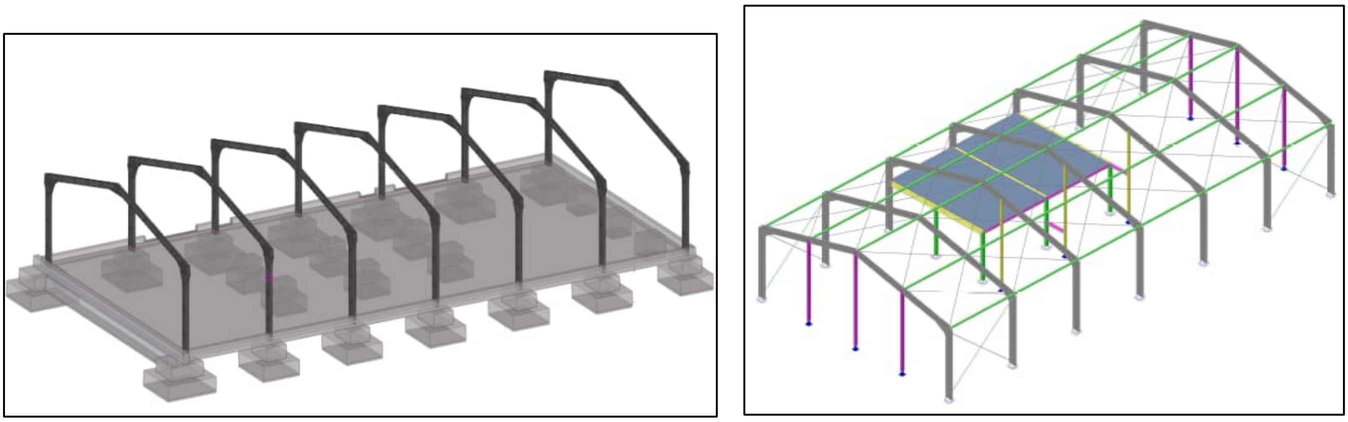


Fig. 8

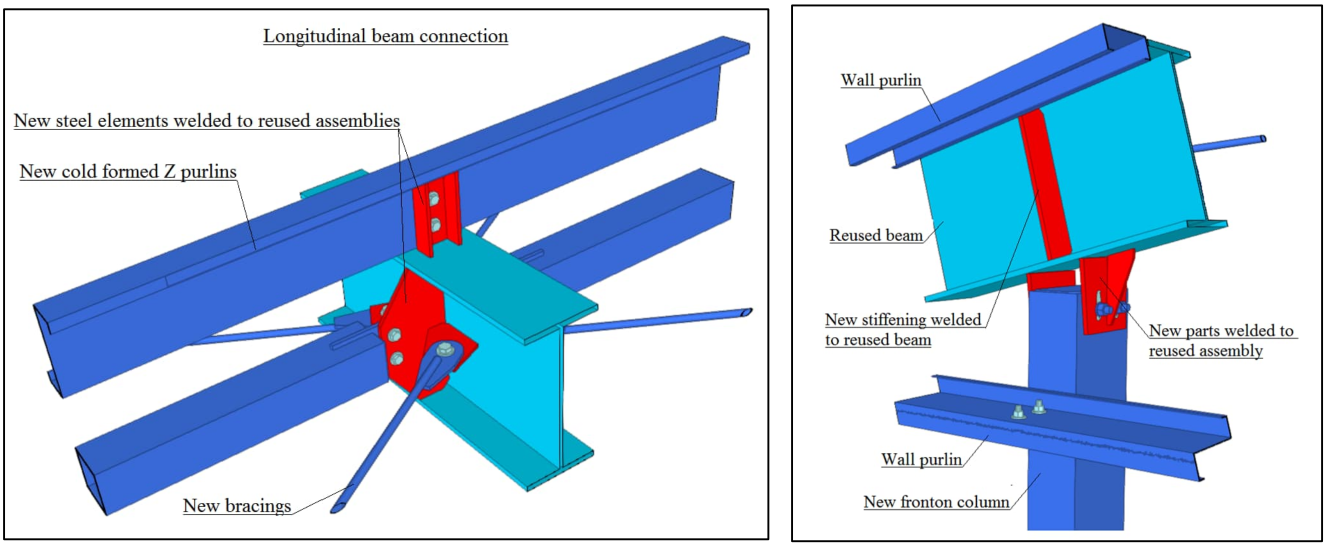


Fig. 9

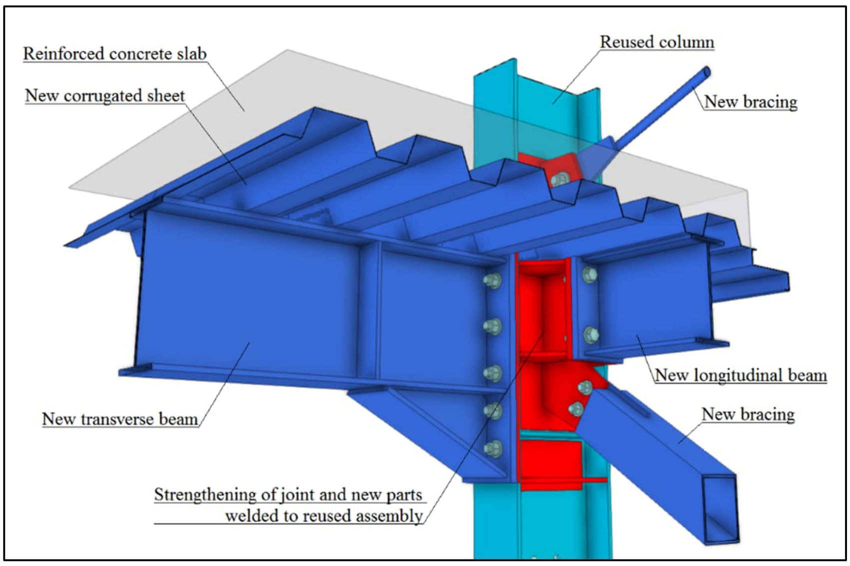


Fig. 10

Finally, the C8 – C11 structures of the new building complex are presented in Fig. 11, where the elements in red are reused elements and blue elements are new elements. The bracing system for both structures was changed by replacing the steel rods with tubular sections (SHS profiles). Also, for all structures, the cladding was mounted on Z200 purlins at the roof and Z150 side rails in the walls, which also required other elements for connecting to the structure.

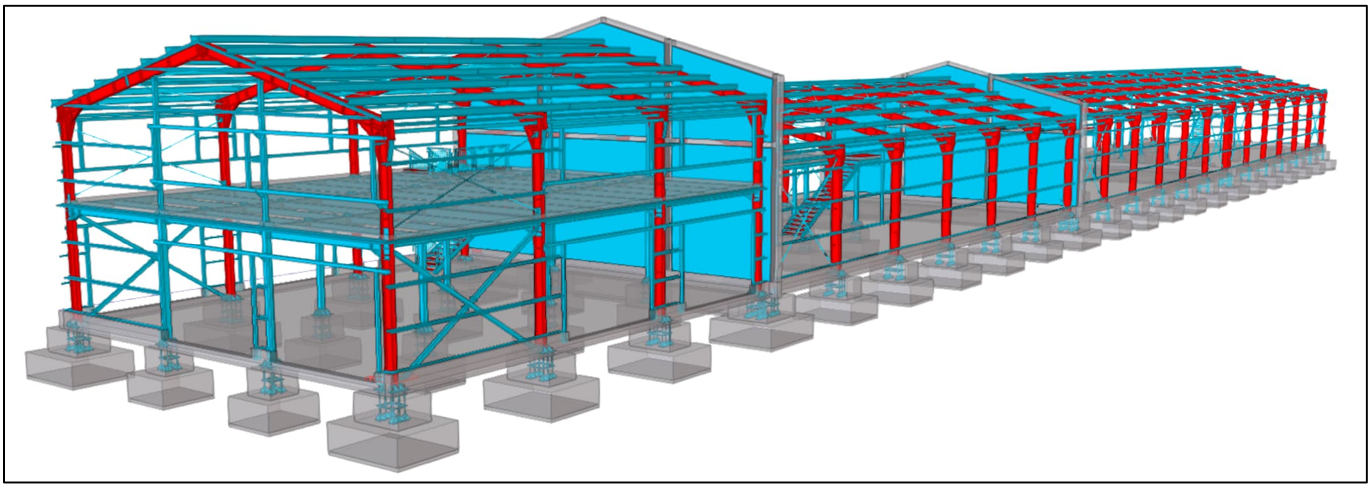


Fig. 11

Cost assessment

The table below shows the type and quantity of elements used for the structure of the C9 hall:

C9 Hall structures		Quantity [kg]
Reused elements	Columns	5622
	Beams	8581
New elements	Anchor bolts	1771
	Parts for strengthening reused assemblies	2491
	Longitudinal beams	2223
	Roof bracings	535
	Wall bracings	227
Structure for mezzanine and stairs		5856
Secondary structure for wall openings		862
Purlins for walls and for roof	Walls	957
	Roof	2223
Total weight of steel structure		31348
Concrete infrastructure		255 m^3

All the bellow prices are without VAT, at the level of year 2019. The reused steel structure was purchased for a price of 0.57€/kg. For the reused elements the interventions mentioned above were necessary, so an additional 4000€ cost for sandblasting and painting were also added. For the dismantling of existing halls and reuse of the assemblies, an expertise was needed, the cost of which was 800€.

The detailed prices can be seen in the table below:

2019	Price [€]
Design and verification	2000
Reused elements	8100
Technical expertise	800
Interventions to existing assemblies	3000
Sandblasting and painting	4600
New steel elements (incl. intermediate floor)	22000
Infrastructure	36000
Transport and assembly of steel structure	4700
TOTAL	81200

Comparative cost study: hall with reused elements vs. hall with new elements

In order to be able to choose the wright solution, a comparison in terms of prices between the partial reuse of existing structures and the construction of the structures with new elements was done. It was necessary to design halls with the same characteristics, but with new profiles.

For the C9 structures, HEA300 columns were used instead of IPE400 and IPE330 beams instead of IPE360. The beam-to-column connections were considered rigid in this case as well, but their geometry differs from the initial variant. Also, the ridge connection is different.

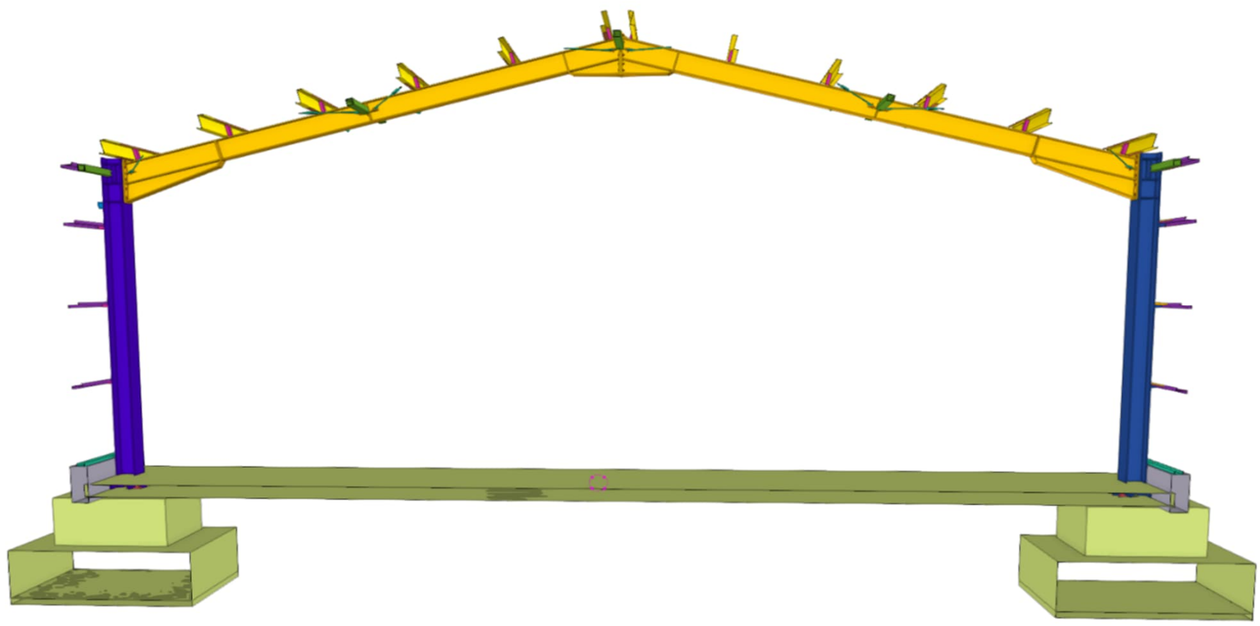


Fig. 12

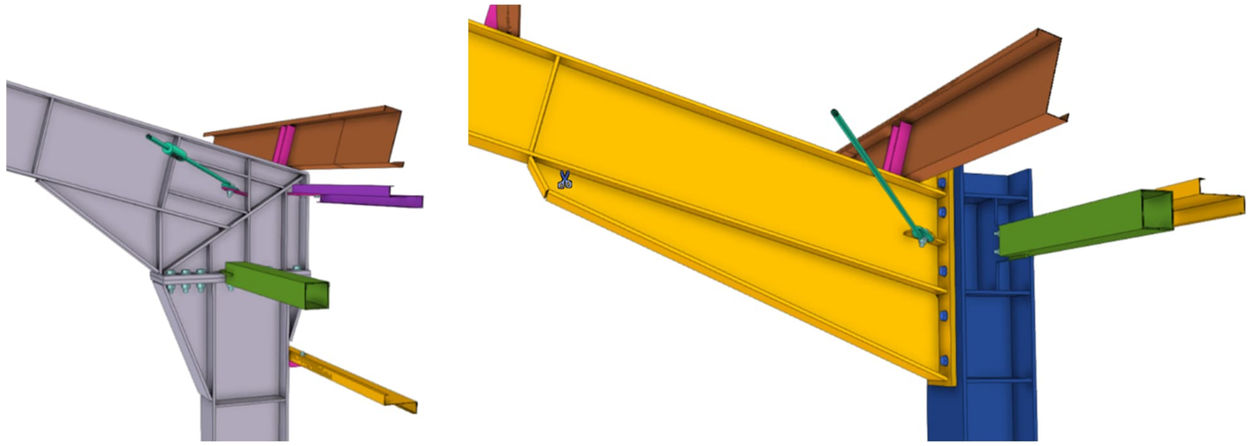


Fig. 11. Old solution vs. new solution

	Reused [kg]	New [kg]
Column assembly	550.7	641.0
Beam assembly	635.8	518.1
Transverse frame	2373.0	2309.0

The material considered in the design of the structure with new elements was also S235 to have similar conditions, and the longitudinal elements, bracings and purlins were kept the same in both cases. The transverse frame weight is close in both cases, however the frame with new elements has a weight 64 kg lower.

For this hypothetical case the table of type and quantity of elements and price centralization are shown below:

C9 hall structures		Quantity [kg]
New elements	Columns	8974
	Beams	7253
	Anchor bolts	1771
	Parts for strengthening reused assemblies	0
	Longitudinal beams	2223
	Roof bracings	535
	Wall bracings	227
Structure for mezzanine and stairs		5856
Secondary structure for wall openings		862
Purlins for walls and for roof	Walls	957
	Roof	2223
Total weight of steel structure		30881
Concrete infrastructure		255 m^3

	Case: reused Price [€]	Case: new Price [€]
Design and verification	2000	2000
Reused elements	8100	0
Interventions to existing assemblies	3000	0
Sandblasting and painting of reused assemblies	4600	0
Expertise	800	0
New steel elements (sanded and painted)	22000	46500
Infrastructure	36000	36000
Transport and assembly of steel structure	4700	4700
TOTAL	81200	89200

d

The result of this hypothetical comparison shows that there is a cost difference of approximately 8000 € between two halls of the same size and close weight of the structure, one with reused profiles and one with new profiles, the one with reused profiles being obviously cheaper. However, price differences may be greater when using a different type of material and reducing the overall weight of the structure. This price study was conducted for conditions as close as possible to see the most unfavourable scenario.

The total value of the economy for the four halls with transverse frames from reused elements was 35000 €.

Conclusions

Further information

This case study was prepared by Viorel Ungureanu, from the CMMC Department of the Politehnica University of Timisoara.

The authors are grateful for the information and images provided by ....

Funded by the European Union

Reuse of Steel Case Study no. 16

The deconstruction and reassembly of steel hall in a new location

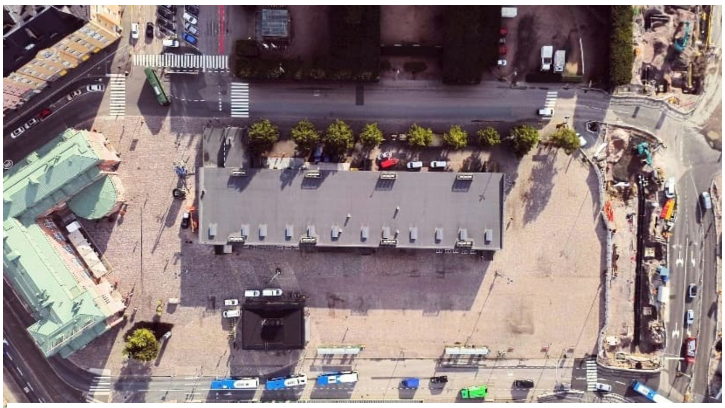
Picture 1 Deconstruction of steel frame hall in Hakaniemi, Finland

Project summary

Location: Helsinki, Finland
Owner of hall: City of Helsinki
New Owner: Veljekset Keskinen Oy
Contractor / client of demolition work: Lehto Tilat Oy
Demolition contractor: Purkupiha Oy
Deconstruction time: Fall 2023
Auction sale price of hall: 440 000€

Description of the existing building

Dismantling of the temporary Market Hall building of Hakaniemi. The building was located on Hämeentie 1 Helsinki, Finland. The building was very centrally located in the heart of Helsinki metropolitan area. The building was designed by Lehto Group. Temporary Market Hall was also known as “The Glass Hall.” Temporary market hall opened in January 2018. This temporary structure enabled the continuation of old Market Hall operations throughout its entire 5-year renovation period in Hakaniemi Square, Helsinki. The Glass Hall operated for 5 years before dismantling. Deconstruction begun in fall 2023. Hakaniemi Market Hall is a well-known building, and this temporary market hall was also well known among citizens.



Picture 2 In the middle is the temporary market hall and on the left side is the old Market Hall

The temporary building was a one-story hall and was built on a pile foundation. The size of the building was about 2 300 square meters (the main building was approximately 92 meters long and 23 meters wide). The load-bearing structure of this 2300 m² hall was a steel frame assembled with bolted connections. The facade of the hall consisted of glass elements and

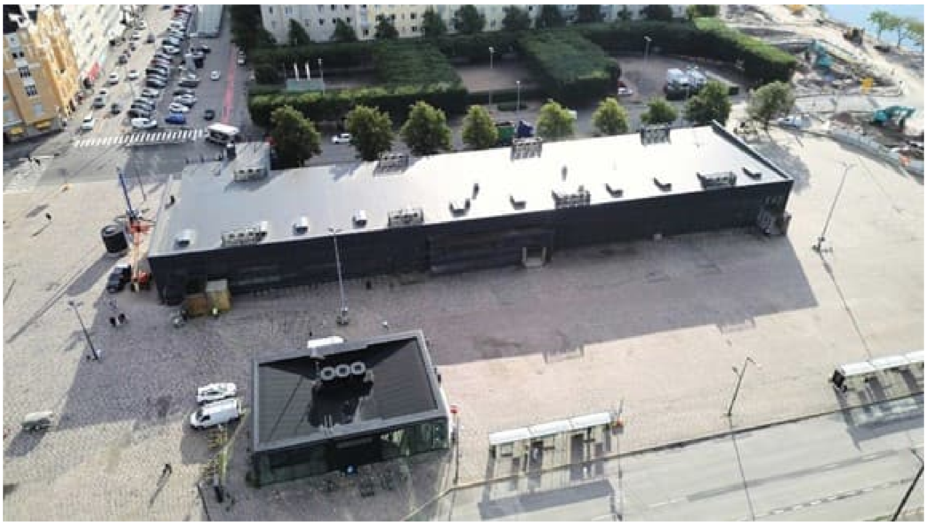
Picture 3 Temporary market hall in Helsinki before deconstruction

wood cladding. The technical facilities of the building and the social facilities were containerized. About 140 companies operate in the hall.

Design process

The planning of the renovation project and temporary facilities was the responsibility of the construction of the urban environment (Helsinki city) in cooperation with the wholesale market. The goal of the Glass Hall was to use the aid temporarily. During the spring of 2023, the retailers moved back to the renovated premises after the renovation.

Originally the Glass Hall was planned to be temporal and mobile. This aspect was already taken into consideration in the design phase. However, the further use of the hall was not clear to owner, city of Helsinki. A few different alternatives have been presented for the further use of the hall. Different option and alternatives were considered at earlier phase. One option was that the hall would remain in its current location but for another purpose. Another option and the most likely option, the hall was thought to be moved to use as temporary facilities at somewhere else, in different location in Helsinki.

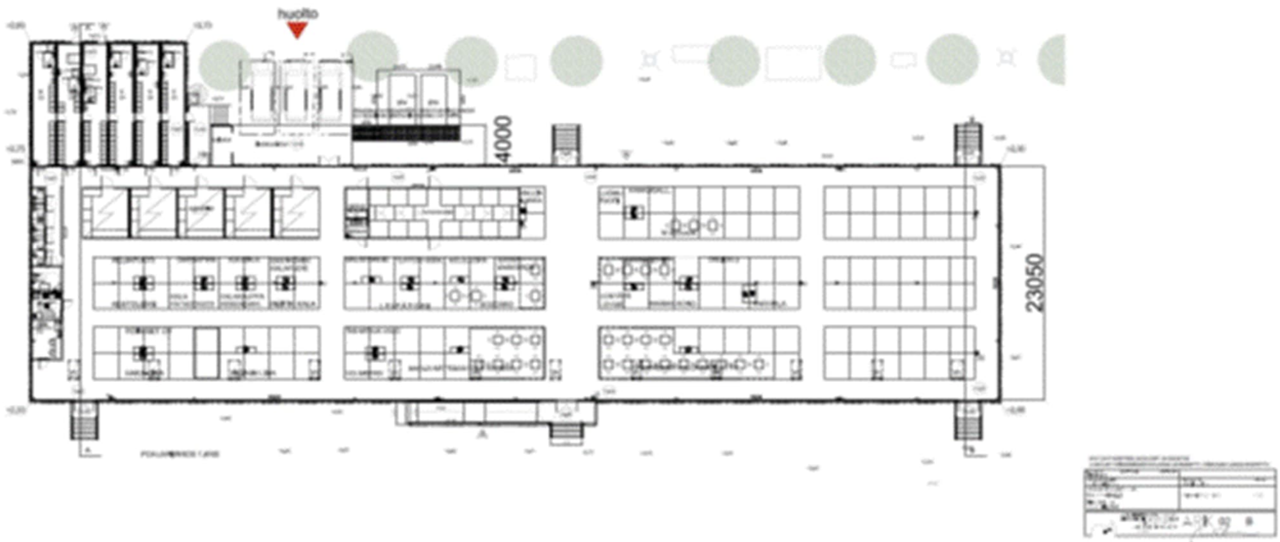


Picture 4 Temporary market hall building of Hakaniemi in Helsinki, Finland (2023)

Since the hall was designed for a temporal use, elements of hall were also designed for easy and possible transport. Elements were design to fit in the trucks.

Deconstruction and Construction processes

The City of Helsinki owned the temporary Market Hall. In the end, the owner decided to sell the temporary hall and it was auctioned because they could not reuse it themselves. The hall was put up for sale in huutokauppa.com and the auction took place between 5.6.-14.6.2023. The highest bid won. A sales brochure and six attachments contained basic information and structural drawings of the market hall. Additional information from the sales brochure: *"The property will be sold in the condition and equipment it is in the advertisement and at the time of the sale. Before submitting an offer, the bidder is obliged to familiarise himself with the object and documents before making a binding offer. The purchaser cannot subsequently rely on a circumstance that could have been detected during the preliminary inspection or from the documents. A separate visit to the object must be agreed in advance with the seller's representative.*"



Picture 5 Structural drawings of market hall from the sales brochure

The highest tender offer was submitted by Vesa Keskinen (Veljekset Keskinen Oy). Keskinen has said in public that the buying decision was made in less than an hour before auction was closing and that the decision might sound an impulse purchase, but it is a deliberate purchase. Keskinen is well-known Finnish public figure who owns Finland's largest and best-known village shop in Tuuri. Tuuri Village Shop is a tourist attraction and an experience destination. The Glass Hall was sold in 6.7.2023.

Deconstruction contract was put out to tender and Purkupiha Oy was chosen as the demolition contractor for the temporal market hall.

The nine-week-long deconstruction programme was carried out in the fall of 2023. Deconstruction begun with the internal strip-out. Deconstruction of the facade involved removal of the wooden cladding panels followed by careful removal of the glass facade elements. After

Picture 6 Temporal market hall during its deconstruction in fall 2023

removing the roof elements and ceiling elements and partially dismantling the floor, the steel roof truss elements were dismantled.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The dismantled parts of the hall were carefully protected for transfers. Due to the limited space and congested location of the hall, logistics required careful planning in terms of scheduling, transportation and the protection of the dismantled parts. The largest elements were transported from the site at nighttime as daytime relocation was not possible. The elements were transferred to the nearby Malmi Airport logistics centre, from where the elements were transported to Tuuri, about 350 kilometres to the north of Helsinki. One estimation is that there were 50 truckloads.

Picture 7 The Market Hall reassembly in Tuuri 2023-2024

Purkupiha cooperated with various parties during and after the deconstruction processes. The protection and transport of the dismantled elements were carried out in cooperation with Purkupiha, the new owner of the Glass Hall, and a logistics company. Purkupiha helped and gave information to the new owner of the hall and helped them for example marking elements during deconstruction and helped with loading and logistics planning. Purkupiha has helped the new owner in the necessary parts even after the deconstruction work.

In Tuuri, the temporal market hall reassembly started soon after its deconstruction. The construction work was completed already in spring 2024. In Tuuri, the Hakaniemi Glass Hall was given a new life as the Village's Fashion Outlet and its opening ceremony was held in 24.2.2024.

Picture 8 Temporary Market Hall in its new location and in the new context as Village's Fashion Outlet in Tuuri 2024

Conclusions

The following key aspects of the process have been identified:

- Hall was originally planned for temporary use, so the hall was designed to being able to deconstruct and it must had been moveable and transferable.
- Helsinki City could not further use the temporary hall itself and they decided to sell it. Selling the hall made it possible to reuse and reassembly the hall instead of demolishing and recycling it.
- Because the hall was designed to deconstruct the building was simpler and easier to deconstruct compared to permanent buildings, and also the hall was quickly reassembled.
- Transports of elements were thought in the design process because elements fit to the trucks.
- The availability of drawings to buyers
- Right timing of different phases is important to enable reuse: decision of the further use vs. selling, arranging auction, allocate time for dismantling.
- Good communication with all parties included in deconstruction and reuse process.
- Demolition contractors had previous experience of deconstruct of the same designers' buildings and therefore were familiar with this type of hall, which made the deconstruct process even more secure.

In conclusion, the design of this steel frame hall significantly contributed its reuse possibility and offers a model for other projects.

Further information

References:

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- Purkupiha Oy: employee and site manager
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  - [AAE3B889-0022-CC4E-8F9B-892B86500000.pdf (hel.fi)]
  - https://paatokset.hel.fi/fi/asia/hel-2023-008579/819e9ac0-6598-42d0-9375-cece0d950577
- Available articles from local and national newspapers:
  - 5D43695A-41A1-C465-B248-8CF798700009.pdf (hel.fi)
  - Hakaniemen lasihallin purkutyöt alkavat syyskuun alussa | Helsingin kaupunki
  - https://www.hs.fi/pkseutu/art-2000005058871.html
  - https://www.vantaansanomat.fi/paikalliset/1616218
  - Hakaniemen väliaikainen halli pakattiin 50 rekkaan ja vietiin Tuuriin – tältä se näyttää nyt | Etelä-Pohjanmaa | Yle

This case study was prepared by Satu Hermunen, from Purkupiha Group Oy

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