2017-2020 PROGRESS

PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

European Commission

Research Fund for Coal and Steel

Provisions for a Greater Reuse of Steel Structures (PROGRESS)

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Final report

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Legal notice

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Abstract

The concept of reusing building components has roots in the past when availability of building materials was relatively poor and their production was slow, tedious and expensive. The practice gradually became difficult or even impossible along with the mass production of building products and with the demands for high levels of structural safety, quality of the materials and health & safety requirements of demolition/deconstruction. Fulfilling these current standards and enabling the most environmentally efficient material circulation at the same time is a challenge recognized by the research community in the recent years. The need for innovations in building materials recovery is becoming more important also for the contractors in building industry who will have to change their operations from the traditional demolition process to more difficult deconstruction in order to retain the value of the building elements. Therefore, the reuse of building components is one of the international strategic spearheads in developing the circular economy in the construction sector.

Large quantities of waste are generated during the production of building components, during construction and demolition. According to Eurostat, construction and demolition activities in Europe are responsible for 35% of solid waste production. The construction sector also consumes about half of all the natural resources extracted in Europe every year, with very high energy demands on their transformation into building products. It is estimated that 40 - 50% of all extracted raw materials are transformed into building products. The vast amount of energy is used in the first three stages of the production process: resource generation, resource extraction and intermediate product manufacture. However, steel construction, as part of the construction sector, has a very good potential to contribute to resource efficiency because steel is particularly suited for reuse (in addition to recycling).

Within the steel construction sector, single-storey steel buildings (SSBs) account for a large proportion of the market. Moreover, structural members in SSBs are typically long span and relatively simple, often exposed and easily accessible in safe working heights. Hence, SSBs offer the greatest potential for reuse. The research in PROGRESS can be viewed as a test case to explore whether the viable circular economy models can be developed for SSBs. If a successful business model cannot be developed for steel construction and SSBs in particular, then finding solutions across the whole construction sector will be very challenging. The lessons learned in the project can be shared with other sectors of the industry.

The steps taken in the construction sector towards energy and resource efficiency are of vital importance. The target of European Waste Framework Directive is that 70% of construction and demolition waste (CDW) should be recycled, reused and/or recovered by 2020. The focus area to achieve this goal is highlighted in the waste hierarchy. The progress in waste recovery in several EU countries showed that the 70% target could be reached especially in the lower levels of the waste hierarchy (e.g. backfilling or downcycling of concrete). Today’s challenge is therefore to move upwards to reuse and waste prevention, both being core targets of PROGRESS project.

Project overview

Table 1 Project overview table

Project overview	
Sector	Steel
Technical Group	TGA4
Grant agreement No.	747847
Title	Provisions for a Greater Reuse of Steel Structures
Acronym	PROGRESS
Beneficiaries	VTT Technical Research Centre (VTT) Steel Construction Institute (SCI) Ruukki Construction (Ruukki) RWTH Aachen University (RWTH) Universitatea Politehnica Timişoara (UPT) European Convention for Constructional Steelwork (ECCS) Paul Kamrath Ingenieurrückbau (PKIR)
Project duration	36 months (1 June 2017 - 31 May 2020)
Work undertaken	Refer to Sections 1 to 9 of this Report
Main results	Refer to Sections 1 to 9 of this Report
On schedule	The project followed the original schedule
Main problems encountered	(a) It was impossible to find a single deconstruction and reuse case in WP7 that would cover all PROGRESS aspects; (b) Three workshops were cancelled due to the COVID-19 restrictions (c) Resources had to be reorganized in WP2 and WP7
Correction actions	(a) WP7 is based on several deconstruction projects (b) Four webinars were organized to replace the workshops (c) UPT and SCI delivered part of D2.1 [5], and VTT part of D7.1 [19]
Reports and other deliverables	Refer to Section 9 of this Report and [1] to [25]
Publications	Refer to Section 8 of this Report and [28] to [36]

Table 2 Budget information per beneficiary

Beneficiary	**Budgeted costs**	**Reported costs**
VTT Technical Research Centre (VTT)	302 324 €	296 836 €
Steel Construction Institute (SCI)	317 694 €	333 634 €
Ruukki Construction (Ruukki)	144 303 €	124 661 €
RWTH Aachen University (RWTH)	245 018 €	252 720 €
Universitatea Politehnica Timişoara (UPT)	143 040 €	182 224 €
European Convention for Constructional Steelwork (ECCS)	214 980 €	193 577 €
Paul Kamrath Ingenieurrückbau (PKIR)	297 638 €	299 627 €

Project scope and objectives

The main objective of the project was to develop products, systems, methods and protocols that facilitate reuse of various components of steel-framed single-storey buildings. The project addressed both deconstruction and reuse of existing buildings, and how new buildings can be designed, constructed and documented to facilitate future reuse. Its scope includes primary structures (frames), secondary structures and multi-material hybrid components of the envelope (see Figure 1).

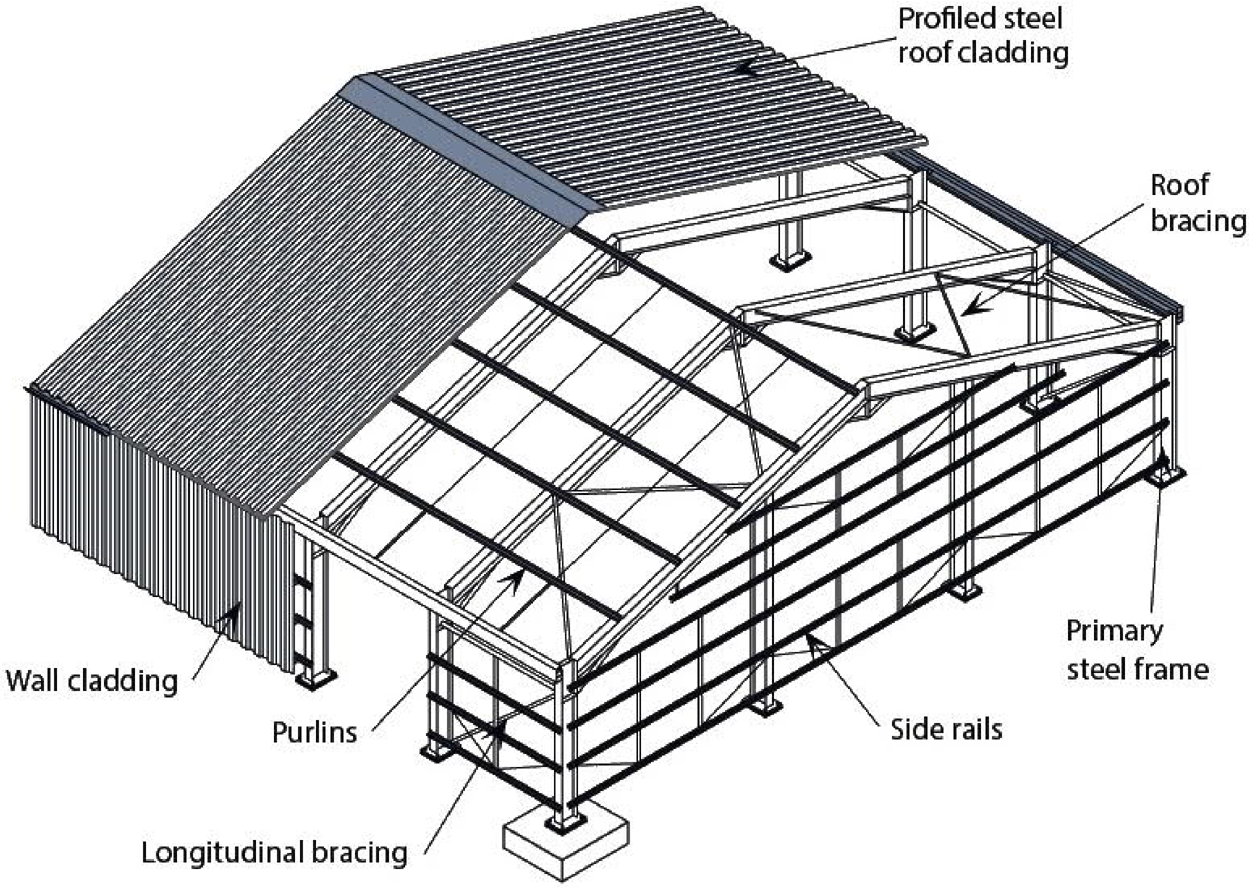


Figure 1 Basic components of single-storey steel buildings

The main purpose of structural reuse is to close the loop of material and product flows form constructional steel and create suitable conditions for the implementation of circular economy principles in the building sector. The lifecycle of building product is characterized by several stages:

- A: Product and construction stage
- B: Use stage
- C: End-of-life stage
- D: Reuse, recovery and recycling potential

Although the impacts of reuse can be observed over the whole lifecycle, the main focus of the project is on the last stage, D. As illustrated in Figure 2, several basic cases of components reuse can be recognized depending on the level of disassembly:

- D_0: Reuse of the entire steelwork or its part (e.g. several bays) without disassembly
- D_1: Reuse of the disassembled steelwork (may include the envelope)
- D_2: Reuse of the fabricated components (e.g. sandwich panels, columns)
- D_3: Reuse of the constituent products (e.g. sections, plates)

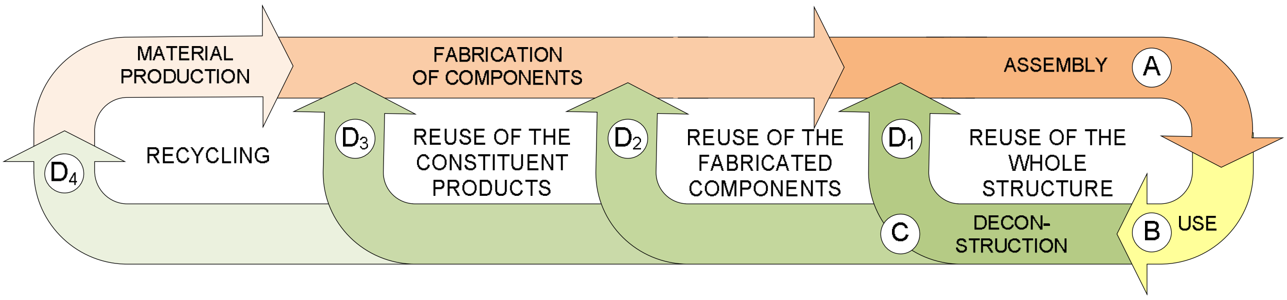


Figure 2 Reuse scenarios in the constructional steelwork lifecycle

From the deconstruction and transport point of view, several possibilities may exist:

- D_A: In-situ reuse without disassembly
- D_B: Reuse on the same site in the same configuration
- D_C: Reuse on the same site in different configuration
- D_D: Reuse on different site in the same configuration
- D_E: Reuse on different site in different configuration

In the case of *in-situ reuse* (D_A) the components are not disassembled and remain connected to the steelwork. They can be repaired, reinforced or coated in order to prevent their disassembly and replacement, and therefore we call this process reuse. Their resistance and serviceability needs to be verified according to the current codes. Typical example is in-situ reuse of the entire primary structure.

Table 3 Classification of reuse cases

	In situ reuse	**Relocated reuse**			
		Same site		**Different site**	
		Same configuration [1]	**Different configuration**	**Same configuration**	**Different configuration**
Entire steelwork	$D_{0\text{-}A}$	-	-	$D_{0\text{-}D}$	-
Disassembled steelwork	-	$D_{1\text{-}B}$	$D_{1\text{-}C}$	$D_{1\text{-}D}$	$D_{1\text{-}E}$
Fabricated components	-	$D_{2\text{-}B}$	$D_{2\text{-}C}$	$D_{2\text{-}D}$	$D_{2\text{-}E}$
Constituent products	-	$D_{3\text{-}B}$	$D_{3\text{-}C}$	$D_{3\text{-}D}$	$D_{3\text{-}E}$

[1] This scenario is unlikely since if the structure was deconstructed, it is unlikely that it would be re-erected in exactly the same configuration on the same site.

The outcomes of the project include recommendations to enable reuse of building components in-situ or in different location and reuse of building components in the original layout or in a different design with the necessary modifications/adaptations to resist the new external loads (due to the relocation) or internal loads (due to the modification of the structural layout).

In particular, the objectives were to

- **Reduce** the technical barriers to reuse through establishing quality verification procedures for the structural elements and envelopes of deconstructed low-rise buildings to be reused;
- **Create** a methodology and metrics to assess and classify the degree of reusability of construction products and systems in single-storey steel buildings.
- **Simplify** the implementation of reusable components through recommendations for design for deconstruction and reuse, and for design using reclaimed elements as well as for safe and efficient deconstruction activities;
- **Support** product manufacturers', facility owners and designers' decision-making by recommended methodology and basic data to calculate the environmental impact and cost of reusing steel components.
- **Propose** the extension of IFC standard and associated software support for Building Information Models (BIM) to include essential data and functionality for reusable steel-based elements;
- **Develop** a prototype online reused steel trading portal to co-ordinate the supply and demand for reused steel-based components;
- **Introduce** novel types of hybrid solutions for envelopes in order to maximize the reuse potential of components, improve the thermal performance of buildings and extend the service life of the envelope.
- **Promote** steel reuse through extensive dissemination (publications, guidelines, workshops, case studies and communications with the stakeholders).

Project consortium

The project consortium consists of two research institutes (VTT and SCI), two universities (RWTH in Aachen and UPT in Timisoara), two companies (Ruukki Construction and Paul Kamrath Ingenieurrückbau) and one European association (ECCS). The seven partners from five EU countries were selected to gather sufficient expertise and facilities for the necessary operational needs of the project and networks to disseminate the results. They also represent the essential stakeholders in the process of steel reuse such as material and products manufacturing and design (Ruukki Construction), deconstruction and possible distribution of recovered elements (Paul Kamrath Ingenieurrückbau) and facility owners (RWTH).

VTT

VTT Technical Research Centre of Finland (VTT, Finland) is a state owned and controlled non-profit limited liability company established by law and operating under the ownership steering of the Finnish Ministry of Employment and the Economy. VTT's activities are focused on three areas: Knowledge intensive products and services, Smart industry and energy systems, and Solutions for natural resources and environment. VTT has a staff of 2192, net turnover in 2015 was 157.9 M€ and other operational incomes were 92.6 M€. Over the years, VTT has gained vast experience from participation in numerous European R&D Framework Programme projects and within various thematic programmes, including the RFCS program. In the subject area of PROGRESS, VTT has coordinated or been involved in several national and international activities and projects. Several groups across VTT participation are focused on structural engineering, material recovery, sustainability, BIM, business models and other issues included in PROGRESS.

Steel Construction Institute (SCI, UK) employs 28 staff with expertise in all aspects of building design and construction. Its mission is to develop and promote the effective use of steel in construction. Through its network of 500 members, SCI has close links with manufacturers, consulting engineers, architects and clients. SCI keeps engineers updated with the latest developments in steel design and equips them to design competently, efficiently and safely through a range of dissemination and education activities. SCI has coordinated many research ECSC/RFCS projects including DISCCO, which studied shear connection systems in composite construction, TABASCO which provided data on thermal bridging, and BATIMASS which investigated the use of steel technologies to enhance the thermal capacity of buildings.The personnel involved will be Michael Sansom Associate Director in the field of Sustainability, who managed the BATIMASS project, and Mark Lawson, specialist in composite construction, who was managing the DISCCO project.

Ruukki Construction (Ruukki, Finland) is an international division of SSAB providing customers with local service. It employs around 3 500 people and is headquartered in Helsinki, Finland. Ruukki manufactures building components that include steel frames for buildings, load-bearing roofing products, rainscreen panels and sandwich panels used in walls. In addition to products, the company also serves customers in design and installation. For consumers and roofing professionals, Ruukki Construction manufactures roofing products under the Plannja and Ruukki brands. Ruukki is focusing strongly on energy-efficient and sustainable construction solutions that meet customer needs and which combine own design and standardized cost-efficient production.

RWTH Aachen University (RWTH, Germany) - The Institute of Steel Construction of RWTH Aachen (RWTH-STB) comprises a staff of about 70. The Institute covers a wide range of topics including structural aspects, energy saving, comfort conditions etc. both theoretically and experimentally and has at present 6 active working groups for structures, materials, dynamics, wind engineering, building physics and life cycle engineering. A very important research item of RWTH-STB in recent years is the investigation of the building physics performance of steel constructions and buildings with numerical and experimental methods, where RWTH-STB as leading institute in Germany in this field is involved as co-ordinator or partner in several national and European research and dissemination projects. Therefore, testing facilities e.g. a hotbox-climate-chamber, IR-camera, an airtightness test rig and the modular research building in steel equipped to test mechanical and physical properties of new lightweight steel components will be used. In addition, various equipment for in-situ measurements of physical building properties are available. Furthermore, RWTH-STB with its expert team on sustainable construction is a founding member of the German Green Building Council (DGNB) and Member of the Round Table Sustainable Building of the German Government (Federal Ministry for Transport, Building and Urban Development, BMVBS).

Universitatea Politehnica Timişoara (UPT, Romania) participates into the project through the Department of Steel Structures and Structural Mechanics (CMMC), with the Research Center of Mechanics of Materials and Structural Reliability (CEMSIG) chaired by Prof. Dan Dubina, former president of ECCS, member EB and TMB, and in TC7, TC8, TC10 and TC13. The CEMSIG research team has achieved significant reputation through participating in important EU projects, such as: FP4 Copernicus RECOS, FP6 PROHITECH, FP7 SERIES: "DUAREM"; ERA-NET INSPIRE, RFCS projects i.e. STEELRETRO, SB STEEL, LVS3 and SBRI+, DIFISEK and HSS-SERF, EQUALJOINTS and STEELEARTH projects. The Research Institute of Renewable Energies (ICER), of UPT, chaired by Prof. Viorel Ungureanu, member of CMMC/CEMSIG and member of TC7 and TC14 of ECCS, will be also involved in the project for specific tasks asking competences in sustainable development.

European Convention for Constructional Steelwork (ECCS, Belgium) is a federation of national associations representing the steel fabrication industry in their respective countries. The aim of ECCS is to promote the use of steelwork in the construction sector by the development of standards and promotional information. It also helps to influence decision makers through the management of working committees, publications, conferences, and by active representation on European and International Committees dealing with standardization, research, development and education. The ECCS brings together the steel producers, the fabricators and contractors organizations, and the academic world through an international network of construction representatives, steel producers, and technical centres. ECCS also includes non-European associations as International Members, professional European organizations as associate members, and representatives of upstream or downstream products or activities as Supporting Members. Its General Secretariat is located in Brussels.

Paul Kamrath Ingenieurrückbau GmbH (PKIR, Germany) is a medium-sized family business located in Dortmund with around 50 employees and active in North Rhine-Westphalia. For six decades, PKIR-GmbH offers professional engineering services in the field of demolition technique. As specialists for complete solutions, PKIR carries out demolition and earthworks, stripping down of buildings and remediation of the environmental damage for buildings ranging from single-family homes to high-rise office. Buildings are stripped, cleared from pollutants and demolished. In some cases, careful demolition and dismantling is used to prepare areas for rehabilitation and upgrading. With a large pool and equipment, depot with own workshops and trained personnel, PKIR is up to all requirements of modern demolition. With prestigious customers like Hochtief, VW, Thyssen Krupp, Deutsche Bahn AG, BTS GmbH, Storck GmbH, PKIR constantly striving to improve operations by acquiring/developing new know-how in order to offer more sustainable solutions and services.

Final summary

The PROGRESS project approaches 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 particular 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.

The project is divided into three stages. In the initial inception stage, essential data are gathered and economic and legal situation is reviewed. The following stage deals with particular issues related to steel components reuse. The results are disseminated in the final stage. The interaction of project Work Packages and Tasks is illustrated in Figure 3.

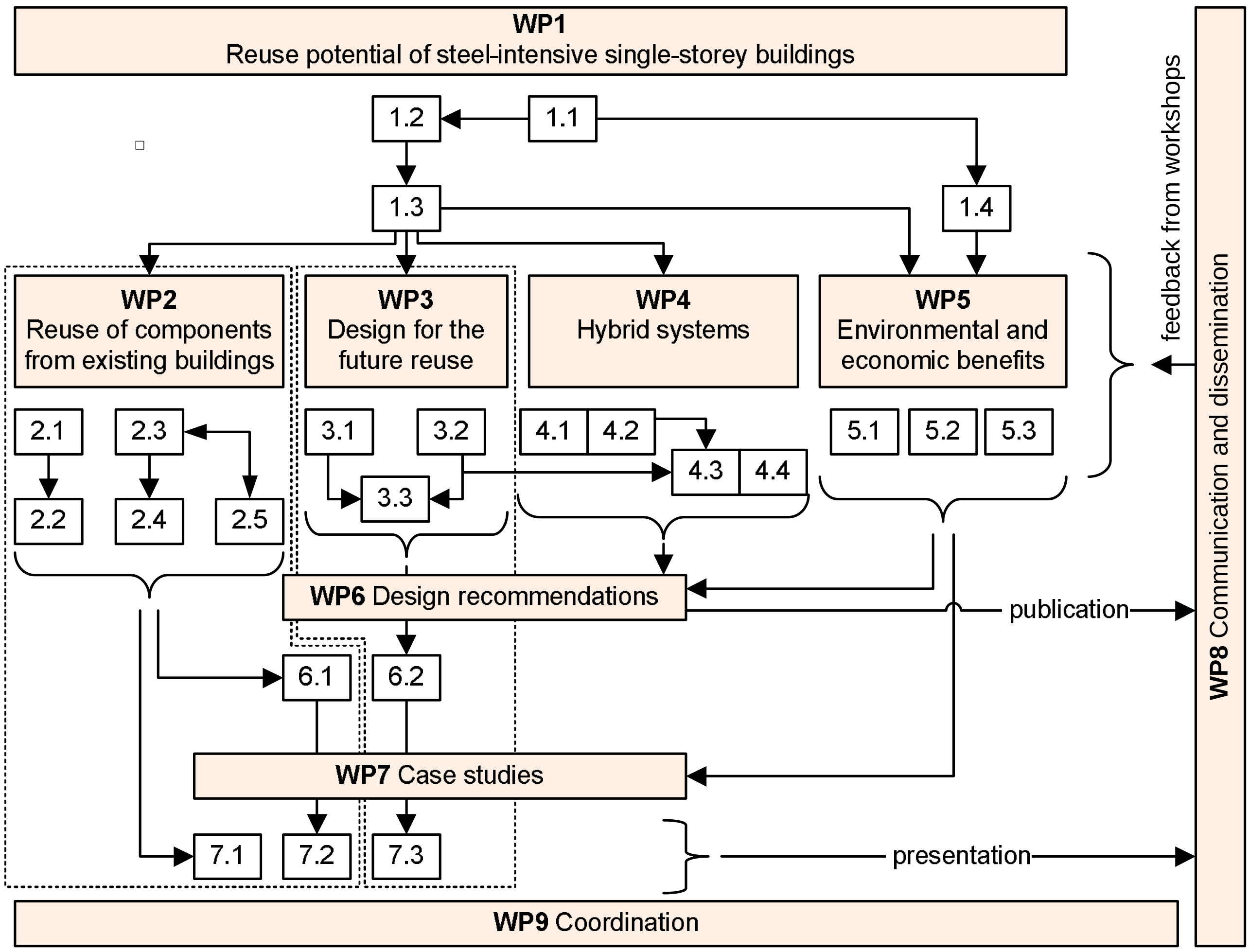


Figure 3. Work Packages, Tasks and their interactions

Reuse potential of steel-intensive single-storey buildings (WP1)

This Work Package focuses on gathering and analysis of basic data concerning the state of the art in reuse of steel and steel-based building components in Europe. The outcome of this WP presents a documented basis to support the overall objectives of the project and the particular goals of the following Work Packages. The thorough reviews and experiences from the successful reuse and deconstruction projects were collected by the project partners and from the practitioners in the building industry. The results are summarized in the form of factsheets (Task 1.1) and analysed to support the development of the assessment of the reuse potential of single-storey steel buildings and their components (Task 1.2 and 1.3). The summary of regulatory barriers and opportunities is produced in Task 1.4. Because several new deconstruction and reuse cases, business concepts, standards and policy documents were introduced during the execution of the project, the knowledge base of the Work Package 1 was continuously updated.

Task 1.1 summarizes experiences from previous deconstruction and reuse project of single-storey steel buildings. The report Deliverable D1.1 [1] contains 14 fact sheets about selected cases (such as in Figure 4) that are used as benchmarks to evaluate technical and market potential of reuse. The cases are selected to represent different reuse scenarios and unique solutions such as the extension of the columns, reuse of historic structure or in-situ conversion of industrial hall into multi-storey building.

Figure 4 Single-storey warehouse building deconstructed and relocated (UK, 2015)

Task 1.2 provides a classification method for various structural and envelope components in accordance with their degree of reusability to support preparation of guidelines for design, deconstruction and reuse (see section 0). The method takes into account the technical reusability and also economic prospect of reuse. The technical performance criteria for the steelwork and the envelope are selected based on the existing assessment methods and guidelines, while the economic assessment is based on the calculation of probability that the component or the assembly meets the demand criteria of the future buildings. The classification method can be used to compare different design solutions or different end-of-life scenarios of the same building. It is described in Deliverable D1.2 [2] and two scientific papers [28],[29]. The possibility to integrate the method in a software package with BIM is discussed in the report.

Task 1.3 reviews the markets and value chains, in order to identify needs and possibilities to increase the share of reused products and systems (see section 1.3). The data about steel consumption, metallic waste generation, recovery and recycling are obtained from several databases and estimation is made for the market size of single-storey steel buildings. The forecast of generated end-of-life material reveals that the amount of steel from the demolished buildings would grow fast in the upcoming years.

Task 1.4 summarizes the regulatory gaps and barriers in the reuse process of reclaimed building elements. The methods and policy instruments to overcome them are proposed together with the identification of the opportunities to support buildings element reuse such as end-of-waste declaration, building passport or sustainable certifications in (see section 1.4). The important outcome of the Task is the clear definition and interpretation of waste and product status of reclaimed steel components. This may enable various waste prevention activities within the regulations outlined by the Waste Framework Directive and Construction Products Regulation.

Reuse of steel and steel-based components from existing buildings (WP2)

This Work Package addresses the issues connected to the reuse of elements from the deconstructed buildings. Its aim is to provide a practical guidance for the whole process starting with the early identification of reusable components, assessment of their suitability for reuse until the verification of their essential characteristics for the certification purposes. The guidance for safe and efficient deconstruction process supported by pre-demolition audits is developed in Tasks 2.1 and 2.2 and two protocols are produced as part of the Tasks' deliverables. Tasks 2.3 and 2.4 propose the methods and tools for the assessment of suitability of materials and elements for the reuse including the recommendations for their modification or adaptation to fit in the new design. The quality verification and testing protocol is developed in Task 2.5. The whole process is based on three possible reuse classes:

- Class A: steel materials with original certificates/documentation.
- Class B: steel materials that meet performance requirements through testing
- Class C: steel materials classified as the most conservative grade

Task 2.1 provides guidance for safe and efficient deconstruction of single-storey steel buildings. It is divided in two parts:

- general approaches to steelwork deconstruction in Section 1 of Deliverable D2.1a [4]
- protocol for the deconstruction of single-storey steel building in Deliverable D2.1b [5].

The deconstruction process is compared to the traditional demolition and the use of different equipment is discussed in D2.1a [4]. The Deliverable describes the main risks in demolition and deconstruction works caused by the structural disintegration or hazardous materials. The use of drones to monitor the structural behaviour or released harmful particles is discussed and the example of aerial photogrammetric 3D scanning is described in detail. The deconstruction protocol (D2.1b) is prepared as a guide to deconstruct single-storey steel-framed buildings so that the entire structure or parts of it or the reclaimed elements can be reused in future. Its aim is to encourage the safe reclamation of structural steel elements from existing single-storey steel framed buildings in the EU so that the reclaimed elements can be reused in subsequent construction applications. Generally, it is assumed that the deconstruction of the steel frame is the same process as its erection with additional effort to maintain the integrity of the disconnected components. The aim of the deconstruction protocol is to create a unitary system for the deconstruction of single-storey steel framed buildings.

Task 2.2 provides a guidance for early identification of reusable steel components. It is divided into two parts:

- basic principles of waste or pre-demolition auditing practices in EU in Section 2 of Deliverable D2.1a [4],
- pre-deconstruction audit protocol for constructional steelwork in Section 3 of Deliverable D2.1a [4].

Waste audit of buildings and infrastructutres before demolition or renovation is an important process for the implementation of the EU Circular Economy Action Plan. The proposed pre-demolition audit protocol is an extension of the European waste audit guidance [48] with the focus on waste prevention by early identification, labelling and documentation of reusable steel components. It gives the auditor possibilities to utilize the tools and methods developed in the PROGRESS project. For instance, it is linked to the testing procedures [7], damage assessment procedure from Deliverable D2.2 [6], reusability assessment from Deliverable D1.2 [2], environmental impact assessment from Deliverable D5.1 [14], and economic assessment from Deliverable D5.2 [15]. The main principle of the waste prevention is based on Task 1.4, where the building owner has to clearly declare his intention to reuse the steelwork instead of disposing it. The important part of the audit is the identification of possible hazardous substances and verification of their limit concentrations and ability to cause environmental damage or any health risks to the site workers and building occupants. All remaining materials are also identified with the appropriate recommendation for their treatment according to the Waste Framework Directive [47].

Tasks 2.3 and 2.4 describe the assessment of the suitability of materials and components to be considered for reuse. The issues related to the materials are covered in Task 2.3 and the components and constituent products are discussed in Task 2.4. The components are further divided into primary structure, secondary structure and envelope. Task 2.4 includes the recommendations how to deal with CE marking of components covered by the harmonized standards. The findings from both tasks are summarized in Deliverable D2.2 [6]. The reuse of reclaimed steel is recommended to be limited to:

- Steelwork erected after 1970;
- Steelwork which has not been subject to fatigue, e.g. not reclaimed from bridges;
- Steelwork from structures which have not experienced extreme loads;
- Steelwork which has not been subject to significant strains, e.g. plastic hinges;
- Steelwork without significant loss of sections' dimensions due to corrosion;
- Steelwork which has not been exposed to high temperature.

Task 2.5 introduces a protocol for sampling and material quality verification in Deliverable D2.3 [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. The 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 (using destructive procedures) one or more representative members from the group. If material properties are assessed based on the protocol, it is recommended that the only modification necessary for structural design is to verify buckling resistance using a modified value for γ_{M1}. This might lead to changes in the structural solution required for a given design scenario (for example additional restraints might be required) but not necessarily a change in member size, as member buckling might not be the critical verification. The protocol recommends that re-certified and re-fabricated reclaimed structural steelwork can be CE Marked in accordance with EN 1090 [50].

Design for the future reuse (WP3)

In this Work Package, technical recommendations for the increase of reusability of the components are provided on component design level (Task 3.1) and building design level (Task 3.2). Moreover, the gaps in the current Building Information Modelling (BIM) definitions and software support were addressed to enable the smooth transfer of all of the relevant information from one building to another (Task 3.3). It is acknowledged that the reuse of steel from buildings designed for deconstruction and reuse is more efficient and may be cheaper than reuse of the components from the traditionally designed buildings. Additional improvement and cost reduction may be achieved by the proper management of the essential information during the service life of the building.

Tasks 3.1 and 3.2 focus on the conception, design, detailing and execution methods for new single-storey steel-framed buildings (SSBs) and steel-based envelope components, so that the reusability of products and systems is the leading principle overall building solution. The focus is on design for future adaptation, deconstruction and reuse. In addition to the structural and envelope components, the work includes the interfaces and connections between these elements of the building. An overview of the design process is made, covering not only the structural concept and products but also regarding load definition, structural analysis and structural design. Proposals for structural concepts and detailing are also presented, in order to investigate ways to increase the reusability of the building as a whole or, as an alternative, to reuse the structural elements within the building. The main areas addressed with T3.1 & 3.2 are the following:

- benefits and barriers and opportunities for reuse in different end-of life scenarios
- relevant Design for Deconstruction principles to increase the future reuse of the steelwork
- overview of current practices in conception, design and detailing of SSBs across Europe
- practices that hinder deconstruction and future reuse of the steel structure in SSBs and principles/solutions for future improvements
- selection criteria for steel structures and steel-based components so that easy deconstruction and efficient reuse are highly prioritized over other design targets
- basic principles in the development of single-storey building concepts focusing on the spatial arrangements, spans, dimensions, functions and forms
- overview of current loading definition across some European countries, proposing alternative procedures to increase future building adaptability
- current design philosophies and principles, proposing general principles for reus

Task 3.3 presents an overview and recommendations on the use of Building Information Modelling (BIM) in the reuse of steel structural components and envelopes from SSBs as defined in the deliverable D3.1 “Summary of design practices for reusable buildings and products” [8]. The role of digital information is addressed with the focus on the digital tools and the stored information for future reuse. The recent standards are introduced including those under development and the guidance about how to address the level of information detail in the structural steel industry. The guidance about the building information will make sure that all relevant material properties and other project parameters are never lost. The following aspects are included in the Deliverable D3.2 [9]:

- description of the use (reuse) cases
- BIM development and implementation
- overview of the gaps in data structure, software functionality and assessment of the integration in the BIM extensions
- demonstration of the proposed BIM for reuse

Novel hybrid systems for envelopes of single-storey steel-framed buildings (WP4)

The Work Package aims at novel hybrid solutions for envelopes of single-storey buildings, either new buildings or renovation projects that improves the thermal performance of an entire building, service life of envelopes and reusability of solutions themselves. Work Package 4 benchmarks the product development process from the conceptualisation phase to a pilot product phase of a hybrid envelope solution of single-storey buildings that improves reusability. New hybrid solution and joining methods are proposed in Task 4.1. The performance of the hybrid solution is confirmed by testing of the elements (Task 4.2) and its connections (Task 4.3) and the product is pilot tested on the on CUBE DemoHouse at RWRH (Task 4.4). Building components and materials for the building envelope were selected and connected in such a manner that they can valuably be reused or recycled after a building's end-of-life. The main goals of the Work Package were:

- to provide durable solutions for the possible extension of the life-span of the envelope
- to optimize building component geometries for wider range of uses and better chances for further utilisation and reuse
- to design connections which are easy to separate for better recycling potential and systematic support for the reconditioning, further use and reuse of construction components and materials
- to select materials with low contamination levels for easier further use and reuse, simple disposal of non-usable residual waste and protection

Task 4.1 elaborates different concepts for reuse of existing or future envelope systems. Based on the discussion within the consortium and consultation with the stakeholders, three concepts were selected to be investigated further in the Work Package 4:

- **Reuse of liner trays** in-situ considers the situation when the inner shell of the existing double-layer system remains on the building and is over-clad with new sandwich panels. This concept enables reuse of the large part of existing insulation material leading to considerable environmental savings.
- **Over-cladding of sandwich construction** is a similar solution for existing sandwich panels that would be removed and disposed otherwise. This concept requires a connecting technology that does not penetrate the original envelope. Therefore, the one-sided fixation was recommended to be thoroughly investigated in Task 4.2.
- **FRP Hybrid Systems** are possible solutions for the new construction. Here, the thin-walled profiles are replaced by FRP profiles or sandwich panels are reinforced with FRP beams. Although the energy performance is improved in the comparison with the traditional systems, the main benefit for reuse is increased load-bearing capacity of the enevelope that allows reduction or complete avoidance of the secondary steelwork.

The concepts are described in detail in the Deliverable D4.1 together with the description of the suitable connections from Task 4.2 [10].

Task 4.2 focuses on the development and testing of connection technologies for the envelope systems (see Figure 5). Functional dismountable connections that do not impair the energy performance of the envelope are essential for the successful reuse of the cladding components. The connection technologies are described in Deliverable D4.1 [10] and their tested performance summarized in the test report (Deliverable D4.2) [11]:

- **One-sided fixation** is the main challenge for the over-cladding of existing sandwich panels and therefore, also for the in-situ reuse of buildings with an envelope made out of sandwich panels. The thorough testing of the mechanical performance of this connection on new and artifically aged sandwich panels revealed that it is possible to design such connections with common safety factors and that the connection is not affected by ageing.

- **Adapter profiles** for sanwich panels provide the reversible connection for the future reuse of new enevelopes. Smart Flashing Connector is a new solution developed in PROGRESS project. The whole system of sandwich panel and connector was then tested in Task 4.3 [12].

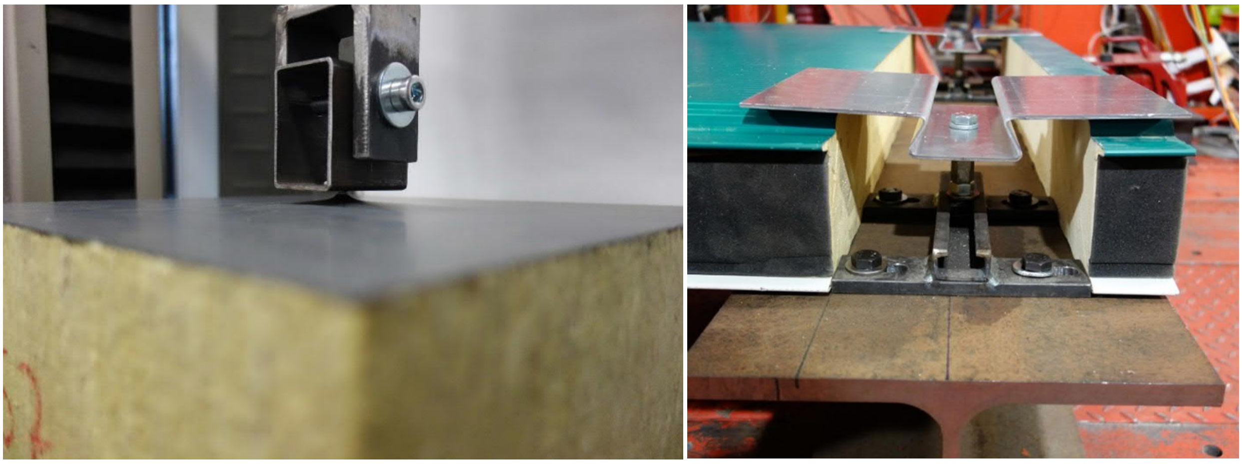


Figure 5 Testing of one-sided fixation (left) and Smart Flashing Connector (right)

Task 4.3 covers the development and testing of the prototype systems for the envelopes. It is based on the findings from the theoretical elaboration of possible solutions in Task 4.1 and experimentally verified connection technologies in Task 4.2. The following systems were considered in this Task:

- **Clamped solution with adapter profiles** is based on the innovative Smart Flashing Connector introduced in Task 4.2. The testing of assembly/disassembly and mechanical performance showed that the system has comparable load-bearing capacity to the conventional screwed connections up to the span 4.8 m, while the installation, dismantling and overall reusability was greatly improved. On the other hand, the thermal performance of the solution can still be improved.
- **Hybrid system** with sandwich panels installed over liner trays was tested in the laboratory and in-situ by over-cladding part of the façade of the Institute for Steel and Metal Lightweight Construction at the RWTH, by a sandwich panel. It was concluded that due to the complexity of the "hybrid element", it makes sense that further research is carried out not only to examine the combination of several components, but also to examine fundamental aspects of the isolated individual components - in this case sandwich elements or liner tray profiles – in more detail.
- **FRP hybrid system** is an improvement of the previous system with the attached FRP profiles to stabilize either lower part or the complete cold-formed web. This is significantly increasing the load-bearing capacity of the cladding system and reducing local failure of cold-formed profiles. Both effect are contributing to a greater reusability of the cladding components.
- **Over-cladding system** with one-sided fixation on the sandwich panels is the last prototype tested in this Task. The profiles were attached on two sides of the demo building over the vertically and horizontally laid walls. It was observed that the assembly is not difficult if there is enough attention paid to the straightness of the profiles.

Task 4.4 provides assessment of the overall performance of the envelope systems studied in Tasks 4.1 to 4.3. The following aspects were assessed:

- energy efficiency,
- environmental benefits according to the recommendations developed in Task 5.1,
- lifecycle costs according to the recommendations developed in Task 5.2,
- fire safety,
- sound insulation.

It is concluded that the main benefit of reuse and lifetime extension of the envelope is the reduced carbon footprint of the current or future building caused by the core insulation material. As the results showed, environmental impact in construction and deconstruction/demolition stages was negligible in comparison with the production stage, but as for economic impact, costs in construction and deconstruction/demolition stages were as high as the costs in the production stage or even higher.

Environmental and economic benefits of reuse (WP5)

Approaches to study environmental and economic benefits of reuse of single-storey buildings are developed and improved in this Work Package and the benefits quantified. A methodology to quantify and declare environmental benefits of reused elements is developed (Task 5.1), resulting in recommendations on the circularity and LCA methodologies to employ within the case studies in subsequent Work Package 7. In parallel, Task 5.2 is dedicated to estimating the economic potential of steel-based elements reuse in SSBs complemented by the business models developed in Task 5.3.

Task 5.1 provides a guidance for the quantification of environmental benefits of reuse according to the various existing methodologies and certification schemes such as LEED, BREEAM, DGNB and CASBEE. It was recognized that the specific guidance about the calculation of the environmental impacts of material that is partly reused and partly recycled is missing. This calculation method was developed in the Task to be used specifically for the constructional steel with the recycling impacts calculated according to the Worldsteel Association's LCI methodology. It was confirmed that the methodology can be used also for the Product Environmental Footprint (PEF) and Environmental Product Declaration (EPD) according to the new EN 15804. The use of the new methodology is demonstrated on two case studies, one of the product and one of the building in Deliverable D5.1 [14].

Task 5.2 focuses on the quantification of the economic impacts of reuse, especially on the lifecycle cost assessment. Deliverable D1.2 [2] identified the greatest potential to maximize the value of the product and to minimize the costs in deconstruction and reuse process stages. Therefore, particular recommendations are provided for the early identification and quality verification procedure developed in Task 2.2 [6] and Task 2.5 [7], effective use of design recommendations and ICT. The Deliverable D5.2 [15] contains:

- Description of the actors and stakeholders in the current and forecast closed-loop value
- chains around the reuse scenarios of SSB's, and their role in creating economic opportunities and constraints
- Qualitative evaluation of the overall economic potential of the reuse stages in various reuse scenarios
- Review of the quantitative approaches to estimate the economic benefits and burdens of reuse cycles as presented in literature
- Evaluation of existing case studies, cost assessment methodology and example calculation
- Summary and recommendations for each of the actors in the supply chain

Task 5.3 reviews and proposes approaches to the development of circular economy business models that are applicable to the supply of reused and reusable single-storey steel framed buildings and/or their component parts. This task builds upon the findings of several other tasks most notably Task 1.3 [3] addressing market size and potential and supply chains for SSBs and Task 5.2 [15] addressing the economic potential of reusing SSBs and their constituent parts. The deliverable report [16] reviews the current state of the art concerning circular economy business models both in general and specifically in the context of the construction industry. The following business models, specific to the scope of the PROGRESS project, are presented and reviewed:

- Hire or leasing of products
- Product as a service or servitisation
- Take back/buy-back model
- Reuse of structural steel elements or whole steel structures (or parts of)
- Information service to facilitate future building adaptation, deconstruction and reuse

Design recommendations on reusing reclaimed steel construction products (WP6)

The guidance developed in this Work Package includes recommendations for primary and secondary structural steel products and for hybrid, steel-based envelope products and systems of existing buildings in **Task 6.1** and future buildings in **Task 6.2**. The publication provides recommendations for all actors in the supply chain, i.e. demolition contractors, steelwork contractors, steel stockholders and building designers (see Figure 6). It was prepared in the format of ECCS publications in order to be published in the future series of ECCS Design Manuals.

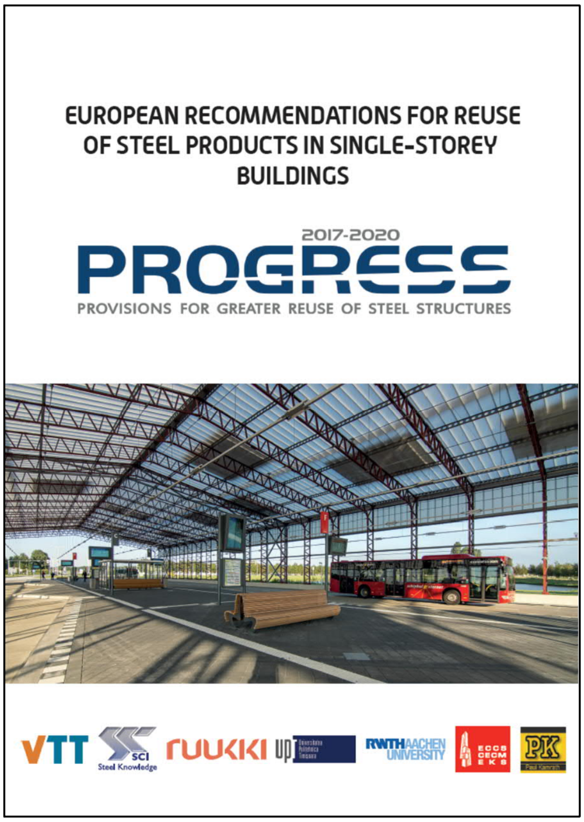


Figure 6 Cover page of the joint deliverable D6.1 and D6.2

Case studies (WP7)

15 case studies in this Work Package provide benchmark of demolition, classification and testing/verification protocols developed in WP2 on a real deconstructed building (Deliverable D7.1a [18]) and the laboratory tests to identify mechanical and chemical properties of the materials (Deliverable D7.1b [19]). The design case studies in Task 7.2 and 7.3 cover the most common reuse situations from the design, economic and environmental point of view. Deliverable D7.2 [20] compares six different design situations of SSB with portal frames in Romania. Three different re-design concepts of and existing SSB with truss girders on columns in Finland are then presented in Deliverable D7.3 [21].

Task 7.1 aims at demonstration of deconstruction and pre-deconstruction auditing techniques (Deliverable D7.1a [18]) and material verification methods (Deliverable D7.1b [19]). The deconstruction part covers a detailed description of the deconstruction and reuse case study of a single-storey steel framed building in Cologne, Germany with a common demolition equipment. It was for instance demonstrated that it is possible to use two excavators to carefully lay down the frames that were later reused. The material verification part covers a wide range of laboratory tests of steel sections and sandwich panels of different age removed from several existing buildings. The applicability of two innovative minimum-invasive testing methods was studied and especially Small Punch Test showed a promising prediction of the material yield and tensile strength on miniature specimen that could be extracted from the steelwork without compromising its structural performance.

Task 7.2 focuses on the design from reclaimed steelwork or its components. It presents four different theoretical case studies with a comparative environmental and economic impact assessment of the same steel building when the structure is build reusing an existing steel structure, using reclaimed elements or using new construction materials. The LCA results showed that the reuse is a strategy environmentally superior to recycling, the greatest gain being visible in the production stage where GHG emissions are between 29-33% smaller when the structure is built with reused steel in comparison with structures built with new steel. According to the LCC results, when it comes to economic potential of the reuse, the scenarios with reused steel elements resulted also in higher potential savings compared to recycling.

Task 7.3 covers several case studies of two different buildings. Two cases of the portal framed building were compared to the cases from Task 7.2 and reported in Deliverable D7.2. Deliverable D7.3 focuses on the single-storey steel building with truss girders on columns re-designed for better reusability. The first part focuses on the design for reuse and presents three design cases. Economic aspects are elaborated in this part for the evaluation of the feasibility of the proposed alterations of the original design. Main observation in this part was that universal reuse design might significantly increase capital investment compared to traditional design. However, it was possible to include two more solutions improving reuse to case project even with minor extra investment with the use of main principles from design for deconstruction like regularity, generality and simplicity increase reuse. The second part of D7.3 explores the real estate valuation of design for deconstruction and reuse of one selected re-design study from the previous part. The study concludes that when the possible benefits of DfD and reuse happen far in future, this is not attractive for the investors. In addition, as the costs of DfD incur in the beginning there is a clear imbalance of the profits and costs from the investor’s point of view. This means that currently, without any external financial incentive, it is not profitable to choose DfD building over the traditional building at least when the service life is more than 10 years.

Communication and dissemination (WP8)

The project outcomes were disseminated through the workshops, webinars, internet presentations, newsletters and publications. The workshops, webinars and interviews also provided a valuable feedback for the proposed assessment methods and protocols in Work Packages 2 to 5.

Task 8.1 provides support for the internet presentation and other publication activities. Project webpage was created in the ECCS website with all the relevant documents, factsheets and workshop presentations (Deliverable D8.1), and a second informative webpage was created at the coordinator's website. The information about the project activities was disseminated by press release published by VTT and newsletters by ECCS and SCI. The particular outcomes from different tasks were published in several conference proceedings and scientific journals.

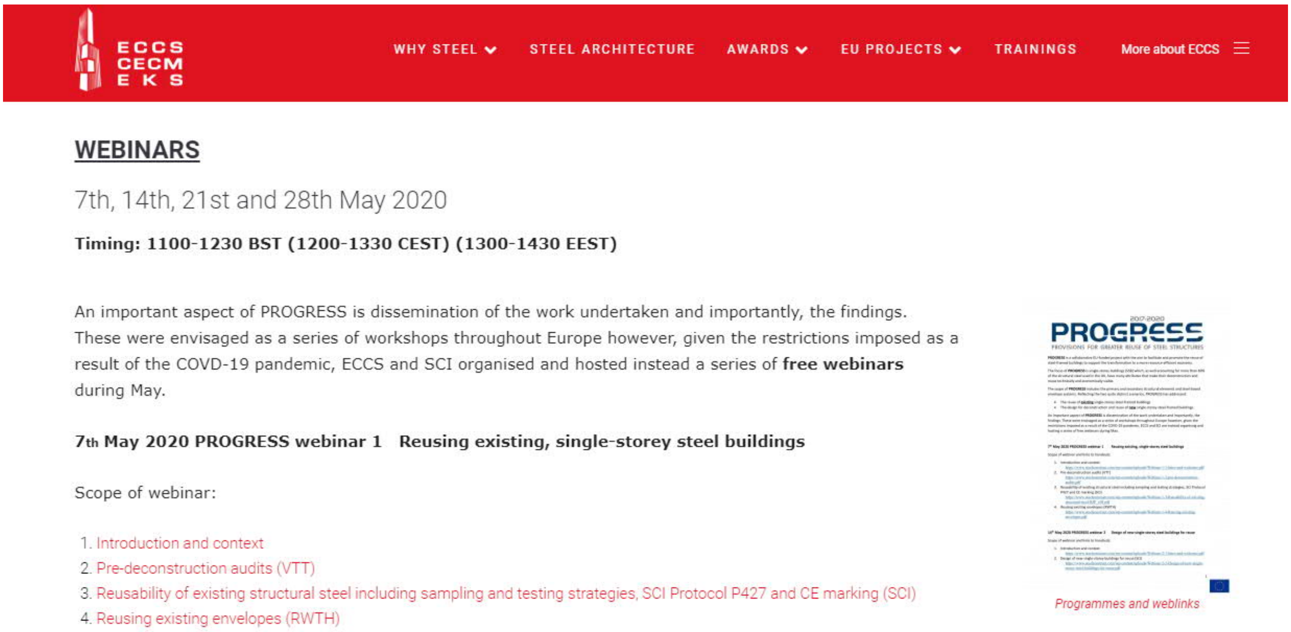


Figure 7 ECCS webpage with webinars presentations

Task 8.2 focused on the organization of eight regular workshops in Finland, Germany, Romania, United Kingdom, the Netherlands, France, Spain and Portugal, and one final workshop in Brussel in Spring 2020. The workshops were generally successful and the PROGRESS received award for the most innovative project or service in Construmat Fair in Barcelona, Spain. Unfortunately, three workshops were cancelled due to the COVID-19 pandemics and had to be replaced by a series of online webinars. Therefore, the Deliverable D8.2 was fulfilled only partly as there was no need for the USB keys for the webinars participants and the proceedings were distributed electronically via ECCS webpage (see Figure 7).

Task 8.3 developed a prototype information sharing portal for steel reuse with the integration of Building Information Modelling. The portal provides information and guidance (from earlier WPs and particularly the Design Guide D6.1) with the focus on systems to trade steel buildings and products. In terms of the functionality of the portal, it has been developed to address both:

- Reuse today scenario, i.e. a traditional 'sell-buy' exchange but devoted specifically to reclaimed structural steel and steel-based envelope products from existing buildings

- Development of a database of new structural steel in newly constructed buildings, i.e. facilitating future deconstruction and reuse.

Project management and coordination (WP9)

This Work Package contains all the coordination activities on the project and Work Package level. It ensures effective project management by:

- coordinating delivery of project results within planned budget and timescale,
- preparation of periodical reports and financial statements to the European Commission,
- promoting close interaction between partners and organising progress meetings with the whole consortium.

Several challenges were encountered during the project implementation such as the need to increase the frequency of consortium meetings from every 3 months to every 2 months in the second reporting period and the coordination of two deliverables with shared responsibilities between more partners (D2.1 and D7.1) that resulted in two reports per deliverable.

1. Reuse potential of single-storey steel buildings (WP1)

Work Package 1 focused on gathering and analysis of basic data concerning the state of the art in reuse of steel and steel-based building components in Europe. The outcome of this Work Package presents a documented basis to support the overall objectives of the project and the particular goals of the following work. The thorough reviews and experiences from the successful reuse and deconstruction projects were collected by the project partners and from the practitioners in the building industry. The results were summarized in the form of factsheets (Task 1.1) and analysed to support the development of the assessment of the reuse potential of single-storey steel buildings and their components (Task 1.2 and 1.3). The summary of regulatory barriers and opportunities was produced in Task 1.4. Because several new deconstruction and reuse cases, business concepts, standards and policy documents were introduced during the execution of the project, the knowledge base of the Work Package 1 was continuously updated.

1.1 Review of existing case studies

Nowadays, great importance is given to limiting the use of non-renewable resources and decreasing the impact on the environment. The reuse of steel structures has a potential to become more environmentally efficient than recycling steel, and therefore a systematic study of successful reuse cases is required to understand the drivers and limiting factor of this process.

Steel structures can be reused in different ways, considering the layout (same or different layout) and the location (relocated reuse or in-situ reuse). According to the type of reuse, specific operations need to be performed; in the case of relocation, dismantling, transportation and reassembly of the structure are required, which are not needed in the case of in-situ reuse. These processes imply additional costs and environmental impact, which need to be considered in order to establish the feasibility of the reuse process compared to designing and erecting a structure made entirely from new steel elements.

An issue regarding the reuse of steel elements or structures is that sometimes little or no information is available for the elements. In this case, the mechanical properties of the material need to be determined by tests, which can be difficult and time-consuming. Generally, the global and element dimensions are determined by in-situ measurements even if the drawings are available. A common feature of all types of reuse is that the old structures need to be strengthened by adding or changing some structural elements due to the fact that the current design codes operate with higher climatic (snow and wind) and seismic loading than the codes in use at the time of design.

At the moment, a database containing information about old steel elements available for reuse does not exist; basically, designing a new structure consisting of old steel elements coming from different sources is impossible. In most cases, the reuse is made by beneficiaries who decided to reuse the entire old structure in one way or another.

The aim of Task 1.1 was to gather information about several case studies dealing with different types of reuse of steel structures in order to draw some general conclusions regarding the aspects and feasibility of the reuse process. Fourteen case studies of reuse steel structures have been identified around Europe, i.e. in Croatia, Finland, The Netherlands, Germany, Romania and UK, being framed in different reuse scenarios.

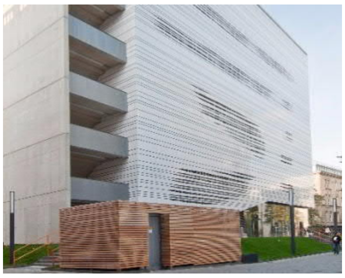
Identification of existing case studies

The scope of this task is to show the experience in projects in which steel structures and steel-based components are removed from existing single-storey buildings and reused either in renovation or in new buildings. The documented findings will be used as a benchmark to evaluate technical and market potential of reuse and development needs from technical and market viewpoints.

Figure 8 Case studies of reused steel structures around Europe

Table 4 Examples of reuse scenarios according to the cases presented in [1]

Image	**Brief description**
	**NTS building, Thirsk, UK** The original order for the building was cancelled in 2008 and the elements were stored. The new building was erected in 2017 by reusing a quarter of the steelwork of the original building.
	**SEGRO warehouse, Slough, UK** The structure was built in 2000 and relocated in a different layout at a new location in 2015.

	**HIDROTIM office, 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.
	**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.
	**UPT Steel Structures Laboratory, Timisoara, Romania** The structure was erected in 1959, consisting of truss elements. Part of the structure was severely damaged in 2017 by a storm. As the structure was designed more than 50 years ago, it needs to be upgraded to fulfil the current codes, operating with higher climatic (snow and wind) and seismic loading than the codes at the time of design.
	**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.
	**Agrocolumna warehouse, Copaceni, Romania** The building was erected in 2004 in Craiova, consisting of a two-storey office building and a warehouse. In 2012, it was moved to Copaceni (227 km east of Craiova) and one more bay was added to the warehouse.
	**Bus station Schiphol – Nord, Amsterdam, The Netherlands** The initial use of the structure was a T2 type hangar for the British Royal Air Force during the World War II. After the war, in 1958 this T2 was taken at Zestienhoven airport and used as a hangar 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.

	**Metis canopy, Otočcu, Croatia** The original structure was erected in Pula and was relocated for reuse in 2011 in Otočcu, 266 km away.
	**S-Market, Urjala, Finland** The original structure was erected in 1980s in Tampere and was relocated for reuse in 209 in Urjala, 60 km away.
	**Fabrication plant, Wuppertal, Germany** The production company has two fabrication sites. Due to growth over the years, this hall was planned to be cleared and populated by modern fabrication buildings afterwards. The owner, however, decided to reuse the original historical steel trusses from the early 1920s.
	**Steel industrial kit hall for multiple locations, Romania** An existing standard kit structure was used to construct buildings in different locations in Romania between 2008 and 2010. Recently, in 2020, a new complex of buildings reused the elements of one of the existing standard kits.
	**Structural strengthening of a steel structure to enable the removal of 2 columns, Târgu Jiu, Romania** The two-storey structure (reinforced concrete columns and steel trusses), built in 2008 is used as restaurant. In order to reconfigure the upper floor and increase the clear space, two central concrete columns were removed, and consequently the strengthening the steel trusses
	**In-situ rehabilitation of a Water Treatment Plant in Brasov, Romania** The building was used as water treatment plant for a local brewery factory, erected in 2003. In 2015 the owner decided to rehabilitate the building, due to the bad thermal insulation and corrosion of some steel components, keeping the function of the building and not interrupting the activity

General conclusions

Based on the presented case studies, the following general conclusions can be drawn:

- Several case studies proved that reuse of the old steel structure was more feasible than designing and erecting a new steel structure with the same dimensions and functionality;
- In most of the studied cases, the entire primary structure was reused (degree of reutilization 80-100%);
- The dismantling process is easier in the case of structures with reduced weight that use bolted connections;
- Regarding the dismantling process, the materials need to be handled carefully, requiring supplementary time; moreover, space for storage of the recovered elements is needed. All these aspects need to be considered in the planning of the project;
- In all the case studies, the old structures needed to be strengthened by the addition or change of some structural elements;
- In the case studies presented, reuse was facilitated by the fact that the structures were used either in its entirety, in-situ or by relocation, so there was no need to search for old steel elements in order to reuse them. If the reuse is made by designing a structure made of old steel elements coming from different buildings, the process is more difficult because there is no database providing information regarding available steel elements;
- The reuse process is easier when the original project information is available (including the certificates for steel products). In this case, the mechanical properties of the steel do not need to be determined by tests, speeding up the design process;
- The cost and environmental impact are influenced by two important factors: steel production and transportation. Steel production is significant in the case of structures erected using new steel elements, while transportation is important in the case of reusing old steel structures or elements. Therefore, the feasibility of reuse is determined by comparing the cost and impact of the reused elements with the cost and impact of producing new steel elements.
- A challenge for the reuse of old steel structures is adapting the building to meet new functional requirements.

1.2 Classification of reusable components

The methodology presented in this section is based on the established performance categories and assessment mechanics of the existing assessment methods (such as BRE Design for Deconstruction [38] and DGNB [37]). It results in a single score (from 0 to 1) calculated as a weighted average of different performance categories.

Unlike deconstruction, the reuse process can lead to several different outcomes (e.g. reusing the whole structure or its parts separately), and therefore the new methodology has to enable the comparison between different end-of-life scenarios. This is achieved by allowing the evaluators to define their own clusters or groups of components and their intended end-of-life treatment (e.g. recycling or reuse).

The technical reusability of each component or group of components is then assessed according the same rules following the flowchart in Figure 9. Since the assessment considers only steelwork and steel-based envelopes, the weighing of the results can be carried out for the components (or groups) total masses or areas and the calculation of their environmental footprint is not necessary as in the BRE scheme. Scoring checklist and associated weighting factors are presented in Table 5 and Table 6. In addition to the technical reusability, reuse possibilities are limited to the actual demand for the specific products recovered from existing buildings. Therefore, a new assessment of the projected demand of the building components or assemblies can be used as a complementary score to the technical reusability.

The method was presented in the Eurosteel 2017 conference in Copenhagen [28] and IALCCE 2018 conference in Ghent [29]. Example calculation was published in Steel Construction Design and Research [33] and the methodology was summarized in detail in Deliverable D1.2 of PROGRESS project [2] for the structural steelwork and steel-based envelopes.

Existing methods for the assessment of design for deconstruction

The possibility to reuse building components depends largely on the ability of the building to be safely and easily deconstructed. Therefore, the assessment of the reusability should preferably follow the similar mechanics as the existing assessment of the design for deconstruction (DfD). Two widely used existing assessment methods are DGNB assessment of design for deconstruction [37] and the methodology developed by the Building Research Establishment (BRE) [38]. Both follow the same structure described in Figure 9, and therefore the reusability classification is based on the same scheme.

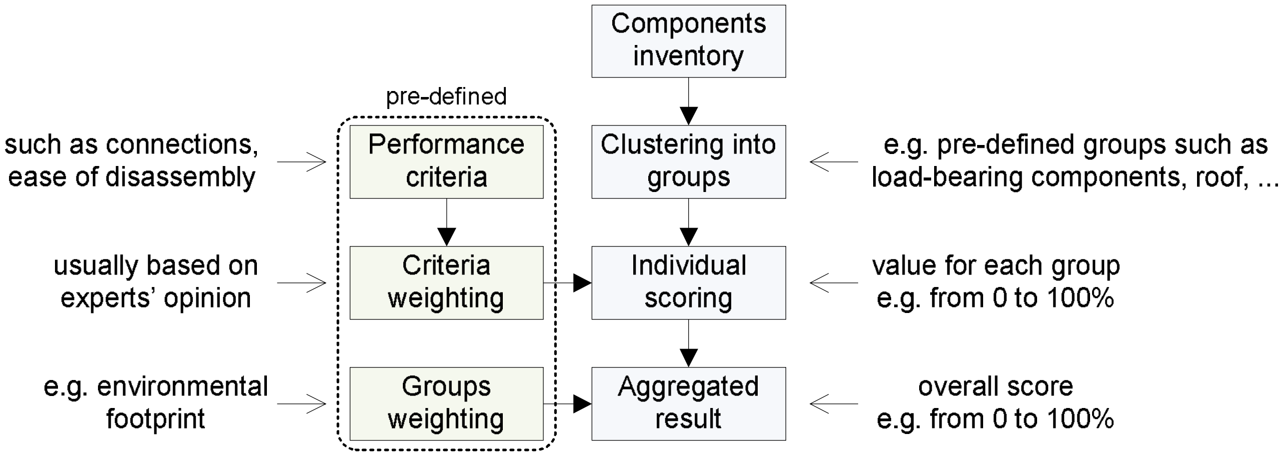


Figure 9 Typical assessment procedure

Performance categories for recycling and reuse

The performance categories used to assess the recyclability/reusability of components in building projects were reviewed and summarized from the VDI-guideline 2243 "Recycling-oriented product development" [39] and DGNB certification system [37]. Based on the results of the literature review and the analysis of performance categories, the following performance categories for building components have been developed for the classification of degree of reusability:

- **Deconstruction/Disassembly:** site operation resulting in transportable parts that will be further handled.
- **Separation/Cleaning***:* workshop process leading to a reusable component acceptable by the salvage yard or material dealer. It is the pre-process of modification.
- **Handling/Manipulation:** lifting, transporting, storage and protection of the reusable components after the deconstruction process.
- **Quality control:** process supporting re-design by confirming the quality of the materials in the component.
- **Geometry checking:** process supporting re-design by showing that the geometry of components conforms to the tolerances in execution standards.
- **Redesigning:** office process governed by the new life target, the availability of components and the result of checks. The purpose of re-design is to modify the components or verify that they can sustain loads in the new life scenario.
- **Repurposing:** the freedom to use the component in a wider scope, different purpose (e.g. column as a beam), and even different industry.
- **Alteration/Modification:** optional workshop process leading to a modified product.

Table 5 Scoring checklist for the structural steelwork

Performance criteria	**very difficult** $\rho_i = 0.2$	**difficult** $\rho_i = 0.4$	**moderate** $\rho_i = 0.6$	**easy** $\rho_i = 0.8$	**very easy** $\rho_i = 1.0$
Deconstruction Disassembly w_i = 30%	Welded connections, high risk of damage during deconstruction	Welded connections between components with difficult access	Mostly welded connections between components	Bolted connections between components with difficult access	Easily accessible bolted connections between components
Separation Cleaning w_i = 10%	Machine cleaning/cutting needed to separate other materials	Hand tools for cleaning/cutting can be used to separate other materials	Bolted connections with difficult access for separation	Bolted connections need to be removed for separation	Free-standing components requiring no cleaning
Handling Manipulation w_i = 15%	Exceeding standard transport dimensions, prone to damage, requires special protection	Standard transport, prone to damage, requires special protection	Manipulation by crane, not damage sensitive	Small lifting devices	Manipulation by hand
Quality control w_i = 15%	No documentation, demanding environment, loading history is difficult to estimate, laboratory tests are needed	Laboratory tests are needed to check material properties	Documentation available, loading history known, on-site test needed to check material properties	Material documentation available incl. loading and maintenance history	Material documentation available Exploited in less demanding environment
Geometry checking w_i = 5%	Components would not pass geometry requirements without modification	Complex geometry 3D scanning required	Need to confirm positions of bolt-holes, etc.	Straightness and distortion check needed (lasers)	Straightness enough to confirm usability (wire, visual, etc.)
Redesigning (reuse of design documentation) w_i = 10%	No documentation, components would not fulfil the standard design requirements without modification	No documentation available, new design is required	Design documentation available	Detailed documentation available incl. loading and maintenance history	Designed to be reused, documentation and maintenance records in digital format
Repurposing w_i = 5%	Unique sizes and shapes, no other application possible	Possible to reuse for another purpose with some re-manufacturing	Limited possibility to use for another purpose	Possible to use for another purpose even outside the construction sector	There is a larger demand for another application than the original purpose
Alteration Modification w_i = 10%	Sizes are unique, reuse would require complete remanufacturing	Requires removal of welded parts	Requires addition and adjustment of bolt-holes	Requires only addition of new components	Requires no modification

Table 6 Scoring checklist for the steel-based envelope

Performance criteria	**very difficult** $\rho_i = 0.2$	**difficult** $\rho_i = 0.4$	**moderate** $\rho_i = 0.6$	**easy** $\rho_i = 0.8$	**very easy** $\rho_i = 1.0$
Deconstruction Disassembly *w_i = 20%*	Adhesive connections, high risk of damage during deconstruction	Rivet connections between components with difficult access	Rivet connections between components	Drilling screw connections between components with difficult access	Easily accessible drilling screw connections between components
Handling Manipulation *w_i = 5%*	Exceeding standard transport dimensions, prone to damage, requires special protection	Standard transport, prone to damage, requires special protection	Manipulation by crane, not damage sensitive	Small lifting devices	Manipulation by hand
Separation Cleaning *w_i = 15%*	Adhesive and rivet connections need to be removed for separation	Removal of joint sealing elements	Hand tools for cleaning/cutting can be used to separate other materials	Screwed connections need to be removed for separation	Separated Profiles requiring no cleaning
Redesigning *w_i = 15%*	Components would not fulfil the standard design requirements without modification	New design is required, similar environmental conditions	Similar design required with different environmental conditions	Loading and maintenance history, same design required and similar environmental conditions	Designed to be reused, documentation and maintenance records in digital format
Repurposing *w_i = 5%*	Unique sizes and shapes, no other application possible	Possible to reuse for another purpose with some re-manufacturing	Limited possibility to use for another purpose	Possible to use for another purpose even outside the construction sector	There is a larger demand for another application than the original purpose
Alteration Modification *w_i = 20%*	Sizes are unique, reuse would require complete remanufacturing, Components are damaged and unusable	Requires removal of adhesive parts, difficult adjustment of rivet-holes	Requires addition and easy adjustment of screw-holes	Requires only addition of new components	Requires no modification
Adjustment Quality check *w_i = 10%*	No documentation, demanding environment, loading history is difficult to estimate, laboratory tests are needed	Laboratory tests are needed to check material properties	Documentation available, loading history known, on-site test needed to check material properties	Material documentation available incl. loading and maintenance history	Material documentation available Exploited in less demanding environment
Recycling performance of materials *w_i = 10%*	Components with high pollutant content, difficult separation of different materials	Components with low pollutant content,	Moderate separation of different materials	Easy separation of recyclable materials	Separated or free-standing recyclable materials and profiles

Reusability index

Technical reusability index r of a single component or group of components is calculated according to Eq. (1) using the parameters from Table 5 and Table 6. The economic reusability index e is the probability that the particular component or structure will be needed in a specified area (e.g. within one country) and time with the flexibility of dimensions that has to be further specified (see Eq. (2) where c is the criteria and n is the expected number of new SSBs in the selected time and location). The single indicator for the whole scenario R and E is then a weighted score of all components and component groups as in Eq. (3).

$$r = \sum \rho_i w_i \tag{1}$$

$$e = P(c_1 \cap c_2 \cap c_3 \ldots) \cdot n \text{ with } e \leq 1 \tag{2}$$

$$R = \sum m_i r_i / \sum m_i \text{ and } E = \sum m_i e_i / \sum m_i \tag{3}$$

It is possible (but not necessary) to further combine the two scores according to the Eq.(4) and arrive to a single number representing both technical and economic aspects of reuse.

$$reusability = R \cdot E \tag{4}$$

The methodology was benchmarked on several case studies[28],[29],[33] and a plan for its implementation in the assessment of impacts and costs beyond system boundaries (Module D according to CEN TC/350) was proposed. Additionally, a possibility to integrate the methodology in a software tool involving BIM model was presented as described in [2].

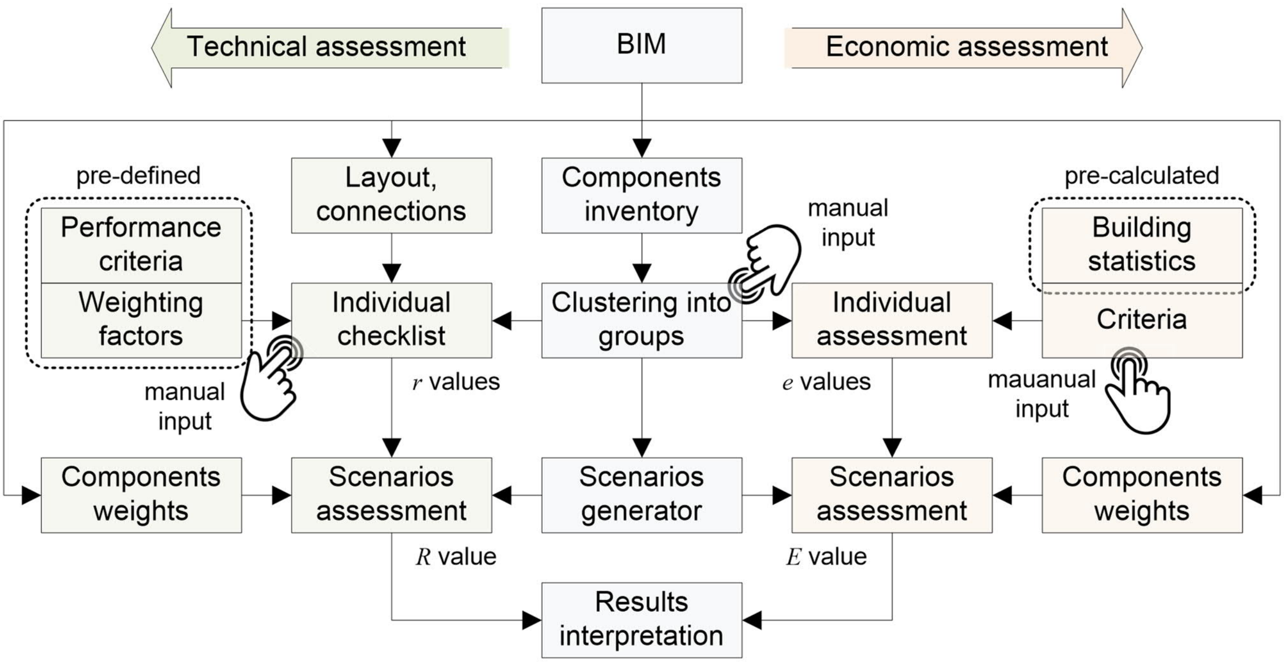


Figure 10 Implementation of BIM and reusability assessment

1.3 Markets and value chains

This section presents figures and data to provide an overview of the market potential of steel reuse in the sector of single storey steel buildings (SSBs). First, the meaning of the steel construction sector and the potential of the SSB market for the reuse of the structural steel system is shown. Then, an overview of the demolition sector and the actual treatment of steel scrap in Europe is given. The data for individual countries and building envelope products is presented in Deliverable D1.2 of PROGRESS project [2].

Steel construction sector

According to the Deloitte report [40], ferrous materials retain their leading position in the construction sector ahead of wood, competing with concrete and new materials such as polymers and ceramics. The outlook of constructional steelwork demand is optimistic. For instance, the consumption of structural steel in UK is predicted to be 1 050 000 tonnes in 2019 according to BCSA forecast [41]; in this market, single-storey buildings account for 60% of the use of constructional steelwork. The apparent steel use (ASU) in EU is shown in Figure 11.

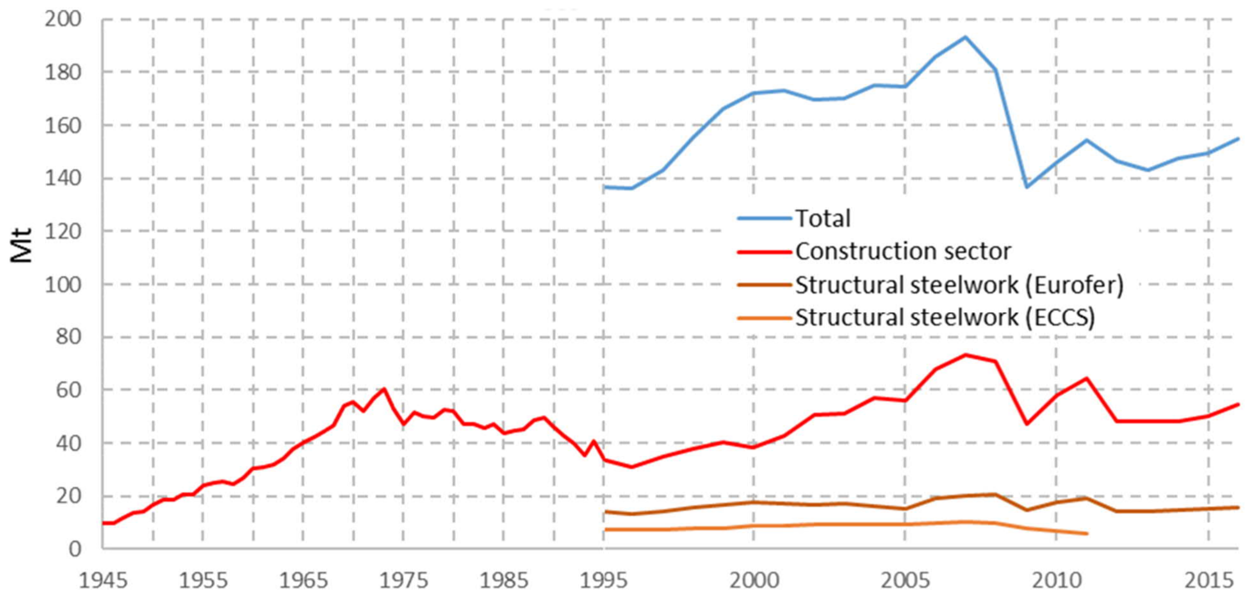


Figure 11 Apparent steel use in Europe, Source: [42] (1945-1995) and Eurofer (1995-2017)

ECCS data on constructional steel consumption in many EU countries are available from 1992 to 2008. For some years, steelwork consumption was broken down (in the ECCS datasets) by building type, for other years it was not. Where the split was not available, the proportion of SSBs from known years, has been used to estimate the steelwork consumption for SSBs. The total consumption of structural steelwork for SSBs, in the 17 countries for which data are available, between 1992 and 2008 is shown in Figure 12.

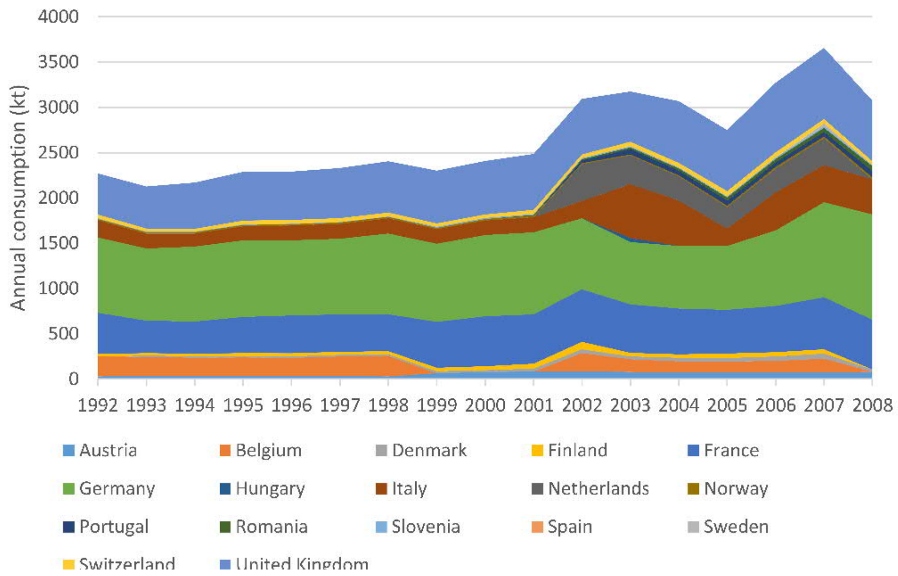


Figure 12 Annual consumption of structural steel in SSBs (1992 to 2008)

The next challenge was to convert the tonnage of steelwork, to a floor area of SSBs. The weight of steelwork per m² of floor area in SSBs varies significantly depending on, amongst other factors, their function, height and location; location is significant since it influences climatic factors including wind and snow loadings. In terms of function, large SSBs can range from relatively lightweight distribution warehouses to heavier manufacturing facilities with requirements for overhead cranes, gantries, etc. Based on UK experience, the range is 23 to 40 kg/m². BCSA suggests an average value of 40 kg/m². Information from VTT based on optimised portal frame geometries from the PRECASTEEL research project [43], suggests a range of 28 to 48 kg/m². It should be noted that this represents the weight of the primary steel structure only. In reality, SSBs range from warehouses to factories; schools and offices. They can be portal framed, use trusses or other structural forms. Insufficient data are available to factor these different forms into the derivation of SSB floor area therefore, for this assessment, an average unit rate of 40kg/m² was used. Figure 13 shows the estimated area of SSB built in the countries listed in Figure 12, between 1992 and 2008.

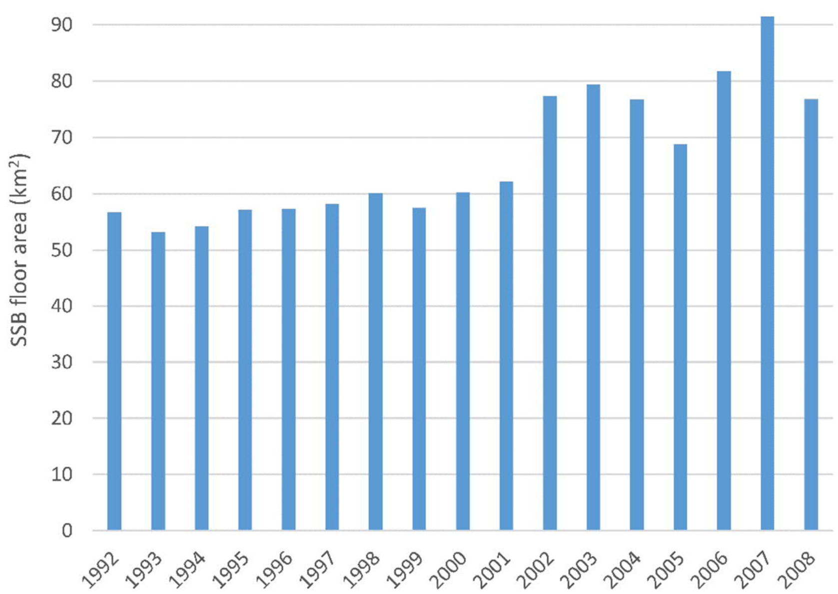


Figure 13 Estimate of the floor area of SSBs constructed in countries from Figure 12

Demolition sector and steel recycling

The demolition sector in Europe is growing. According to the European Demolition Association's industry report [44], 43% of the companies involved in the demolition business reported increase of their business in 2016, while only 15% of companies observed reduction. The business prospects are even more optimistic for 2017 with 47% of companies expecting increase and 8% expecting decrease of their business. The demolition companies are generally planning to invest more in equipment and workforce in 2017 than in the previous years. Since the use of steel in the construction sector in Europe has almost tripled between 1960 and 1975, a significant increase in the number of steel buildings becoming available for demolition is expected in the near future as their service life approaches its end. Single-storey steel buildings will be among the first ones because of their typically shorter life expectancy.

As the volume of demolished buildings increases, the amount of waste generated by the construction sector grows. According to Eurostat [45], the waste from NACE-F (construction activities) increased from 760 Mt in 2004 to 860 Mt in 2014. The metallic waste generated by the construction sector in EU-28 was 19.4 Mt in 2014 as illustrated in Figure 14. However, the recovered waste is about 10% lower according to Eurostat (e.g. 89.5 Mt of total metallic waste was recovered in 2014, while 97.1 Mt was generated), and therefore it can be estimated that the European construction sector recovers about 800 Mt of metal annually.

Figure 14 Generated metallic waste in Europe, Source: Eurostat, waste statistic by economic activities

Most of the recovered steel scrap is used directly in recycling in European steel mills or exported. The net export of steel scrap from the EU was 15.4 Mt in 2012 (21% of ferrous metal waste generated from all economic activities) and increased to 17.8 Mt in 2016 [45] with over 10 Mt received by Turkey (see Figure 15).

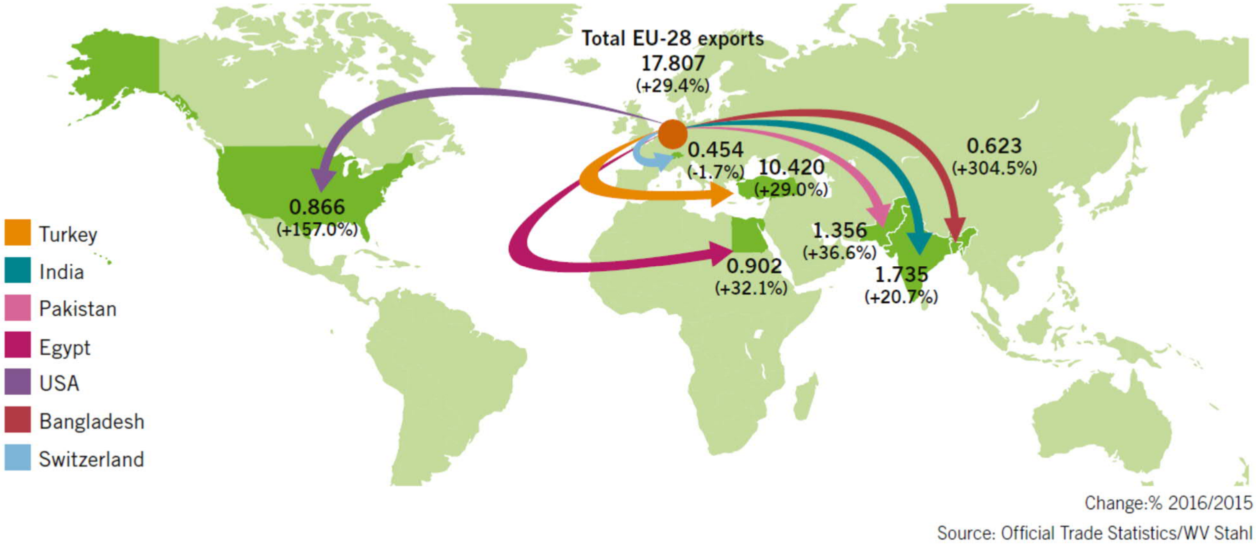


Figure 15 Main flows of EU steel scrap export in 2016 [46]

Over 88 Mt of steel scrap was used in European crude steel production in 2016, which was 54.4% of the total steel produced. The capacity of scrap utilization in steel production is mostly governed by the amount of electric arc furnaces (EAF) in Europe. In 2016, almost 40% of crude steel was produced by the EAF route in the EU; above the world average of 24.3% [46].

Figure 16 shows the amount of recycled steel scrap in the EU form 2004 to 2016. The data for treated metallic waste was obtained directly from the Eurostat database without any modification. The arising scrap was calculated from BIR data as “Use + Export - Import – Own Arisings”.

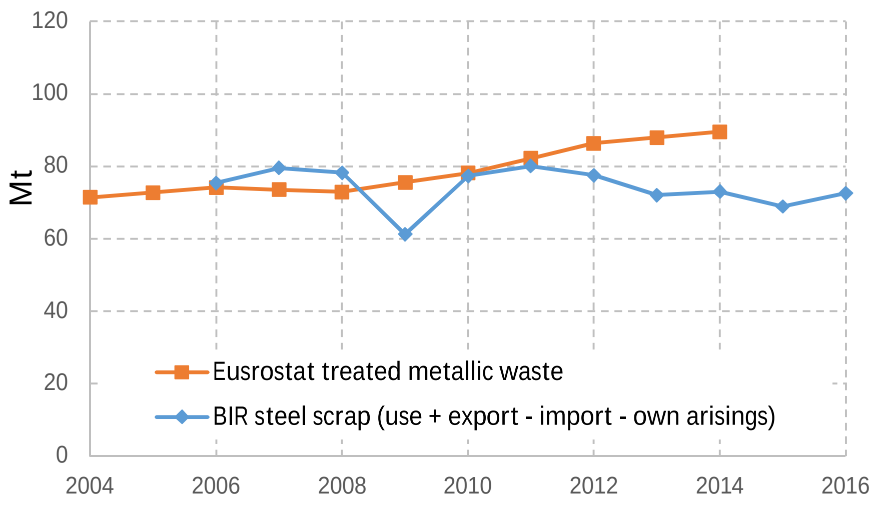


Figure 16 Recycled steel scrap in EU

The recycling of steel is well established and already highly efficient process. It can be assumed that there is very little potential for further improvement of recycling. Nevertheless, if further optimization of the environmental impact is sought, the actors involved in the assessment of steel as a building material must be prepared to take into account the reuse potential of steel components in addition to its recycled material value.

1.4 Legal barriers and opportunities

This section covers the following aspects related to legislative barriers and opportunities for the reuse of steel structures:

- interpretation of product or waste status of reusable steel structures, including approaches for the assessment of hazardousness caused by contamination and paint
- end-of-waste concept
- CE-marking
- Environmental Product Declarations.

For the interpretation of product and waste status, besides a literature study, also a small survey was conducted by contacting authorities/stakeholders in UK, Germany, Denmark, Austria, the Netherlands and Flanders region in Belgium. As result of the work, the project group elaborated recommendations for the interpretation of the waste or product status.

It is recommended that the component maintain its product status if:

- it is used for the same purpose and the end user is known (the same purpose means that it conforms to the same product standard e.g. structural steelwork is reused as structural steelwork),
- its technical requirements are fulfilled (the requirements are typically laid down in the harmonized standard such as EN 1090-2 [50], and their conformity can be verified either by the existing CE marking or by testing),
- it is not further processed (remanufactured) other than cut, cleaned, repainted (further processing means remanufacturing to “as new” condition or to different product standard),
- it is not regarded as hazardous waste (concentration limits should be checked against the mass or volume of the whole component), and
- its use does not lead to overall adverse environmental or human health impacts (for instance leaching chemicals due to the damaged coating).
- The recommended process ensures that the reused product would be able to fulfil the general End-of-Waste criteria [47] and has the quality corresponding to the requirements of the relevant design codes.

It is essential that the implementation of these criteria does not create unnecessary barriers to reuse and does not limit the existing trade of reusable products. In fact, with an efficient materials traceability system, the declaration of product status does not require any special measurements or testing (except the visual inspection of the coating integrity).

The principle of waste status assessment is illustrated in Figure 17 and several examples are presented in Table 7.

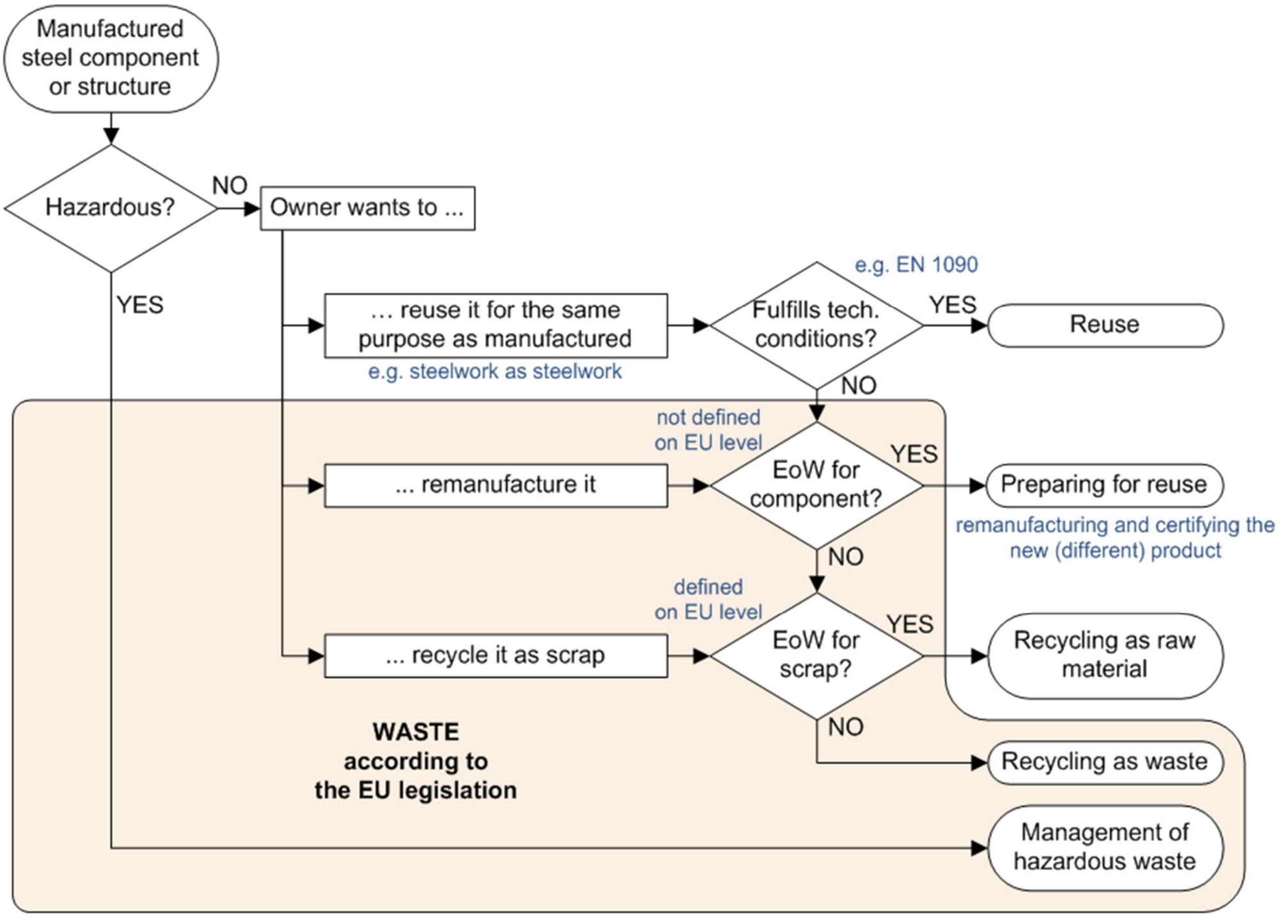


Figure 17 Waste and product status of reused components

Table 7 Examples of product and waste status recommendations

Case	Status	Rationale / comments
The steel end-of-life (EoL) product is fulfilling the technical requirements for the application, the coating layer is appropriate for the planned application, and the product is reused without modifications (only cleaned and potentially cut).	Product	The status of the steel component can be compared to clothes to be shortened and cleaned. It is not likely that SVHC will exceed 0.1% threshold for notifying SVHCs in articles according to REACH, because the beam and the coating containing SVHC is considered as one material. For other hazardous substances (e.g. zinc), the same logic in interpretation can be applied.
The steel EoL product is reconditioned, repaired or remanufactured in the workshop to “as new” condition.	Waste	Such product will also need a new Declaration of Performance (DoP) according to the corresponding harmonized standard because it will be marketed as new product. Its End-of-Waste (EoW) requirements are typically fulfilled by this process.
The steel EoL product is modified and not corresponding to product requirements given to original product.	Waste	Its status has to be re-evaluated by using the EoW concept.
The steel EoL product is sent to steel mill for recycling.	Waste	If the product is sent for re-melting, it would be considered as waste. The steel mill typically handles EoW processing according to the EU requirements.

The Task focused on the key elements in the Construction Products Regulation, also including information of the responsibilities of the Manufacturer, Importer and Distributor. Especially the applicability, content and requirements given in the harmonised standards are discussed. Our current understanding is that reusing reclaimed steel is allowed under the relevant harmonised standard (EN 1090-2). Issues with labelling and traceability of new steel sections through the supply chain have been identified as a potential barrier, although not explored in depth. It is important that any testing and certification requirements for reclaimed sections are not more onerous than those applied to new steel sections. Table 8 and Table 9 summarize the identified barriers and opportunities related to reuse of steel structures identified and discussed in the Task report [3].

Table 8 Summary of opportunities for reuse of steel structural elements

Opportunity	**Implication / expected impact**
EU Waste Framework Directive [47] sets preparation for reuse as the highest priority in the waste processing hierarchy.	Most of the national legislations already follow the Waste Framework Directive and require material owners to prioritize preparation for reuse over other means of recovery.
The amendment to Waste Framework Directive outlines the rules for preparing for reuse of municipal waste and envisages that similar rules will be made for the industrial waste.	Particular reuse targets and methods for declaration of reuse will create a legislative pressure to increase reuse of the recovered waste.
The new EN 1090-2 [50] allows the use of non-CE marked steels if their properties are specified.	According to our interpretation and recommendations from the Norwegian research, CE marking of steelwork fabricated from reused constituents is allowed under this harmonized standard.
Standardized approach to declare environmental and economic benefits of reuse is provided by CEN/TC 350 series of standards [74], [80], [90].	It is possible to acknowledge design for future reuse or design from reused components by better LCA/LCCA results. Authorities may use this information for instance to allocate financial incentives for more environmentally responsible design or to set up rules for green public procurement.
The new mandate of CEN/TC 350 requires the calculation methods to be developed in accordance with PEF criteria.	The future editions of CEN/TC 350 standards is expected to contain calculation methods especially for the declaration of net impacts beyond the system boundary.
Landfilling and backfilling of recyclable CDW is getting gradually more difficult due to wider use of landfill bans and increasing fees in EU.	This approach will make reuse and high-level recycling economically feasible in a wider range of situations.

Table 9 Summary of barriers to reuse of steel structural elements

Barrier	Recommendation for its mitigation
Waste Framework Directive [47] sets a rigid requirement of 70% of CDW to be recovered disregarding the fact that with increasing reuse (as waste prevention) the fraction of unrecoverable waste may grow despite its decreasing amount. No targets for waste prevention are provided.	We recommend that the information of reused components (preventing the generation of CDW) is collected wherever possible and allowed to contribute to the 70% target and that the particular target for waste prevention is formulated on EU level.
Waste Framework directive does not recognize the situation when the waste producer is contracted by the building owner. This results in different interpretation of responsibilities in different Member States.	We recommend that the Directive is amended and the roles and responsibilities of waste holder and producer are specified in more detail.
Some national or regional legislations require all materials and components to become waste.	We recommend the basic definition of waste status from the Waste Framework Directive to be respected to allow harmonized approach for marketing of reused components. We also provide recommendations on additional requirements for maintaining the product status as mentioned earlier in this Section.
It is not clear if the concentration limits of hazardous and dangerous substances in composite products should be applied per material (e.g. layer of coating) or per product.	We recommend that the concentrations are calculated per mass of the whole product if it is going to be reused without separating its layers. The individual materials may still become hazardous waste if they are going to be separated (e.g. shot-blasted paint).
Some of the harmonized standards under CPR do not allow CE marking of reused product mostly because of the factory production control requirements.	For such products, it is possible to achieve CE marking via ETA approval.
Standardized rules for the assessment of environmental (LCA) and economic (LCC) impact only exists for the products that become waste at their end-of-life stage.	We recommend that the CEN/TC 350 standards are amended to be in-line with the Waste Framework Directive.

2. Reuse of components from existing buildings (WP2)

2.1 Safe and efficient deconstruction

Buildings now reaching their end-of-life, were not constructed with thought of how they could be deconstructed and their components reclaimed for reuse in a new building application. Even today, demolition procedures are not deeply investigated. As buildings constructed over the last 50 years reach their end-of-life and redevelopment on these so-called brownfield sites is required, demolition techniques and the reclamation of products and materials become increasingly important.

There is a lack of clarity and rigour about definitions relating to reuse and recycling. This is exacerbated by many manufacturers who exploit this by making dubious claims about their products. For the purposes and in the context of this project, the following definitions are provided.

- **Recovery** means 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.
- **Reuse** is defined as the subsequent use of a product or component after its first life. It may be repurposed, but the object will only have minor alterations, retaining a similar (or the same) form.
- **Recycling** steel involves re-melting of scrap to form new semi-finished products. This operation is less energy intensive than steel production from iron ore, but still represents a significant energetic cost. Typically, electric arc furnaces, used in recycling, generate around 25% of the greenhouse gas emissions associated with making steel from iron ore via the blast furnace route.

The selection of demolition method is dependent on several factors concerning the physical aspects of the building to be demolished, with safety and economic issues, i.e. the location of the building, the type of structure and materials involved, the space available on-site for segregation and storage, health and safety of operatives undertaking demolition work, permitted levels of nuisance and, finally, on the time and money available. There are several methods of tackling a demolition, all of which have various merits relating to the factors above.

The complete deconstruction protocol developed in Task 2.1 of PROGRESS project is presented as annex to this report.

2.2 Pre-deconstruction audits

Pre-deconstruction audit is one of the most important steps towards the early identification of valuable and reusable components in the building that can be reused resulting in improved environmental performance and possible financial revenue from their sale. The situation concerning demolition audits in EU member states was analysed (see Figure 18). It is expected that current practices will improve in the near future since the publication of European Commission's common guidance for the waste and materials auditing [48].

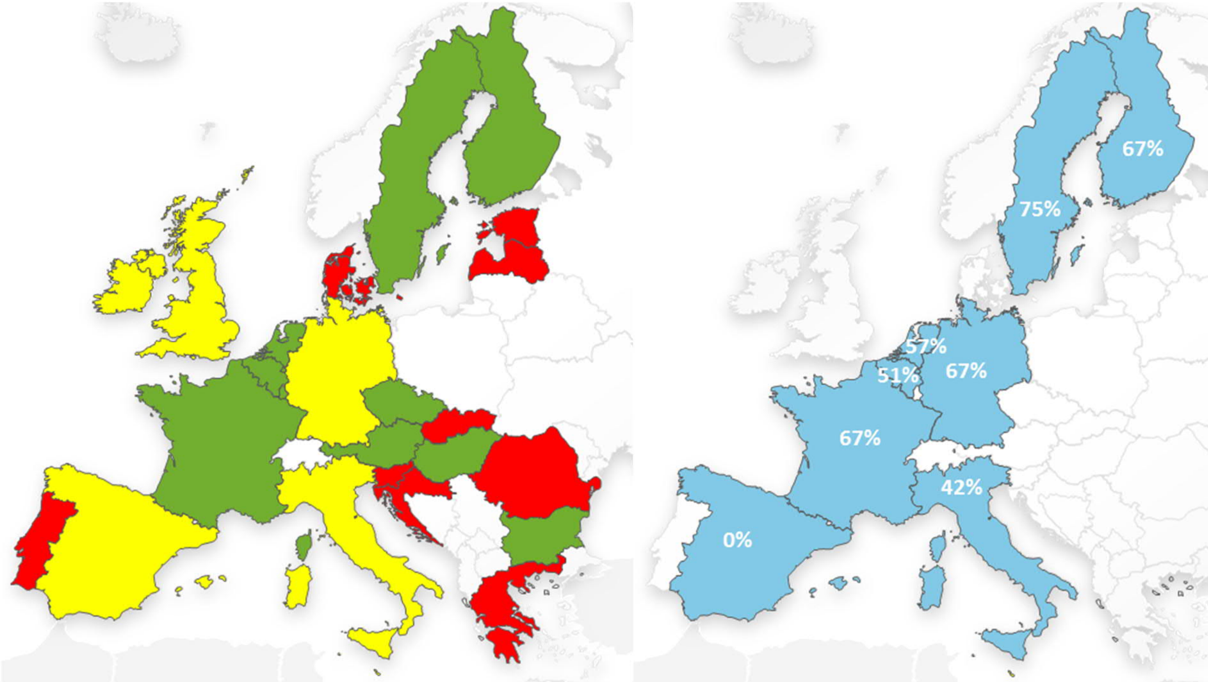


Figure 18 left: countries performing waste audit in EU (compulsory audits are green, limited audits are yellow, and countries without widely implemented auditing are red), right: % of respondents of the survey thinking that the audit is happening in their country [44].

The outcome of the Task was therefore to develop a specific procedure for the pre-deconstruction audit of single-storey steel buildings with the objective of maximizing the reuse of components or the whole assembly. The procedure is in-line with the EU guidelines and follows the recommended steps: Documentation research (or desk study), Field survey (or on-site visit), Condition evaluation (or material assessment) and Recommendations. The first two steps were expanded in the Task as described in Figure 19. Condition evaluation step is covered in more detail in Deliverables D2.2 [6] and D2.3 [7], and recommendations should be based on the outcomes of the survey and summarized in the final inspection report. Quality assurance should be based on the presence of at least one of the following systems:

- **Traceability of the components and materials:** The responsible authorities should approve or establish a tracing system that enables following the information about the materials and products in buildings from the initial design, construction until the final deconstruction and possible reuse of the products.
- **Certification of the auditor:** As an alternative quality assurance procedure, the certification system can be established that guarantees the required expertise and independence of the auditor.

As was identified in Deliverable D1.3 [3], the owner of the building materials will become the responsible waste holder when the decommissioning process of the building is initiated. He might be the last person that has possibility (depending on the local legislation) to prevent generation of waste by clearly declaring his intention to reuse parts of the building. Therefore, the most important part of the audit report is the declaration of reuse of components by the building owner. Such components will be then excluded from the waste inventory produced by the auditor.

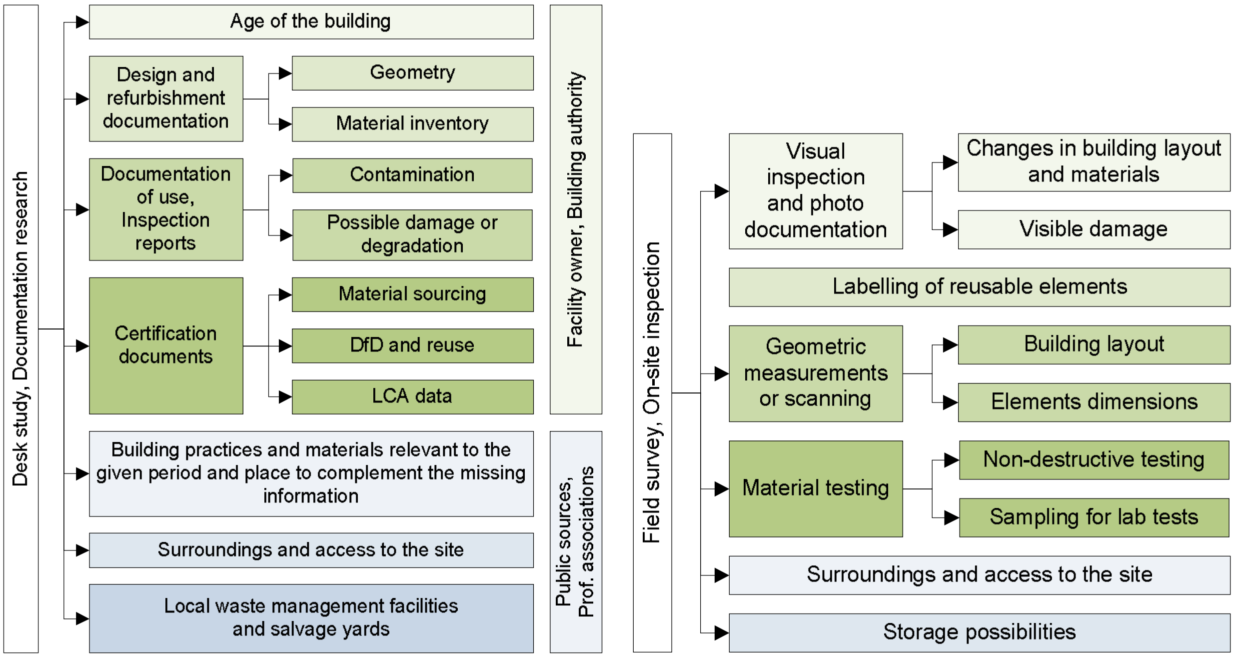


Figure 19 Description of the documentation research and field survey steps

Additionally, the auditor might indicate components suitable for reuse even if the intention to reuse them is not declared by the building owner. The materials contained in such components should be listed in the waste bill, because they become waste as the owner officially discards them. This information is important for the further possible end-of-waste processing of the reclaimed steelwork or its parts.

The declaration of hazardous and dangerous substances is crucial in the auditing report since the circulation of certain materials is regulated in EU and its Member States. However, it is often possible to reuse steel components after their decontamination or by proving, by chemical analysis, that the concentration of regulated substances does not exceed their limit values as discussed in Deliverable D1.3 [3]. The role of the auditor is to recognize reusable steel components and assemblies, identify the structural system and connections in order to

The recommended template of such report was developed in [4]. It gives the auditor possibilities to utilize the tools and methods developed in the PROGRESS project. For instance, it is linked to the testing procedures [7], damage assessment procedure from Deliverable D2.2 [6], reusability assessment from Deliverable D1.2 [2], environmental impact assessment from Deliverable D5.1 [14], and economic assessment from Deliverable D5.2 [15].

2.3 Suitability of materials and components to be used in a new design situation

The aim of steel reuse is to identify the conditions under which components from existing structures, affected by previous use, can be reused in new construction. Hereby, a summary of the criteria for reusability of structural steel and steel-based components is presented, in order to establish a rational basis for development of verification and approval procedures. The challenge consists in identification and evaluation of the effects of different deterioration processes such as ageing and weathering, time-variant 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. The evaluation successively considers the material, the constituent products and structural components.

The first step regards the material properties assessment and acceptability criteria enabling or limiting the potential reuse of these components followed by the definition and classification of reusing situations with associated acceptability criteria for the steel products. Quantification of the material properties and assessment of the condition of the structure includes a range of tests that must be performed with the following factors in mind: (i) a balance between obtaining sufficient information for a reasonable judgement and seeking too much information, (ii) effectiveness of combinations of tests, (c) prevalence of Non-Destructive Testing (NDT), (iv) careful drilling or cutting in the case of Destructive Testing (DT), for avoiding potentially serious damage to the structure.

Regarding material performance requirements, two assessments must be considered: (i) mechanical properties, and (ii) chemical composition. As a minimum, the mechanical properties need to reveal the strength (both f_y and f_u), ductility (elongation after fracture) and impact toughness. Although the strength can categorise the steel in different grades, the yield ratio (f_u/f_y) and ductility represent reference values for the analysis of the structure. Elastic or plastic analysis is allowed if the yield ratio is bigger than 1.05 or 1.10, respectively, while the elongation after fracture must be minimum 12% or 15%, respectively. The requirements for a specific chemical composition are necessary for preparing the welding procedure specification, if welding is anticipated for the structure made from reclaimed steel.

Both new steel and reused steel elements have to follow the traceability rules which will identify if the material is satisfactory against its reusability. Reclaimed structural steel products for use in new design situations have to be traceable to a CE marked Type 3.1 or Type 2.2 Inspection Certificate, see EN 1090-2 [50], which are essential documents that contain the mechanical and the chemical properties of the steel and assures that the steel product meets the specified properties.

The implementation of adequacy and quality assessments is achievable through a classification necessary to establish whether the reclaimed steel material should be allowed for structural reuse according to EN 1993 with or without any restriction. The classification consists in three material classes: Class A - complies with the material performance requirements through material testing, Class B - complies with the material performance requirements through material and have approved quality assurance by testing, and Class C - unidentified steel, free of damaging defects, and may be permitted to be used for structures or members that do not require CE marking. The overall criteria and classification of reclaimed steel material should follow the flowchart presented in Figure 19.

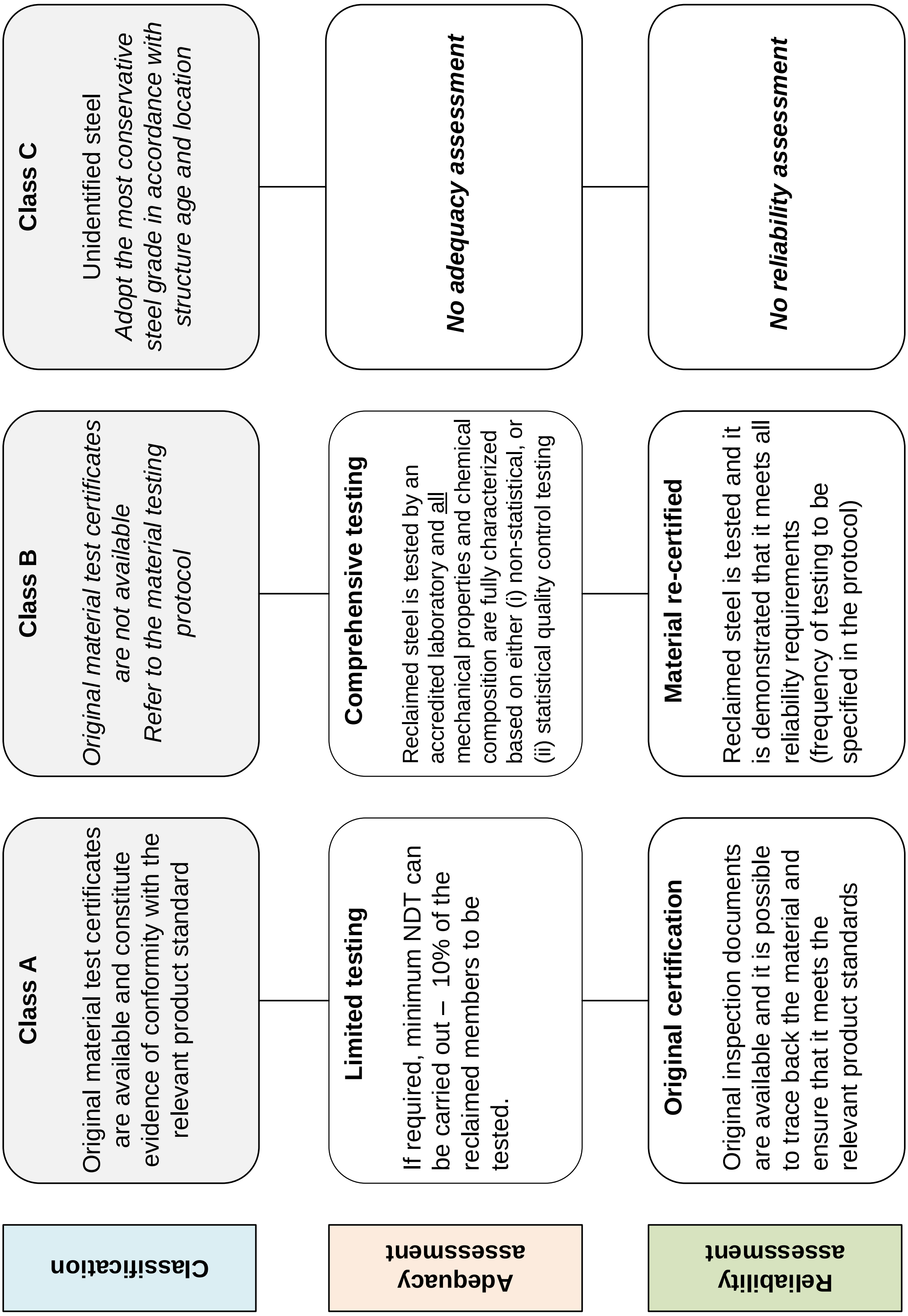


Figure 20. Overall framework for classification of reclaimed steel material and design parameters

The second step of evaluation is performed on the constituent products. A constituent product in the reuse context represents an individual element extracted from an existing structure selected for disassembly, and then reused as a new product for erection and fabrication of another structure, e.g. hot-rolled and cold-formed steel profiles. Such product will need a new Declaration of Performance (DoP) according to the corresponding harmonized standard because it will be marketed as new product. The following procedure is proposed for verification of the reusability of steel members as constituent products:

- Documentation showing the location and building structure where the members were recovered from, including date of construction of original building, should be provided.
- All products to be reused should come from a building structure erected after 1970 that was not exposed to extensive dynamic loading and other severe conditions, e.g. fire.
- All surfaces should be visually inspected, to ensure that the steel surfaces are free of rust. In the case of structural hollow sections, the weld seam has to be inspected and it has to be demonstrated that there are no defects.
- Members from reclaimed steel should not include welded or bolted splices along the length and should not have holes in the vicinity (say within 100 mm), of locations where new holes are to be drilled in the member.
- Sectional dimensions (if not known) should be measured and sections classified according to product standards. Three locations along the members for comparison against nominal values should be selected.
- For open cross-sections (wide flange H- and universal I- beams), cross-section size should be measured to comply with EN 10034 [51].
- For closed cross-sections, e.g. Circular Hollow Sections (CHS) and Rectangular Hollow Sections (RHS), cross-section size should be measured to comply with EN 10219-2 [53] and EN 10210-2 [54].
- Tolerances on the member straightness should comply with EN 1090-2 [50] and tolerances on twist, for CHS and RHS should comply with EN 10219-2 [53]. Tolerances on older sections may be different and therefore straightening may be required.
- Members from reclaimed steel should not have areas of accelerated localised corrosion or showing other evidence of localised section loss. The members should have a smooth surface. However, bumps, cavities, or shallow longitudinal grooves resulting from the manufacturing process are permissible, provided the remaining thickness is within tolerance.
- Diffuse necking is not permitted in any cross-section, e.g. connections areas and elements in tension.
- If the existing painting contains toxic substances (e.g. lead, cadmium and/or asbestos), remove existing coatings and surface scaling by preparing the surfaces to EN ISO 8501-1 [55]. Steel paint that contains lead carbonate and lead sulphate can be encapsulated with other paint.
- Reclaimed sections which are beyond economic repair/reconditioning shall be scrapped.

After analysing the constituent products, further work for verification of reusability will be performed function of the situation categorised in the following:

- **Option 1:** The original documentation exists, and the elements can be identified/confirmed according to the product standards. All surfaces are free of rust. Minimum measurements to confirm the section and length tolerances are needed.

- **Option 2:** The original documentation is missing. Reclaimed steel elements are measured to obtain the actual dimensions and thicknesses. Detailed measurements are taken to confirm the section and length tolerances. All surfaces are checked against rust.
- **Option 3:** The reclaimed steel elements do not meet the tolerances and are beyond the economic repair. These elements can be used as non-structural elements or can be sent to scrap.

A CE Mark for the constituent products indicates that a product is consistent with its Declaration of Performance (DoP) as made by the manufacturer. CE Marking can be either affixed to the product, issued with accompanying documentation or made available on demand through electronic means. There are two forms of CE Marking, which are applicable to structural steelwork: (1) material and product standards – relating to the manufacture and properties of the product; (2) execution standards – relating to the design and manufacture of load bearing components and structures. If not available for reclaimed steel, the process for certification must be repeated and the Declaration of Performance must accompany the products. The overall framework for verification of the reusability of individual members is presented in Figure 21.

In the third step, the evaluation of reusability of structural components or entire primary structure should be performed. According to EN1090-2 [50] a component represents part of a steel structure, which may itself be an assembly of several smaller components. A list of principles for a sustainable approach must be considered simultaneously with the design scope to facilitate a greater reuse of structural steel. It can be reminded here the use of connections with high degree of demountability and the provisions of easy and permanent access to connections for maintenance during the structure life.

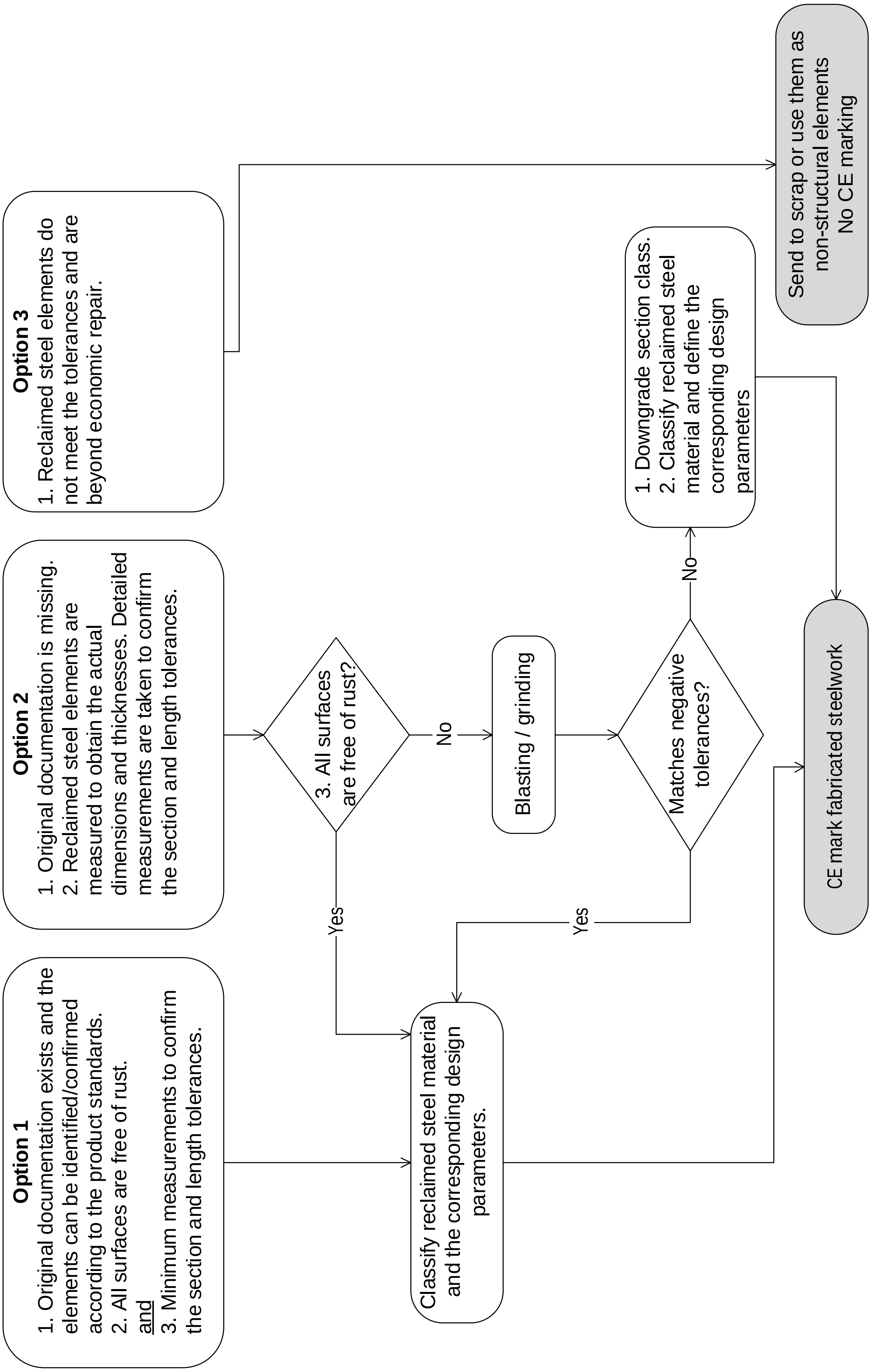


Figure 21 Overall framework for verification of the reusability of individual members

The following selection and acceptance criteria for reuse procedure is proposed for verification of the reusability of a steel component, i.e. part of a structure, or entire primary structure:

- The structural components or entire primary structure should be a part of a single-storey steel building. The building structure should have been erected after 1970 and should have not been exposed to extensive dynamic loading and other extreme actions.
- First, the individual structural members are evaluated. The term “evaluation”, in this context, is as defined in EN 1090-1 [56].
- The reclaimed steel components should not have areas of accelerated localised corrosion or show other evidence of localised section loss. If corrosion affects the characteristics of the components, they should be redesigned according to the new dimensions or, if are beyond economic repair/reconditioning, shall be scrapped.
- For all reused components, or entire primary structure, documentation showing the location and building structure where the components were recovered from, including date of construction of original building, should be provided.
- All reclaimed steel should be certified to the section properties and classified according to the system proposed in the first step of this section regarding material reuse evaluation.
- Careful visual inspection of every reclaimed member, and assessment against the tolerances should ensure that the element has not undergone plastic deformations and therefore residual strains, and reserves of ductility, are no different to that of ‘initial’ steel.
- All welds should be 100% visually inspected throughout their entire length for surface imperfections in accordance with EN ISO 17637 [64]. If surface imperfections are detected, additional surface testing by liquid penetrant testing or magnetic particle inspection should be carried out on the inspected weld.
- Bolts from the previous application should not be reused. They can be reused for secondary structure or for non-structural applications.
- If the existing painting contains toxic substances (e.g. lead, cadmium and / or asbestos), remove existing coatings and surface scaling by preparing the surfaces to EN ISO 8501-1 [55]. Steel paint that contains lead carbonate and lead sulphate can be encapsulated with other paint.
- The reused steel component/detail/structural component or module/primary structure can be CE marked to EN 1090-1 [56].

After checking the eligibility and compliance with tolerances in EN 1090-2 [50], further decisions can be taken based on the following classification of the structural components (see Figure *22*):

- Class (RSC1): the structural component has not been CE marked in the first life and has to be certified as a new structural component/structure;
- Class (RSC2): the structural component has been CE marked in the first life according to EN 1090-1 [56] and the original documentation is available;
- Class (RSC3): the structural component has been CE marked in the first life according to EN 1090-1 [56], but in this case an existing CE marking is not available.

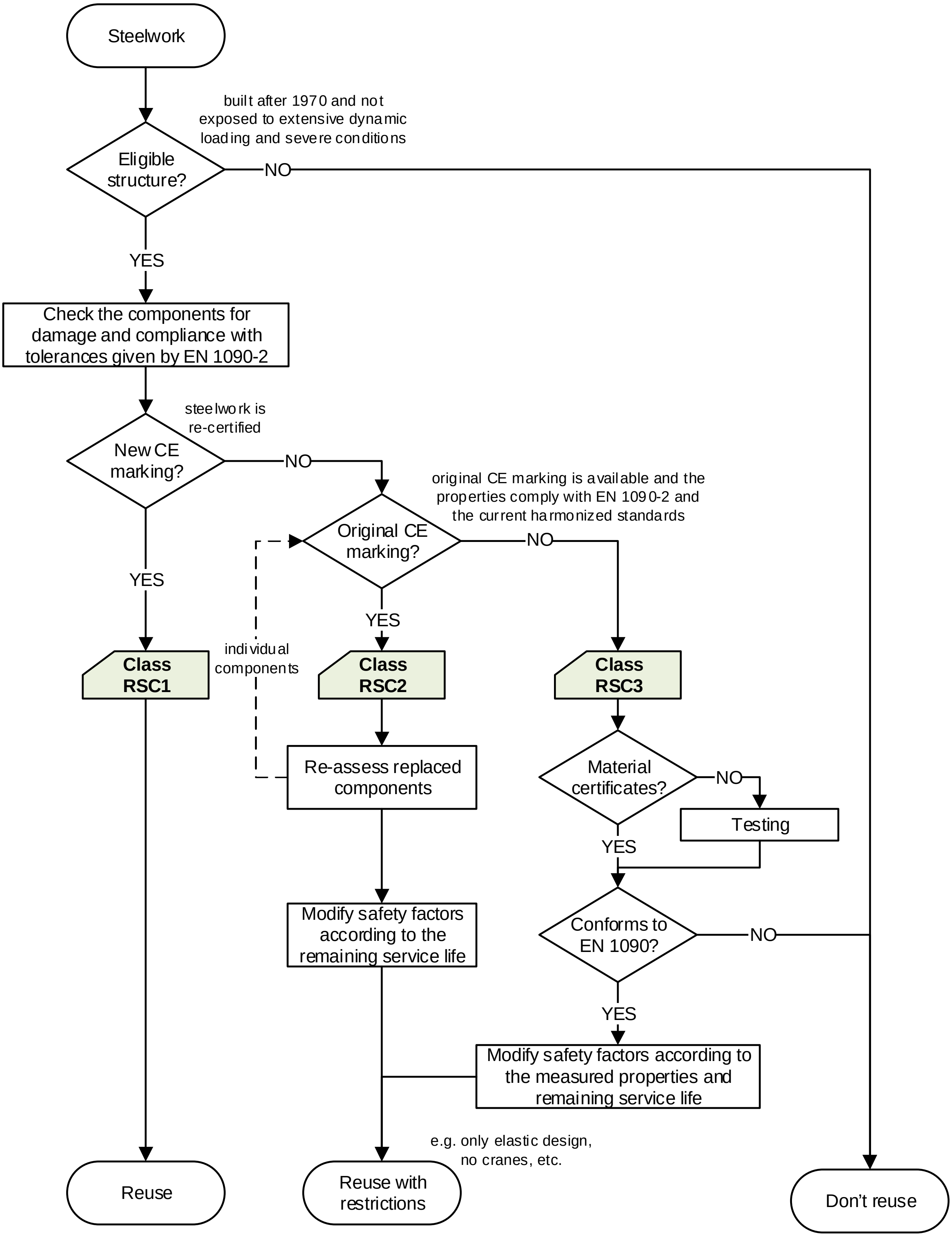


Figure 22 Overall framework for verification of the reusability of components or entire primary structures

Special care is needed if existing connections are to be re-used. In particular, any welding should be subject to careful inspection and test. Visual inspection of 100% of the welds is recommended. When delivered, the reclaimed components must be accompanied by a formal declaration, following the requirements of EN 1090-2 [50]. The declaration must make clear which properties were assumed, and which were determined by test. The contractor or the stockholder is responsible for creating a CE Mark and applying it to their product. The overall framework for reuse process of steel structure/components is presented in Figure 23.

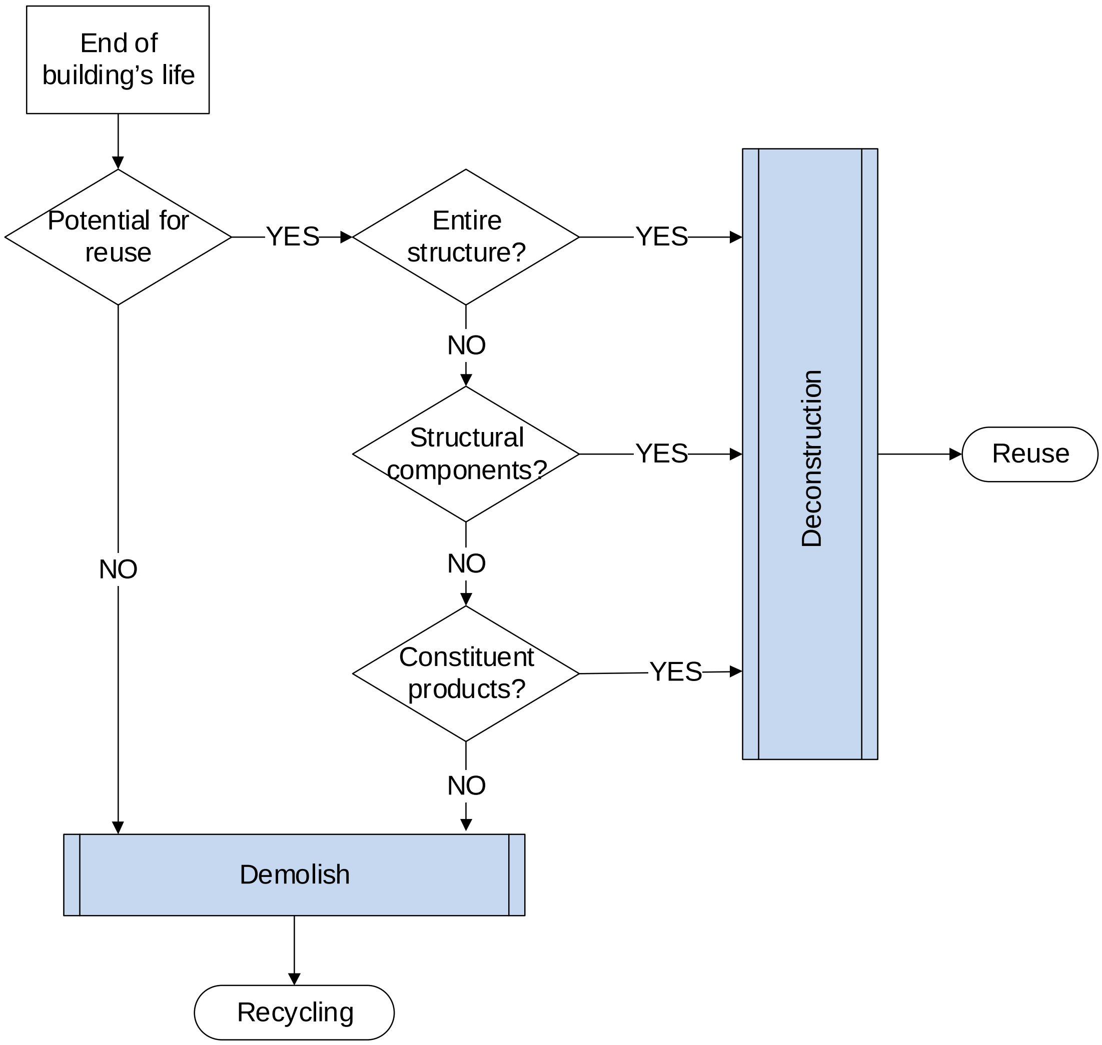


Figure 23 Overall framework for reuse process of steel structure/components

An additional step for steel structure reuse evaluation can be dedicated to the secondary steelwork elements. A procedure for the selection and acceptance criteria is proposed for the reusability of secondary steelwork:

- The structural components (member composing the secondary structural system) or the secondary structural system, should be a part of a single storey steel building and should have not been exposed to any extreme actions.
- First, the individual structural members are evaluated according to EN 1090-1 [56].
- All reclaimed steel should be certified to the section properties and classified according to the system proposed in Section 4 of this document.
- All dimensions (if the initial drawings are missing) of the components/structure shall be measured to check they meet the tolerances, at the level of cross-section, member, or structural system (see EN 1090-4 [65]).
- Bolts from the previous application can be reused.
- Determination of the protective layer thickness.
- The reused steel component/ structural component can be CE marked according to EN 1090-1[56].

Overall, quantification of the material properties and assessment of the condition of the structure, or structural components is essential to evaluate structural reusability and this process can be performed on a scientific basis gathered in the Deliverable D2.2 [6].

For the development of future verification and approval procedures, the present document highlights that reclaimed structural steelwork can be CE Marked in accordance with EN 1090-1 [56]. There are no differences in the fabrication processes, procedures, standards or tolerances for either new steel or reclaimed steel. It is therefore appropriate that re-fabricated, reclaimed structural steelwork can be CE Marked in accordance with EN 1090-1 [56].

2.4 Sampling strategies and testing methods for steel construction products

Task 2.5 focused on sampling and testing techniques for existing steel construction products. The findings are presented in deliverable D2.3 [7] which is a quality protocol giving guidance on data collection, inspection and testing methods to ensure that reclaimed structural steelwork can be reused with confidence.

Traditional sampling and destructive testing is invasive and expensive; this can affect the economic viability of reuse projects. Therefore, robust sampling strategies and cost effective non-destructive testing techniques are required.

Assessment for reuse, classification of reclaimed steel, and overall reclamation process

The inspection techniques for the assessment for reuse should involve:

- Visual inspection: examination for corrosion, cracks, deformities, damage, etc.;
- Field survey: geometrical survey of positions and sizes of members and details;
- Dimensional inspection: Measurements using Vernier callipers, micrometres, three-dimensional laser scanning, ultrasonic measurements, etc.

Two steps are proposed: preliminary assessment and comprehensive assessment. The first step is intended to classify the steel and evaluate the opportunities for reuse and the feasibility of the desired reuse scenario. The second implies a more thorough inspection/ survey and grouping of elements for testing and evaluation. Under the protocol, reclaimed steelwork is classified (see Figure 24 and Figure 25) in one of three classes:

- Class A: steel materials with original certificates/documentation.
- Class B: steel materials that meet performance requirements through testing;
- Class C: steel materials classified as the most conservative grade.

Assessment of fabrication processes

Special care is needed if the existing connections are to be re-used. Any welding should be subject to careful inspection and adequate testing.

As a general recommendation, at least the same amount of weld testing required by EN 1090-2 [50] should be applied to reclaimed steel elements. Visual inspection of 100% of the welds is mandatory. Table 10 suggests a minimum number of welded connections to be inspected by non-destructives tests. A connection may have different weld segments. In a typical rafter-columns connection, welds between flanges and webs need to be assessed. Each of these welds may be assumed as one connection according to Table 10.

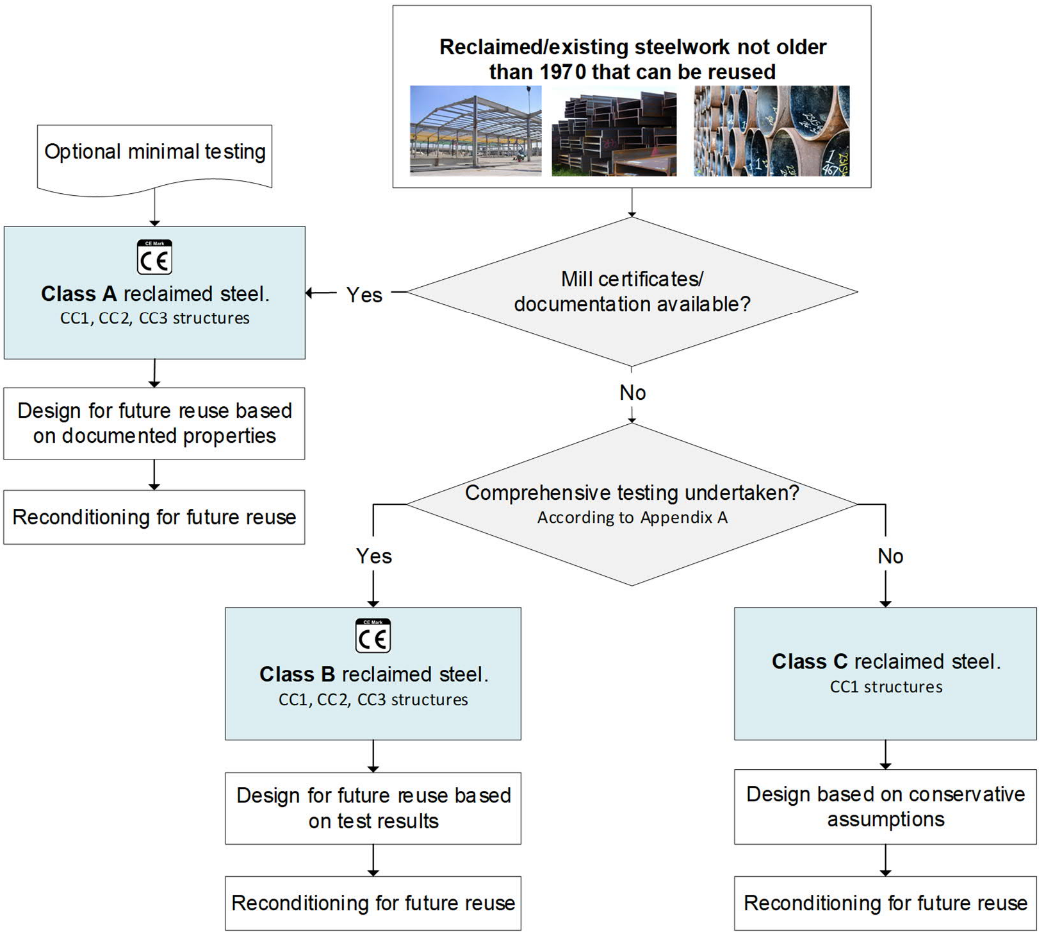


Figure 24 Overall framework to undertake the adequacy assessment of steelwork

Table 10 Suggested minimum percentage of welds to be tested

Total number of connections	Number of connections to be tested	Total %
6	3 (minimum)	50%
10	4	40%
15	5	33%
20	6	30%
30	8	27%
40	10	25%
50	12	24%
75	16	21%
100	20	20%
200	30	15%
300	40	13%
500	60	12%
1000	100	10%
2000	150	8%

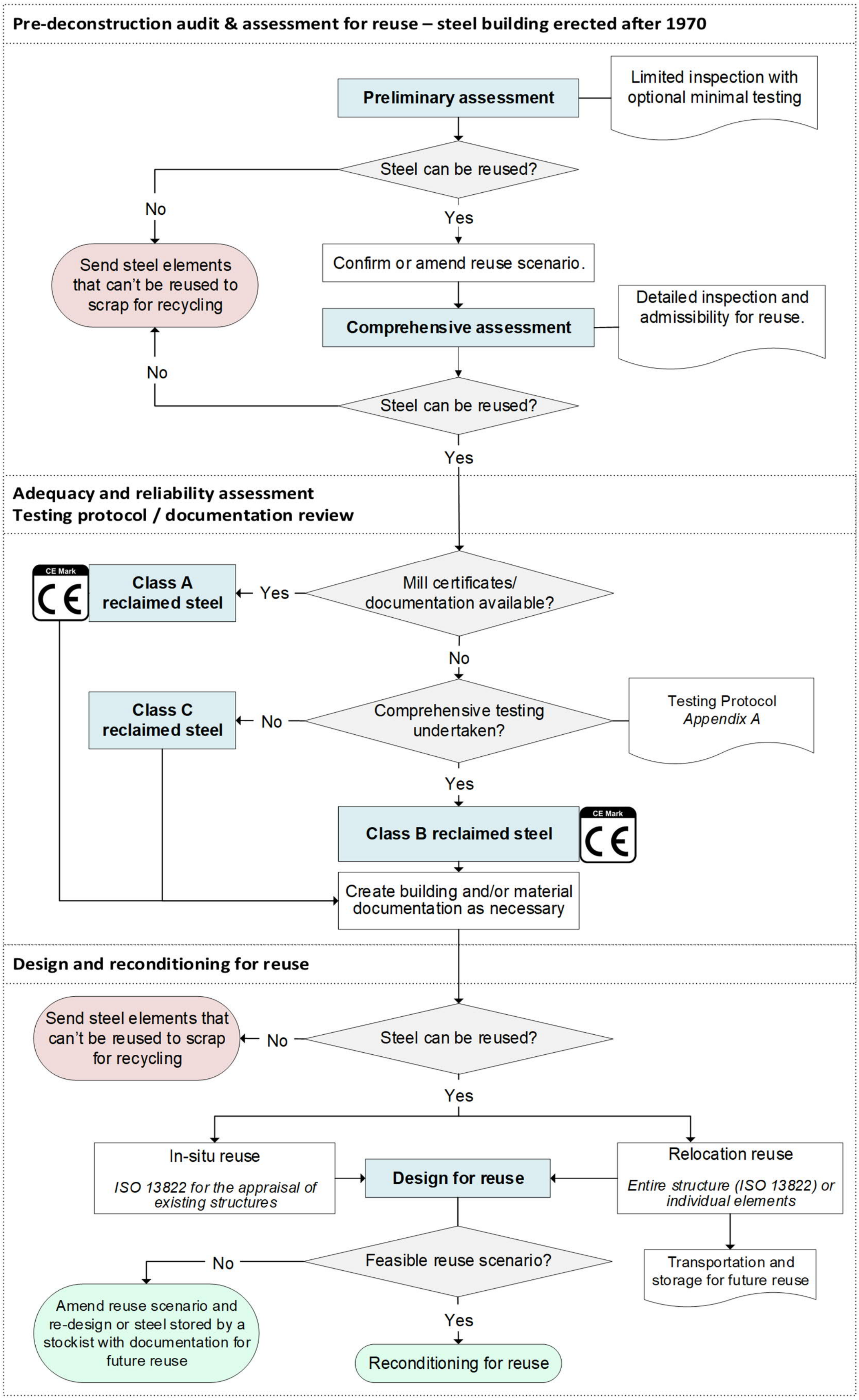


Figure 25 Overall process: from reclamation to reuse

Definition of group of elements to be tested

Reclaimed steel members are to be considered as a group, provided they come from the same source structure and meet the following requirements:

- Structural steel erected after 1970;
- Are of the same serial size;
- Same structural function, e.g. rafters, floor beams, columns, bracings, etc.;
- Identical detailing (length, connections, etc.).
- Local stiffeners are not considered as detrimental for grouping.

If steelwork originally manufactured to an alternative specification/product standard (other than the EN standards), is to be placed on the market, material manufactured to different product standards should not be mixed within a group – the source and manufacturing standard of all material in a group should be consistent.

A group should comprise a maximum weight of 20 tonnes. Several groups of 20 tonnes will be required if large numbers of the same member are reclaimed. Defining a group of elements to be tested in this manner allows certain material characteristics to be established for the group by testing one or more representative members from the group. For cold-formed elements, a group should comprise a maximum weight of 4 tonnes.

In this protocol, the concept of a ‘group’ has special significance, as outlined above. In product standards such as EN 10025-2 [57] or EN 10346 [58] section, a similar term is ‘test unit’, indicating a collection of steel products of a specified total maximum weight of the same form, grade and quality, and delivery condition. A ‘test unit’ can contain products of various thickness, whereas in this protocol, a ‘group’ is limited to members of the same serial size. In product standards, tests are specified to be undertaken from samples in the test unit; in this protocol, tests are specified to be undertaken from samples in the group of reclaimed elements.

Properties to be declared: hot rolled and hollow sections products

This section summarizes the steel properties that need to be assessed for reclaimed hot rolled steel elements according to EN 1090-2 [50] clause 5.1 (including hollow sections - Table 11).

Properties to be declared: cold-formed products

This section summarizes the steel properties that need to be assessed for reclaimed hot rolled steel elements according to EN1090-4 [59] clause 5.1 (Table 12).

Table 11 Material properties to be declared according to EN 1090-2 [50] clause 5.1

Property	To be declared	Procedure
Strength (yield and tensile)	Yes	Determined by destructive and non-destructive tests.
Elongation	Yes	Determined by destructive tests.
Stress reduction of area requirements (STRA)	If required	Generally, not required to be declared.
Tolerances o dimensions and shape	Yes	Based on dimensional survey.
Impact strength or toughness	If required	If required, determined by destructive tests. Conservative assumption as the default.
Heat treatment delivery condition	Yes	Conservative assumption as the default. Hollow section according to EN10219.
Through thickness requirements (Z-quality)	If required	Generally, not required to be declared.
Limits on internal discontinuities or cracks in zones to be welded	If required	Generally, not required to be declared.
In addition, if the steel is to be welded, its weldability shall be declared as follows:		
Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608, or	-	Not applicable for reclaimed steelwork.
A maximum limit for the carbon equivalent of the steel, or;	Yes	Maximum to be declared from manufacturer’s test certificates.
A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated	Yes	Determined by non-destructive and destructive tests.

Table 12 Material properties to be declared according to EN 1090-4 [59] clause 5.1

Property	To be declared	Procedure
Yield strength or 0,2 %-proof strength (ReH/Rp0,2)	Yes	Determined by non-destructive and destructive tests.
Tensile strength (Rm)	Yes	Determined by non-destructive and destructive tests.
Elongation after fracture A80 mm in %;	Yes	Determined by destructive tests.
Tolerances on dimensions and shape, including minimal thickness	Yes	Based on dimensional survey.
Bend radius to thickness ratio, if relevant	If required	If required, determined by destructive tests.
Metallic coating composition, designation and layer mass and thickness	Yes	If required, determined by non-destructive or destructive tests and visual inspection
Adhesion of metallic coating	Yes	Based on visual inspection
In addition, if the steel is to be welded, its weldability shall be declared as follows:		
A maximum limit for the carbon equivalent of the steel, or;	If required (note: welding procedures are often not used)	Maximum to be declared from manufacturer's test certificates.
Chemical composition in sufficient detail for its CEV to be calculated		Determined by non-destructive and destructive tests.

Minimal testing

Minimal testing is intended for the cases where material documentation is available (Class A steel) or to perform a preliminary assessment of existing steelwork. The optional minimal testing is intended to confirm that a certain existing material documentation is related to a certain group of steel elements. Only non-destructive tests are recommended.

Table 13 Recommendations for minimal testing

Characteristic to be determined	Type of testing	Percentage of elements to be tested
Tensile and yield strength	Non-destructive	10% - with a minimum of 3 tests per group/unit

Comprehensive testing (Class B reclaimed steel)

The recommendations for comprehensive testing require 100% non-destructive testing in combination with non-statistical or statistical destructive testing. The non-destructive testing of all reclaimed members establishes that a group of members can be represented by destructive test results from one or more representative members from the group. Non-statistical testing is only recommended for hot rolled or hollow sections.

Table 14 Testing procedure for hot rolled and hollow section products

Consequence class	NDT to establish yield strength, ultimate strength and CEV	Minimum number of DT to establish yield strength, ultimate strength and CEV and elongation	Acceptance approach
CC1	All members to be subject to non-destructive tests	1	Non-statistical (maximum value of CEV)
CC2		1	
CC3		3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)

Table 15 Testing procedure for cold-formed products

Consequence class	NDT to establish yield strength, ultimate strength and CEV[1]	Minimum number of DT to establish yield strength, ultimate strength and CEV[1] and elongation	Acceptance approach
CC1	All members to be subject to non-destructive tests to establish yield strength and ultimate strength (and CEV if required1).	3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV if required[1])
CC2		5	
CC3		7	

[1] Usually not required as welding procedures are not often used with cold formed elements

Reliability assessment

The results of non-destructive and destructive tests shall be compared with the minimum values presented in Table 16 and Table 17 in order to determine the steel grade.

Table 16 Recommended minimum strength for the reliability assessment of hot rolled and hollow section products

Steel grade	Yield strength [N/mm^2]			Tensile strength [N/mm^2]			f_u/ f_y mean	Reference Standard
	f_y design	min.	mean	f_u design	min.	mean		
S235	235	267	293	360	397	432	1.47	EN 10025-2; EN 10219
S275	275	313	343	410	452	492	1.43	EN 10025-2; EN 10219
S355	355	391	426	470	505	540	1.26	EN 10025-2; EN 10219
S460	460	490	529	540	560	594	1.12	EN 10025-3/4; EN 10219

Table 17 Recommended minimum strength for the reliability assessment of cold-formed products

Steel Grade	**Yield Strength** [N/mm^2]			**Tensile Strength** [N/mm^2]			f_u/ f_y mean	**Reference standard**
	f_y design	min.	mean	f_u design	min.	mean		
S220	220	226	242	300	303	330	1.364	EN 10346
S250	250	257	275	330	333	363	1.320	
S280	280	288	308	360	364	396	1.286	
S320	320	329	352	390	394	429	1.219	
S350	350	360	385	420	424	462	1.200	
S390	390	401	429	460	465	506	1.179	
S420	420	432	462	480	485	528	1.143	
S450	450	463	495	510	515	561	1.133	

Assessment of hardness test results

The hardness of an individual member should be taken as the average of three measurements. If this average value for an individual member differs by more than 10% from the average value for the group of members, the inconsistent member should be removed from the group. The characteristic value of hardness H_v of the entire group should be determined using Table D1 from EN 1990 [60], assuming “V_x unknown”.

Correlation between hardness and material strength

If the Vickers hardness test is used, the following relationship between hardness and strength can be used to estimate the material properties as follows:

$$f_y = 2.70\,H_v - 71 \text{ and } f_u = 2.50\,H_v + 100$$

Where H_v is the Vickers hardness for the group, f_y is the yield strength and f_u is the ultimate strength.

Non-statistical testing

In addition to the 100% non-destructive testing, a single destructive test (taken from any member in the group) is required to respect the minimum values from Table 16 or Table 17.

Statistical testing – assessment of tensile test results

In addition to the 100% non-destructive testing, a minimum of three destructive tests are required. The characteristic value of yield strength and ultimate strength of the entire group should be determined using Table D1 from EN 1990 [60], assuming “V_x known”. Characteristic values should respect the minimum values form Table 16 or Table 17.

Assessment of Class C reclaimed steel properties for design

For hot rolled and hollow sections, it is recommended to assume a S235 steel grade for the design. As a wide range of steel grades are likely to be available for cold formed products, it is recommended to assume a yield and tensile strengths of 120 MPa and 260 MPa respectively.

Assessment of cladding elements

Table 18 - Summary on evaluation procedure for reuse of sandwich panels

Evaluation criteria	Property
	Mechanical strength
Testing cross panel tensile strength 3 samples, a minimum (EN 14509 [61], A1): Calculate characteristic result for tensile strength. Testing one sample for shear strength (EN 14509 [61], A.3 or A.4)	
1. Tensile strength Actual value ≥ 0.9 x Declared value, and: 2. Shear strength Actual value ≥ 0.9 x Declared value	**If YES:** No further testing is required. All declared values for mechanical strength can be used.
	If NO: New declared values to be determined with a test programme according to EN 14509 [61] for (i) tensile strength, (ii) compression strength, and (iii) shear strength. The wrinkling strength is reduced with the same amount that shear strength is reduced.
	Durability
Tensile strength Actual value ≥ 0.9 x Declared value	**If YES:** no further testing is required. Panels are fit for use.
	If NO: For Miwo panels: The 7 days testing (see EN 14509 [61] clause B.3.4) is to be done. The reduction in tensile strength after ageing shall not exceed 15 % of the mean value of the tensile strength in ambient temperature. For all other panel types: The procedure in EN 14509 [61] Annex B.2 is followed so that the panels are tested 14 days in the temperature as described in B.2.4. The reduction in tensile strength after ageing shall not exceed 17% of the mean value of the tensile strength in ambient temperature
	Tolerances
Damage is evaluated by visual inspections	If no serious damages or faults are found, then the panel can be reused.
	If serious damages are found causing weakness in strength, insulation behaviour or tightness of joints, then those panels are rejected.
	Moisture content
Wetness of core material	If no notable wetness of core material found, the panels can be reused
	Thermal behaviour
For PU panels: Closed cell ratio actual value ≥ 0.9 x value obtained by type testing and change in density < 10%	**If YES:** No further testing is required; original thermal conductivity value can be used.
	If NO: New test for determining thermal conductivity is to be done following the rules in Section A.10 of EN 14509 [61].
	Fire safety
Small flame tests, see clause C.1.2 of EN 14509	Tests to be done with core material including fire retardants. The classification is checked and if needed reclassified. The panels are fit for use where fulfilling the requirements in the project for reuse.

3. Design of new buildings for reuse (WP3)

The objective of Tasks 3.1 and 3.2 was to research and develop design guidance on how to design and construct new, steel-framed single-storey buildings so that they can be more easily adapted, deconstructed and reused in the future. The findings are presented in deliverable D3.1 [8].

Research focused on the conception, design, detailing and execution methods for new single-storey steel-framed buildings (SSB) and steel-based envelope components, so that the reusability of products and systems is the leading principle overall building solution. In addition to the structural and envelope components, the work will include the interfaces and connections between these elements of the building.

Bespoke design situations of SSBs with cranes (where fatigue is relevant) are outside of the scope. The scope included the structural systems most commonly used in the EU the SSBs market, i.e. conventional portal frames and trussed solutions.

An overview of the design process was undertaken, covering not only the structural concept and products but also regarding load definition, structural analysis and structural design. Proposals for structural concepts and detailing are also presented, in order to investigate ways to increase the reusability of the building as a whole or as individual reclaimed elements.

The main areas addressed within D3.1 [8] are summarised below.

Identify the opportunities for reuse, as well as identifying the different end-of life cycle scenarios:

- Building reuse or relocation;
- Component reuse or relocation in a new building;
- Material reuse in the manufacture of new building components;
- Materials recycling (down-cycling) into new building materials.

Present the currents benefits and barriers of reuse of steel work:

- Environmental;
- Economical;
- Social;
- Technical;
- Organisational/Governmental/Legislative.

3.1 Design of reusable buildings and building products

The most relevant identified benefits and barriers are presented. Principles for promoting the reuse of steel as a feasible business model are presented. Information on the costs related to the reclaiming process are also addressed.

Present relevant Design for Deconstruction (DfD) principles and concepts to increase the future reuse of steelwork

To facilitate future reuse, designing the building to allow easy future deconstruction is essential. General principles for Design for Deconstruction are presented, giving recommendations and a checklist that help to disseminate the most relevant principles in the industry.

Present an overview of current practices in conception, design and detailing of steel single storey buildings (SSBs) across Europe

An extensive overview of current practices in SSBs across Europe was made, covering not only the primary structure but also secondary structure and cladding systems used. Typical details were collected from European practice, concluding with a summary or regional practice for the main countries of interest.

Identification of practices that hinder deconstruction and future reuse of the steel structure in SSBs, as well as presenting principles/solutions for future improvements

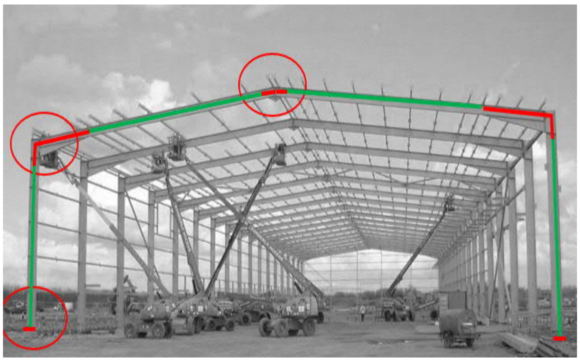
By reviewing the most common practices in European countries, it was possible to identify the critical detailing that currently hinders the reusability of the building or building components (see Figure 26). Solutions to improve the reusability of the components were proposed.

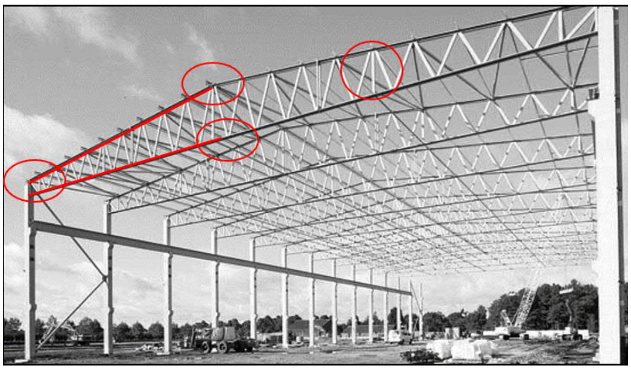
Develop selection criteria for steel structures and steel-based components so that easy deconstruction and efficient reuse are highly prioritized over other design targets

By analysing the practices and identifying the problems within each structural solution/approach, it was possible to identify the most appropriate practices for structural steel reuse. It was also possible recommend ways to increase the reusability of the structural elements.

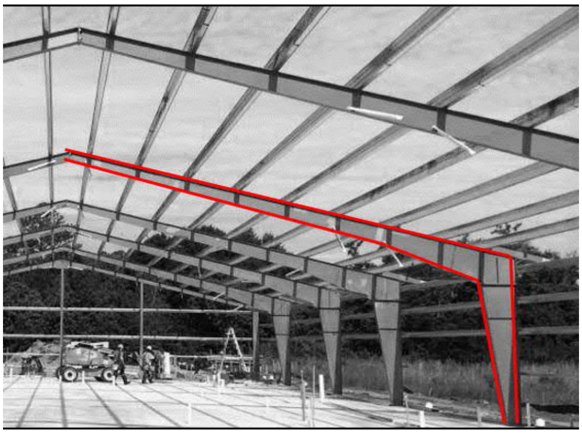
Define basic principles in the development of single-storey building concepts focusing on the spatial arrangements, spans, dimensions, functions and forms to maximize the implementation of the most reusable building elements

One of the most important principles for increasing the reusability of structural components is to implement standardization principles when defining the building geometry and detailing. General principles and proposals for standard dimensions are presented.





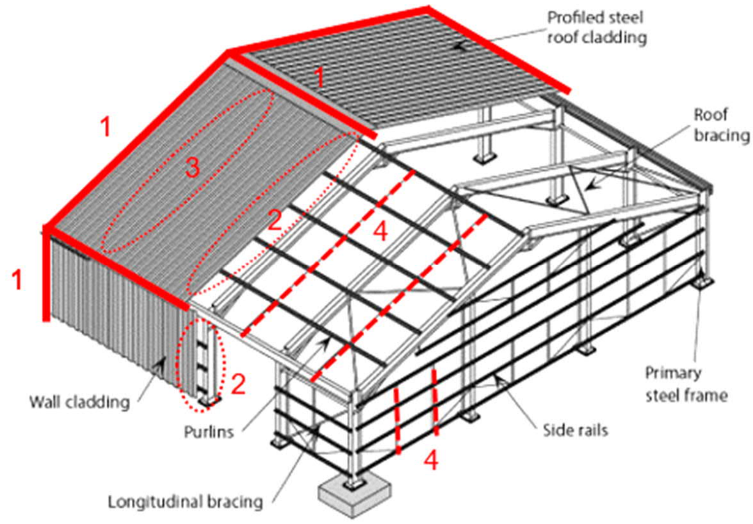
Eaves, apex and based connection in portal frames



Tapered segments with limited future applications

Tapered trused rafters; elements with smal length

Studs welding: permanent attachment of the slab



1) Building edges;
2) Connections between secondary structure and claddings;
3) Connections between cladding modules;
4) Anti-sag bars

Cladding and secondary steelwork detailing

Figure 26 Examples of details that hinder the reusability of structural components in SSBs

The ability to achieve a sensible level of standardisation of the primary structure depends on:

- The form of construction, as portal frames have inclined rafters and trusses have well defined lattice forms.
- The dimensional requirements for the structure and the spacing of frames.
- Column heights depend on the application of the space and the need for a mezzanine floor etc.
- Loading applied to the structure, which is likely to be similar within one region and building type.

- The minimum use of different structural and secondary components for given member lengths and loading.
- Design of connections using bolts, and standardisation of the components in these connections.
- Design of end gables (end frames) to be of the same form as the internal frames;
- Design and detail columns to act as edge or internal columns in a possible multi-bay portal frame scenario;
- Eaves connections must try to avoid the use of haunched segments; the solution with simple end plates, with possible lines of bolts over and below the rafter is recommended; for longer spans, haunched solution must be required for strength and/or connections stiffness; designer must bear in mind that little influence on the overall member design and overall frame stability is achieved by introducing an haunched apex.

A conventional portal frame system offers the possibility of reuse of its individual components, as most of the primary members, without modification, are long and with a typical span to depth ratio of 40 to 50 for columns and 50 to 65 for rafters (identified in green in Figure 27). The lengths in green may be separated from the more specialist critical zones (identified in red in this Figure) by cutting to obtaining beam and column segments.

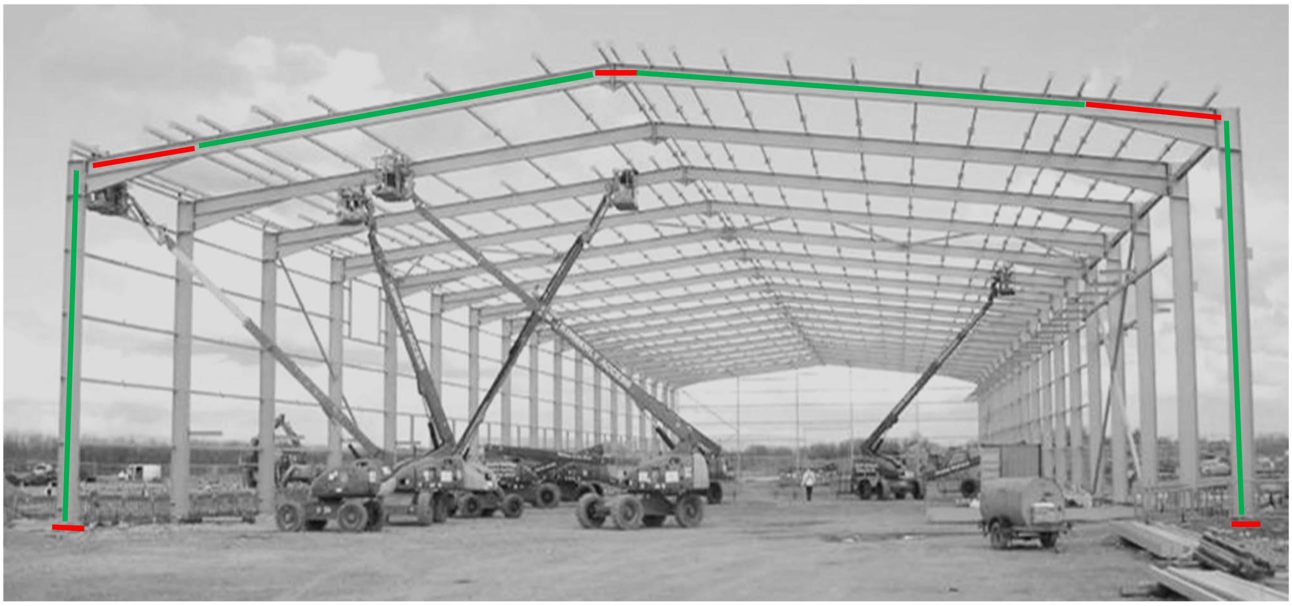


Figure 27 Opportunities for reuse in portal frame: segments with minor modifications

It is recommended to design portal frames for the following standardized dimensions:

- Span increments of 3m. Typical spans are 30 m, 36 m and 42 m using rolled sections;
- Roof slope of 6° to the horizontal;
- Frame spacing of 6 or 7.5 m with 7.5 m being preferred for purlin and side rail systems;
- Columns with a height to the top of the column of 7.5 m as a standard (6 m may be used for portal frame spans less than 30 m and 7.5 m for longer spans). The height to the underside of the haunch may be up to 1 m less than the column height;
- Design the columns for the additional load from a mezzanine floor on a 7.5 m square grid with the floor level at 4 m above the ground floor slab, which would require 7.5 m long columns; the square grid approach ensures that the columns can be used in a possible multi-bay future application;
- Haunch length of 10 to 12% of the span and of a depth equal to twice that of the rafters, being 10% recommended as the standard dimension;
- End gables should be the same as the internal frames to facilitate building expansion,
- Column bases with 4 bolts that may be treated as nominally pinned at the ultimate limit state but which may offer some rotational stiffness for sway deflection calculations,
- Bracing in the form of circular or square hollow sections with a typical range of cross section sizes (diameter/width) between 130 mm and 200 mm diameter with lengths between 3 m up to (but excluding) 12 m length between the frames (at 7.5m spacing); avoid using “x” bracing arrangements; it’s preferable to use few robust members that can be reclaimed without modifications;

Present an overview of current loading definition across some European countries, proposing alternative procedures to increase future building adaptability: design classes for SSBs design.

Relocation of a building to a new location with the same layout, may be not possible due to changes in the loadings that will act on the building in the new location. This task included a comprehensive overview of load requirements in several European countries, establishing the differences between them, proposing adjustments in the load definitions as well as identifying countries where, due to similar load scenarios, the relocation of the building may be more appropriate. Countries were allocated to different design classes, according to the load definition of each National Annex. Typical self-weights for permanent loads one SSBs were proposed for short-span and long-span cladding solutions.

Table 19 Proposed snow classes S1 to S4 for design of roofs

Country	Characteristic snow load s_k (kN/m^2)			Snow Class
	min. [a)]	country average [b)]	min. European value	
Finland	2.00	2.75	2.00	S1
Romania	1.50	2.00		
Norway	1.50	3.50		
Sweden	1.50	2.50		
Germany	0.45	0.85	1.00	S2
Italy	0.60	1.00		
United Kingdom	0.45	0.65	0.70	S3
France	0.45	0.65		
Ireland	0.40	0.55		
The Netherlands	0.70	0.70		
Portugal	0.10	0.30	0.40	S4
Spain	0.30	0.40		

a) Assuming the average altitude for the less critical zone of the country
b) Assuming the average altitude for the zone representing most area of the country

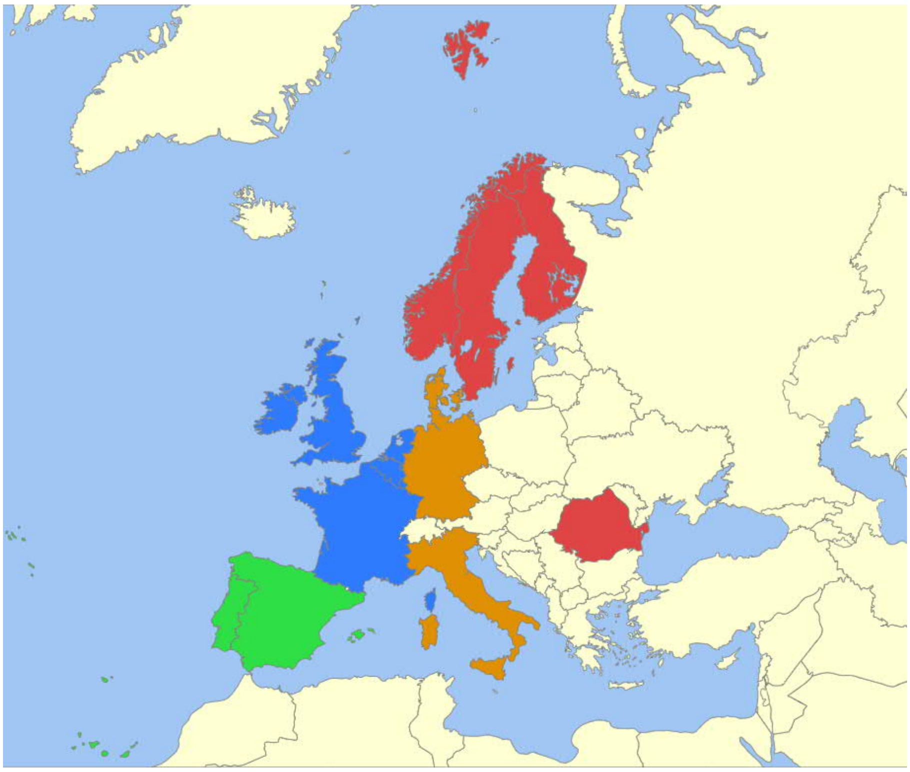


Figure 28 Proposed design classes for the snow load map based on [60]

Table 20 Basic wind velocity: wind classes W1 to W4 (reduced version)

Country	v_{b0} (m/s)			$q_{b0,mean}$ (kN/m^2)	$v_{b0,class}$ (m/s)	$q_{b,class}$ (kN/m^2)	**Wind Class**
	min.	max.	average				
Croatia	20	48	29	1.05	>28	1.05	W1
Greece	27	33	29	1.05	>28		
Romania	27	35	31 a)	1.20	>28		
Italy	25	31	27 a)	0.91	28		
The Netherlands	25	30	27 a)	0.91	28		
Portugal	27	30	27 a)	0.91	28		
Spain	26	29	27 a)	0.91	28		
Belgium	23	26	24	0.72	26	0.85	W3
Denmark	24	27	25	0.78	26		
France	22	28	24 a)	0.72	26		
Germany	23	30	25 a)	0.78	26		
Ireland	25	28	26	0.85	26		
Norway	22	31	25	0.78	26		
United Kingdom	22	32	25 a)	0.78	26		
Finland	21	26	22 a)	0.61	23		
Hungary	24	24	23	0.66	23		
Poland	22	26	23	0.66	23		
Sweden	21	26	22	0.61	23		
Switzerland	20	24	21	0.55	23		

a) Usual value from the NA/local standard

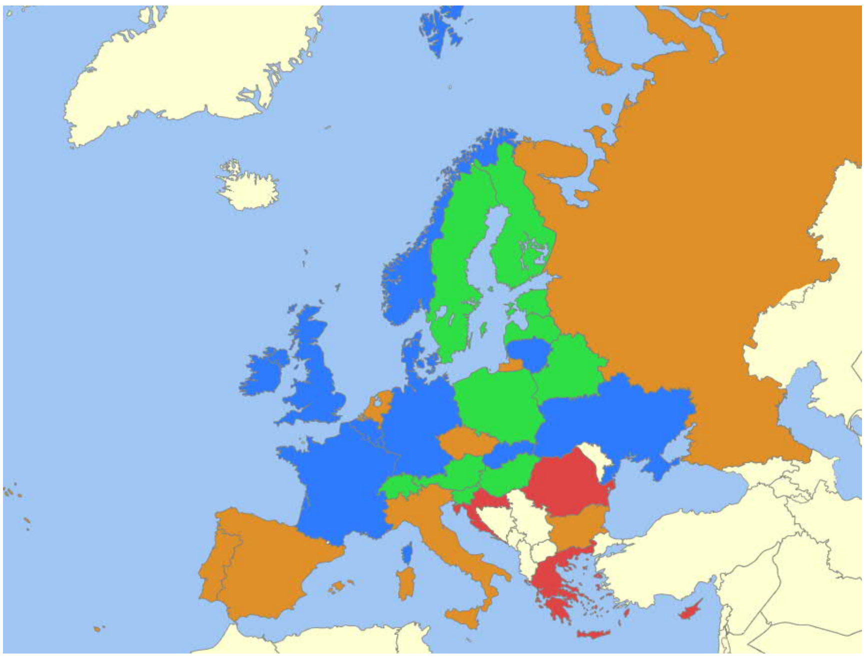


Figure 29 Proposed design classes for the wind load map

Review current resign philosophies and principles, proposing general principles for reuse

The analysis and design processes were devised in order to provide guidance on the design of reusable buildings in terms of the following topics:

- Global analysis: elastic global analysis is recommended for re-use of structures;
- Second order effects: guidance is presented;
- Serviceability (SLS): stress checks and deformation limits;
- Deflections and deformations limits based on a cladding performance-based design, rather than general limits often used;
- Cladding and secondary steelwork for member stability: best practice is presented;
- Steel sub-grade definition: best practice is presented and guidance for new single storey buildings was presented. The use of SCI P419 [62] was suggested for structures non-subjected to fatigue;
- Design for structural member stability according using the following modified partial factor: $\gamma_{\mathrm{M1,mod}} = K_{\gamma_{\mathrm{M1}}} \gamma_{\mathrm{M1}}$ with $K_{\gamma_{\mathrm{M1}}} = 1.15$;
- Reliability assessment for reclaimed steel and reusable components/buildings;
- Design of existing buildings as part of the process of a possible relocation of a new building was studied; proposal partial factors for a reduced structure life time were prosed as follows:

Table 21 Design values of actions for strength (STR) according to EN 1990 [60]

CC/RC	**Persistent and transient design situations**	**Permanent actions**		**Leading variable action**	**Accompanying variable actions (i > 1)**
		Unfavourable	**Favourable**		
1 (K_{FI} = 0.9) 15-30 years	Eq. 6.10	$1.215\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.35\,Q_{\mathrm{k},1}$	$1.35\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10a	$1.215\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.35\,\psi_{0,1}\,Q_{\mathrm{k},1}$	$1.35\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10b	$\xi \times 1.215\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.35\,Q_{\mathrm{k},1}$	$1.35\,\psi_{0,i}\,Q_{\mathrm{k},I}$
2 (K_{FI} = 1.0) 50 years	Eq. 6.10	$1.35\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.5\,Q_{\mathrm{k},1}$	$1.5\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10a	$1.35\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.5\,\psi_{0,1}\,Q_{\mathrm{k},1}$	$1.5\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10b	$\xi \times 1.35\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.5\,Q_{\mathrm{k},1}$	$1.5\,\psi_{0,i}\,Q_{\mathrm{k},I}$
3 (K_{FI} = 1.1) 100 years	Eq. 6.10	$1.5\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.65\,Q_{\mathrm{k},1}$	$1.65\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10a	$1.5\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.65\,\psi_{0,1}\,Q_{\mathrm{k},1}$	$1.65\,\psi_{0,i}\,Q_{\mathrm{k},I}$
	Eq. 6.10b	$\xi \times 1.5\,G_{\mathrm{k},j,\mathrm{sup}}$	$1.0\,G_{\mathrm{k},j,\mathrm{inf}}$	$1.65\,Q_{\mathrm{k},1}$	$1.65\,\psi_{0,i}\,Q_{\mathrm{k},I}$

Proposal of alternative structural approaches and structural details to increase building reuse and individual components reuse

Alternative structural concepts and detailing are presented to facilitate reuse of conventional portal frames and trussed solutions. Alternative solutions for cladding systems and secondary steelwork were also studied.

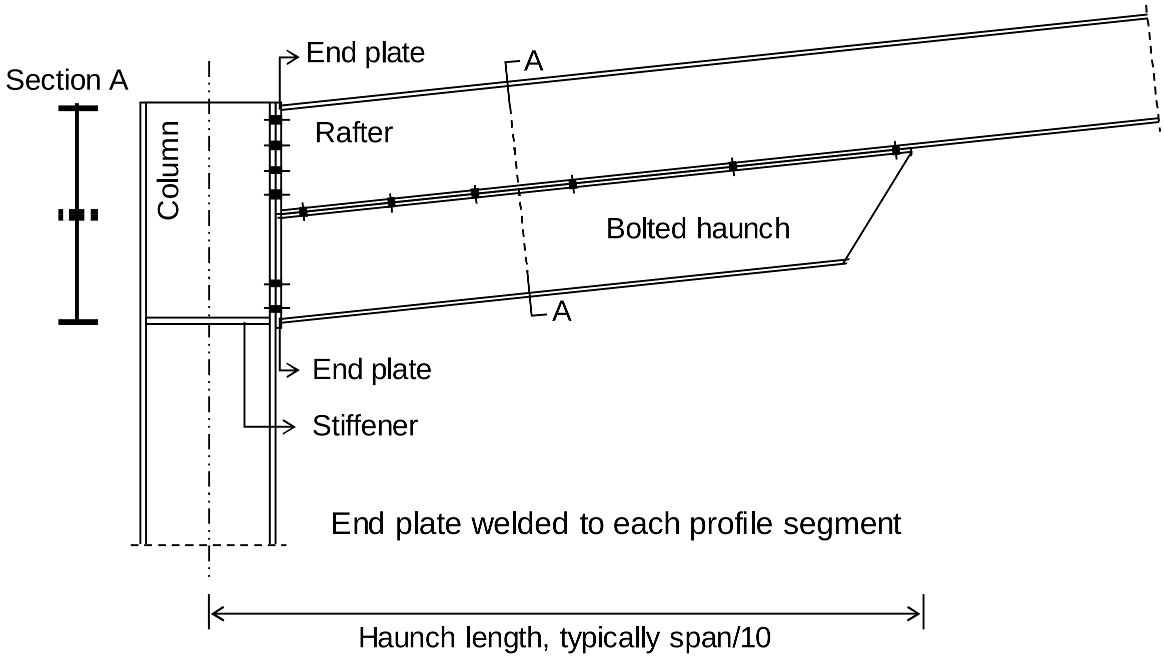


Figure 30 Bolted haunch components in a portal frame

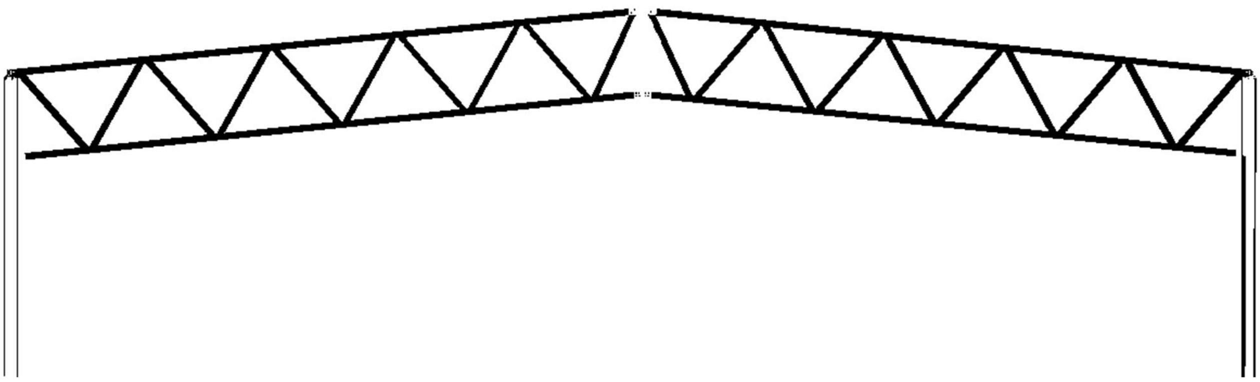


Figure 31 Steel truss system for better re-usability

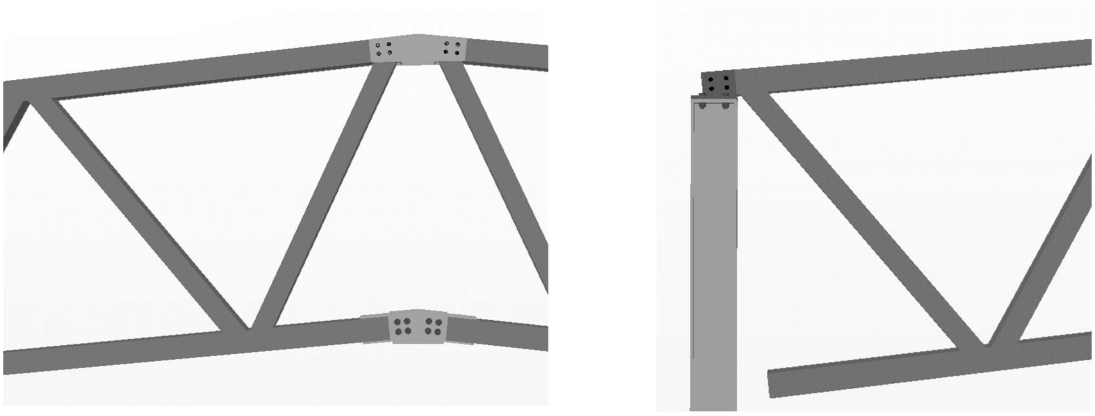


Figure 32 Connectors enabling truss assembly to different slopes

3.2 Building information modelling

This Task introduces an overview and recommendations on the use of Building Information Modelling (BIM) in the reuse of steel structural components and envelopes from the single storey steel framed buildings (SSBs) as defined in the deliverable D3.1 “Summary of design practices for reusable buildings and products” [8].

The role of digital BIM information is addressed in the Task report, Deliverable D3.2 [9], focusing on the digital tools and the stored information for future reuse. The recent standards are introduced including those under development, as well as guidance about how to address the level of information detail in the structural steel industry. The guidance about the building information that will essentially make sure that all relevant material properties and other project parameters are never lost. The following aspects are included in the Task report:

- description of the use (reuse) cases,
- BIM development and implementation,
- overview of the gaps in data structure, software functionality and assessment of the integration in the BIM extensions,
- demonstration of the proposed BIM for reuse
- conclusions and final recommendations

Approaches to manage key data about characteristics and data properties of a product/ building component

Many approaches to use intelligent information and BIM in order to support reuse and recycling work-flow are possible. However, only a few studies on BIM use case for circular economy have been executed so far.

There are four main approaches or development streams, which try to find some common standards/ principles for managing product information needed in reuse and recycling. General information of a product is easier to extract from BIM models or Maintenance databases, but key data about characteristics and data properties of each product or building components are harder to find. Managing product information with their property level data is seen as challenging and unclear task, because of (a) low customer demand/ non-matured business cases, (b) only a few defined BIM use cases on property level, (c) technology and method readiness and (d) tools and services time to the market.

Today the properties needed for a certain data transfer or data drop activities are defined in the BIM guidelines, based on practices developed in BIM based projects data-flow. This type of harmonization of the data needs in data-flow process requires manual input of the needed properties to the attributes of BIM objects. As known, manual work contains risks for human errors and this is one the reason the property level data management should be as automated as possible.

DeepBIM is a term used for more detailed information applied in analyses, calculations, simulations and performance assessment. BIM use cases for deconstruction, reuse and recycling need detailed information on products and building components of a building. In this repost we have identified four methods for a carrier of detailed information/ property level information of a product or building component, in data transfer or data drop action. These are:

- API interfaces which software vendors develop ad-hoc between systems and tools to meet needs for information content or transfer.
- OpenBIM based approach is based on defining the IFC-file content for the needed data/ information transfer actions.
- BIM classification and for instance ETIM- structure are foundation to every day business needs for delivering product information in project level. These approaches are usually supported in national tools and databases of product information.
- OpenIFD based approach and defining General Product Data Sheets, is evolving approach for managing product information, from harmonized standards and other sources.

The two latter are emerging approaches and available to business only after enriched with data, adapted to the processes and implemented to information services and software. Methods for detailed information carriers, with some drivers and barriers are explained in chapter 1.1.4

BIM as integrated information management is used and several BIM use-cases are matured in many European countries. Due to national BIM guidelines and requirements, strategies of organisations' and digital transition of the real estate and building sector, the BIM deployment is moving on. National targets and requirements for using modelling is in main role when defining new BIM use cases. Design for deconstruction, reuse and recycling is a new BIM use case and a national question: should we include BIM use case for circular economy on national level BIM guidelines and what are the information requirements?

The standardization of information management for openBIM and openIFD approaches is led internationally, and on European level, similar way than harmonised standards of products and building components. Both standardisation areas and standardisation bodies are essential for a fluent integrated management of product level detailed information during assessment tasks of circular economy processes, using indicators such as deconstructability, product reuse potential and recycling percentage.

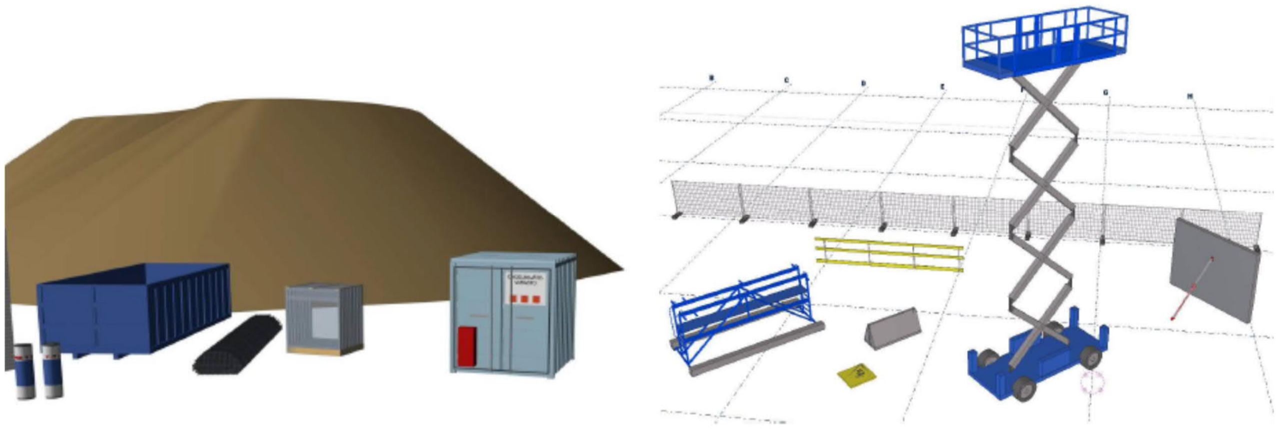


Figure 33 Examples of on-site planning objects created in TurvaBIM (left) and BIM Safety (right).

Semantic representation of the basic product and material information essential for reuse

The Europen Commission Delegated Regulation 157/2014 allows manufacturers to make available product information on their websites. It also states that the *“schema for the machine-readable format should preferably use standard or widely used data schemas, so that the information is interoperable with most architectural tools.”* It is recommended to divide the machine-readable information in two basic categories:

- **Declared and/or certified nominal properties**: This includes for example Smart CE marking according to CWA 17316 [67] and Smart EPD proposed in this Task. The information should be typically formulated according to the relevant harmonized standards, often verified by independent inspection body and digitally signed. It is expected that the information will change only exceptionally during the lifetime of the product. The information is intended especially for the building authorities issuing building/demolition/renovation permits, and therefore it is important that the authorities will be able recognize authenticity of the information and that the authorities are involved in the development of the information standards.
- **Measured or assessed properties:** This information originates typically form the measurements, laboratory tests, numerical simulations or various lifecycle databases and should describe the current performance of the product as precisely as possible. This information is intended especially for the property owners, investors, designers and contractors to help them to recognize economic and environmental value of the integrated products, and therefore it is important that the information is presented in the relevant format, updated reguralry, and the relevant stakeholders are involved in the development of the information standards.

From the point of the view of the PROGRESS project objectives, the first information category is the most important, because it enables to guarantee nominal properties of the products beyond the building’s lifecycle and has a great potential to decrease or eliminate the need of re-certification and repeated testing of the products. An example of such information is the Declaration of Performance (DoP) according the relevant harmonized construction product standard. This information is typically provided in printed form or in pdf, which is difficult or impossible to automatically interpret and further process in the building information databases. The solution is semantic technology that makes sure that the information can be provided both in human readable format (e.g. HTML) and machine-readable format (e.g. XML), such as the framework for Smart CE marking provided by the CEN Workshop Agreement CWA 17316 [67]. Example of the structural steel properties (tensile and yield strength) declared according to EN 10219-1 [52] is in Figure 34.

The structure of the declaration data proposed in the workshop agreement was found suitable for general declarations of any product properties. Therefore, the modification suitable for the Environmental Product Declaration (EPD) is proposed in the Task. Example of the Smart EPD environmental impacts in the Product stage (A1-3) is in Figure 35.

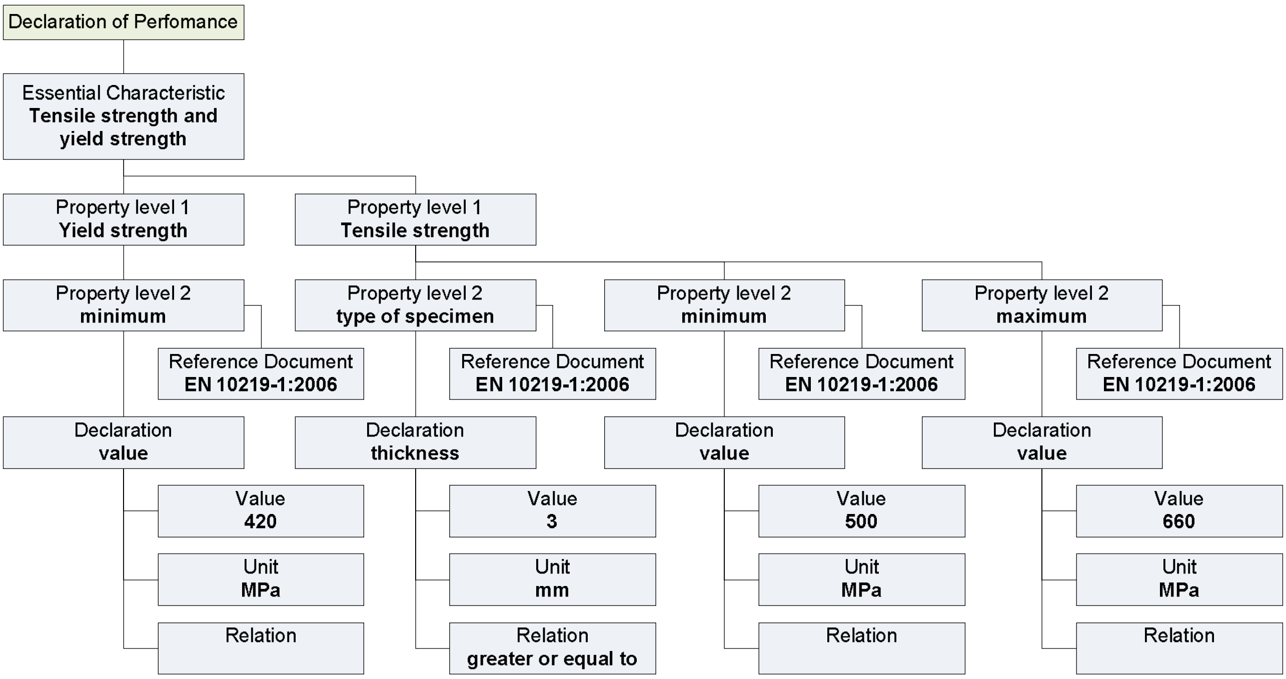


Figure 34 Declaration of Performance of steel product according to CWA 17316 [67]

The advantage of using the same data structure for both of the essential declaration documents is that the information can be easily shared or cross-referenced, for instance with the implementation of the 7th Basic Requirement for Construction Works (BRCW 7) according to the Construction Products Regulation (CPR) [68]. This requirement contains for instance declaration of recyclability of the construction works and their materials, use of secondary materials and durability of the construction works. All these parameters have to be consistent with the declared impacts in EPD, and therefore their link in the BIM structure will be beneficial.

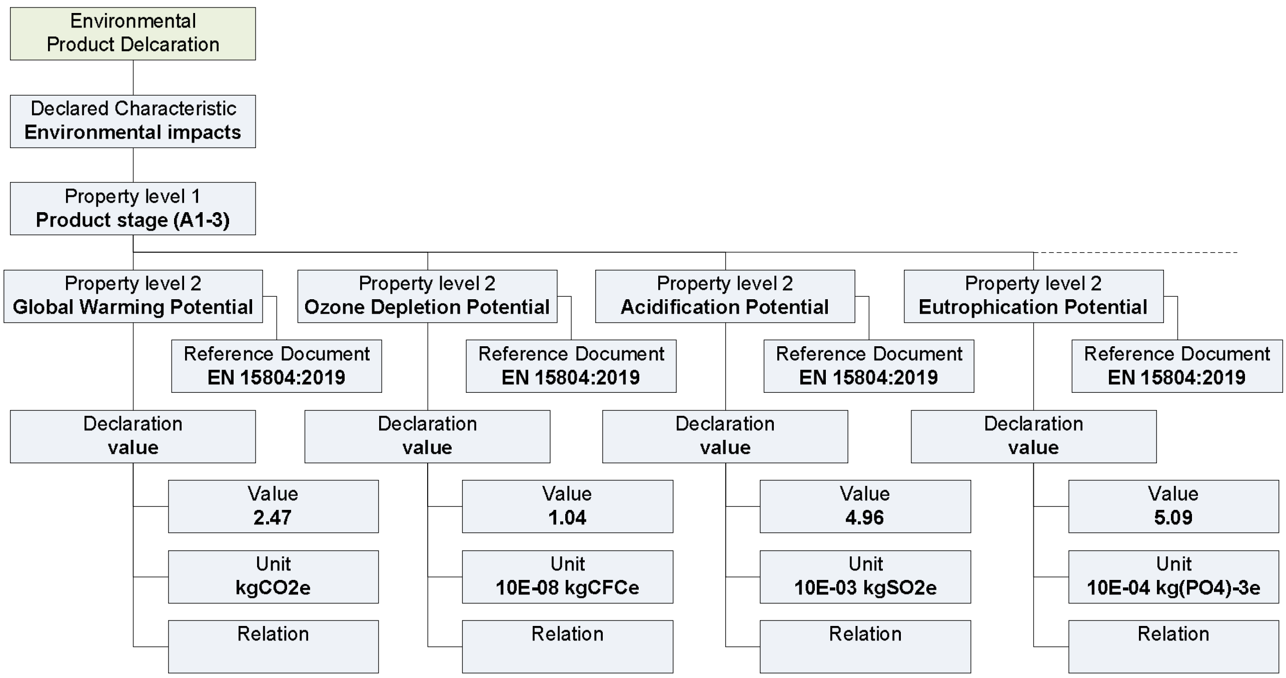


Figure 35 Proposed Smart EPD within the same data structure as DoP [9]

BIM and digital product information tracking

A physical component tracking is often implemented during fabrication and erection processes. However, the component tracking is often lost and not preserved during the life time of the building. It is advised that a form of physical component tracking must be preserved during the lifetime of the building, linked with a digital model where the relevant building and member information can be kept. This measure will facilitate the application of reclaimed steelwork without the need for further testing.

Bar codes, QR codes or Radio frequency identification (RFID) provide an efficient and reliable method of component tracking. This technology can be used as a digital passport for each reclaimed member. It is also possible to store the relevant information needed for future life cycles in a simple QR code, bar code or RFID (see Figure 36).

Figure 36 Examples of component tracking with RFID and QR codes

The level of information that a 3D BIM model needs to accommodate is a responsibility of all project actors. The ISO standards EN ISO 19650-1 [69] and EN ISO 19650-2 [70] introduced the concept of level or information need (LOIN), for which is suggested that each project actor must define the relevant information to be stored for the purpose of the element on a specific project. Within the scope of the project, the concept are discussed in the report from a structural engineering point of view. The following standards offer some general guidance to specify the LOIN of an element:

- prEN 17412 [71];
- prEN ISO 23387-1 [72];
- ISO/DIS 20887 [73].

However, these standards are rather general for the concept of LOIN. For the definition of LOIN, the actor should try to answer question related to the object such as “who”, “why”, “how”, “when” or relevant numerical quantities for a specific purpose. The process can be performed for topics such as responsibilities, material/product properties/characteristics and geometry, reusability, sustainability, health and safety, costs, structural analysis outcome, appearance/coating, on-site position, labelling, ID, linked documentation, etc. The suggested information needed for the product tracking during its lifecycle and reuse is presented in the Deliverable D3.2 [9].

4. Novel hybrid systems for envelopes (WP4)

4.1 Elaboration of new hybrid solutions

Within the framework of this Task, innovative hybrid systems have been developed in numerous workshops with partners within the project but also with associations and industrial companies that are not part of the PROGRESS consortium. For this purpose, the status quo, main barriers and challenges to the reuse of steel building envelopes are described first. Two common forms of construction are: double-skin designs and sandwich constructions. These two construction methods are examined in more detail below.

Double-skin designs

As presented in Deliverable D4.1 [10], double-skin cladding systems are usually fixed using self-tapping self-drilling screws, rivets and fired pins. This practice, when disassembly processes are required, tends hinder the reusability of the cladding systems, as the process can easily induce damage to the cladding systems. Besides the fixings between claddings and secondary structure, there are usually additional self-drilling bolts applied between cladding modules, which increases considerably the effort for careful disassembly and reassembly processes. Therefore, one key point for a more reusable cladding system is the number and type of fixings that are used between the cladding and the secondary structure. Some other important topics are the details of eaves and gable parapets, ridge detail, or simply wall junctions. The number of connecting elements, as well as auxiliary steel plates to effectively seal the building or just to make an efficient compatibility between cladding modules are substantial. The following main barriers regarding the reuse of double-skin systems in lightweight steel construction could be identified:

- **Many components and connections:** Double-shell systems in particular consist of many different individual parts. This leads to a high effort of dismantling. Furthermore, an assessment of each individual component has to be done. This requires a high expenditure of time, which makes a reuse expensive.
- **Financial incentive:** A financial incentive is necessary for the reuse of metal building envelopes. Only if there is any financial advantage, the use of old components will be attractive for customers. Otherwise they will always prefer a new envelope due to the fact that the outer layer of a used system has aesthetical disadvantages.
- **Outer layer is not acceptable:** For various reasons, it is very likely that the outer layer will not meet the requirements of the new building. Due to aesthetic reasons, as minor damages (dents, scratches), it is difficult to imagine reuse of the outer layer of the building envelope. Furthermore, after certain years of use, the presence of corrosion is possible, which would not be accepted. Therefore all components have to be checked.
- **Type of fasteners:** The current fastening possibilities for cladding systems have been optimised in terms of assembly, water and air tightness as well as load-bearing capacity. The ease of dismantling has not played a role so far. Therefore, it is currently to be expected that the dismantling process of double-skin systems will induce damage to the cladding systems.
- **Static aspects:** Also structural design boundary conditions must be considered. Existing building components that are affected by refurbishment or disassembly and reuse need a renewed static proof based upon present technical rules and the assumptions for wind- and snow loads were subject to significant changes in recent decades. After a systematic

record of the normative development in this sector, possible means for the static proof of the refurbished/reused components concerning the additional lightweight steel construction systems and the changed load assumptions have to be investigated.

Sandwich construction

Following main barriers regarding the reuse of current sandwich panels could be identified:

- **Insufficient thermal insulation:** If a complete exterior wall element, such as a sandwich panel, is to be reused, the problem is that the thermal resistance standards of these elements dates from the time when the old building was erected. Therefore the reuse of such panels would not meet today's more onerous standards. An energetic improvement is therefore necessary in most cases. On the other hand, the current level of energy standards in Europe is already so high that future re-use of building envelopes of current construction should be easier.
- **Outer layer is not acceptable:** For various reasons, it is highly likely that the outer steel sheet of a sandwich panel will not meet the requirements of the new building. With the exception of use in agriculture, stables or the like, it is difficult to imagine reuse of the building envelope with existing optics. These will mainly be aesthetic reasons, as minor damages (dents, scratches) or corrosion will not be accepted. It is also common that sandwich panel screws have been screwed too tight causing failure to the panel sheeting.
- **Screw holes:** Screws in existing, planned force-transmitting connections, which have already been loaded, may only be exchanged for thread-forming screws with a larger diameter, whereby the hole must be drilled out to fit the thicker screw. In addition, screw holes that are not reused should be avoided for optical and building physics reasons. Furthermore, the screw holes dictate the range of the panel. If any span range divergent from the existing one is required on any new building, the Sandwich panels cannot be used.
- **Limited service life of the individual components:** The recommendations for the selection of corrosion protection systems of the International Association for Lightweight Metal Building Envelopes says: "The expected service life of a corrosion protection system may differ from the technical service life. The service life of components is limited. In the area of depreciation, periods of about 15 years are reasonable, in the area of sustainable construction more than 40 years are desirable. Experience shows that a service life for industrial buildings of approx. 20 to 25 years is realistic. After that, these buildings are usually replaced due to a change in demand." In addition, the sealing tapes become porous over time and may no longer meet the requirements for air tightness.

On the other hand, in new buildings, the technical level of current sandwich panels systems is already quite high, which may enable future reuse. For this reason, new connection technologies for sandwich construction that facilitate easy dismantling and efficient future reuse are developed and tested in Task 4.2.

Regarding the innovative hybrid solutions, following three different options have been selected to be tested in Task 4.2 and 4.3 in order to overcome the aforementioned barriers and challenges:

Reuse of liner trays

Due to the reason that it is currently to be expected that the dismantling process of double-skin systems will induce damage to the cladding systems, within the framework of PROGRESS, the scenario in which the inner shell of the system, e.g. the liner tray, remains on the building, see scenario D_C (same site, different configuration, see Table 3) is considered.

Inner shells of double-skin systems that would be destroyed during dismantling can only be reused if they stay in place. Therefore, solutions must be found. A solution for liner tray wall systems could be to cover them with sandwich panels which leads to an improvement of the appearance and energy performance. The approach of this innovative hybrid solution is to carry out the energetic refurbishment of existing double-skin wall systems during operation (without cost-intensive downtime). The old trapezoidal profiles must be removed for this purpose, see Figure 37 left. These can most likely not be reused due to damage and aesthetic limitations, but will be recycled. The liner tray profiles remain in place and are reused. In this way it can be ensured that the use of the building is not interrupted during renovation and the work, e.g. manufacturing, can continue inside the building. What happens to the mineral wool depends on its condition. If it is still in good condition, it can remain in the liner trays and can also be reused. If it is soaked or otherwise damaged, it would have to be replaced with new insulation and fed into the material recycling.

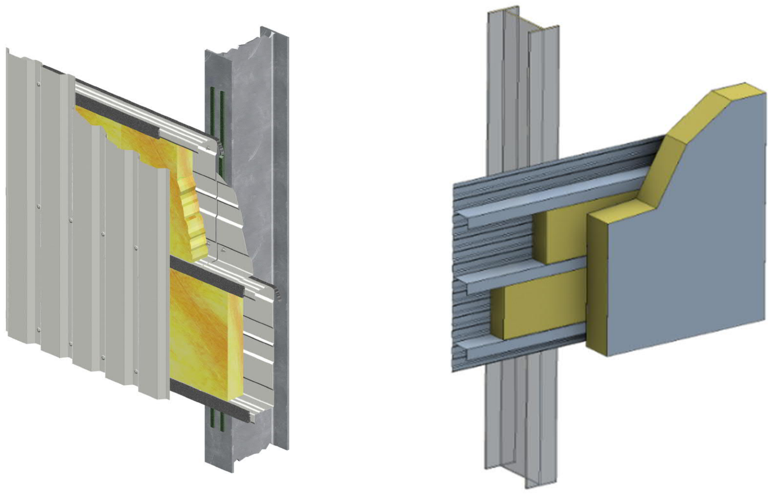


Figure 37 Double-skin wall system with liner tray profiles (left) and reused liner tray profiles and sandwich panels (right)

In order to improve the thermal and aesthetic quality of the existing façade, additional sandwich panels should be installed on the outside, see Figure 37 right. Sandwich panels with double-sided steel face layers and polyurethane or mineral wool insulation core provide a highly effective option in this context. They not only have very good thermal properties but can also be installed very quickly and economically. In addition, so-called modular lightweight steel build-up systems offer a further alternative to energetically enhance existing building envelopes.

From a building physics point of view, not only do the aspects of thermal insulation have to examined, but also questions arising from the change in the moisture-technical behaviour of the rehabilitated component. Also structural design boundary conditions must be considered. Existing building components that are affected by the refurbishment need a renewed static proof based upon present technical rules and the assumptions for wind- and snow loads have been significantly changed in recent years. After a systematic recording of the normative development in this sector, possibilities will be investigated to prove the energetically redeveloped construction elements using the additional lightweight steel construction systems with correspondingly changed load assumptions.

Over-cladding of sandwich construction

Over-cladding of these constructions offers potential in several aspects:

- It can be used for both scenario D_C (same site, different configuration) and scenario D_E (different site, different configuration), see Figure 38.
- The poor aesthetics of the old outer surfaces can thus be enhanced.
- Insufficient thermal insulation can be improved by insulating the space between old sandwich panel and new cladding.

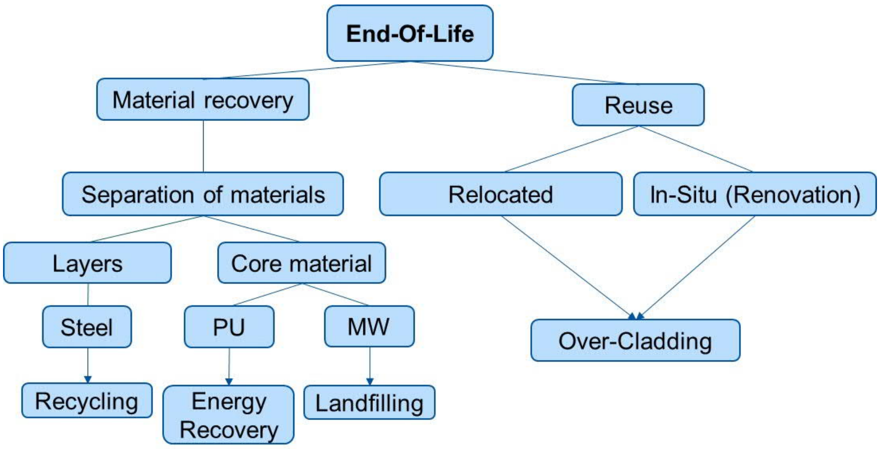


Figure 38 End-of-Life scenarios of sandwich panels

Up to now, sandwich elements are fixed directly to the substructure by push-through mounting by direct or indirect connections, see D4.1 [10]. In order to promote the reuse of sandwich panels, a new method of fastening sandwich panels could be one-sided fixation. One-sided fixation means a screw which is only fixed into the foam core of a sandwich element from one side. This kind of fixation offers potential for promoting the reuse of sandwich panels for the following reasons:

- In the case of a planned renovation of the building envelope, the old sandwich panels could be reused with the aid of the one-sided fixation by fixing distance profiles from the outside, which allow the sandwich panels to be covered with new facade elements.
- The sandwich panel is not penetrated and therefore, there is no weakening of the building physical properties of the sandwich panel.
- The one-sided assembly process brings advantages in the construction process.
- If the one-sided fixation is used at the inner metal sheet to fix the sandwich panel to the substructure, there is a further advantage: The outer metal sheet shows no changes. After the dismantling only holes are visible from the inside, the outer sheets remains untouched. This would greatly facilitate the reuse of the sandwich panel.

Further investigations regarding the load-bearing behaviour of one-sided fixation of new and used sandwich panels were carried out in Task 4.2 [11].

FRP Hybrid Systems

Through the integration of additional profiles into the double-skin system, which take over the load-bearing function of the secondary structure, large parts of the secondary structure could be avoided and the number of individual structural components could be reduced.

For new construction solutions, the first focus is on the development of novel systems in which thin-walled steel profiles are replaced by FRP profiles. The second one is reinforcement of sandwich panels using FRP beams. Thereby, the reinforced sandwich panel has an increased load bearing capacity and is able to take vertical loads, so the substructure can be reduced. Furthermore, such systems can improve the energy performance of the wall element and fasteners can be used that are better suited for the non-destructive dismantling process.

Currently, profiles in the building envelope are mostly made of steel or aluminium. Due to the very high thermal conductivity of these metals, undesirable thermal bridging effects occur. If instead a poorly heat-conducting material (e.g. FRP) is used in the direction of the heat flow, the thermal bridging effect can be reduced in the area of the profile. Therefore, innovative materials such as FRP will be used in combination with steel. The benefits are the increase of the load capacity and the improvement of local load introduction (screws) compared to pure FRP beams. These hybrid beams should substitute conventional steel profiles in typical wall and roof systems in lightweight metal construction as shown in Figure 39.

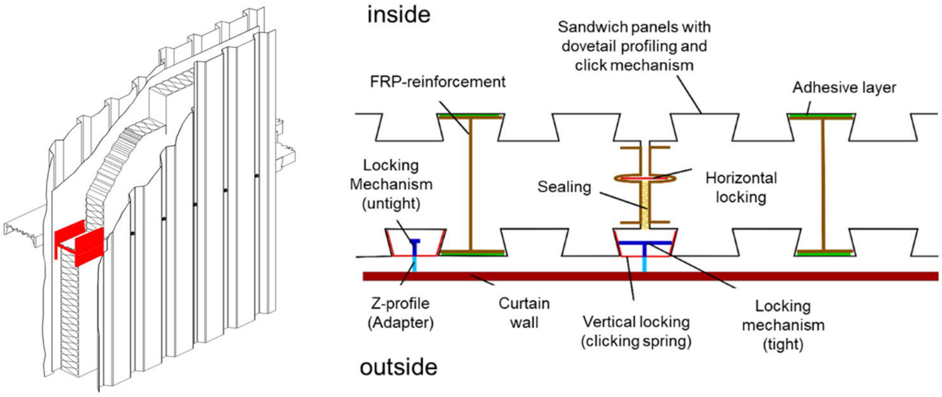


Figure 39 Double-skin systems using hybrid profiles made of fibre-reinforced-plastics (FRP) and steel

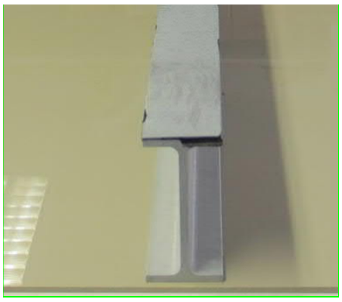


Figure 40 Hybrid profiles made of fibre-reinforced-plastics (FRP) and steel

The new hybrid system encourages the future reuse of individual components because:

- Possible replacing/upgrading of the outer layer, which means a reuse of the remaining components.
- The integrated profile could ensure that parts of the secondary structure could be avoided. This would considerably speed up the dismantling and reconstruction process and thus promote reuse.
- Fasteners can be used that are better suited for the non-destructive dismantling process.

4.2 Joint and connection technologies for the new hybrid solutions

This Task deals with the design of joints and connections that facilitate easy dismantling and efficient future reuse of envelope solutions. In Deliverable D4.1 [10], a summary of the types of joints and connections commonly used in single-storey steel framed buildings is given. In the following, two proposed innovative connection solutions are presented, which were tested under this Task regarding their mechanical properties.

One-sided fixation of sandwich panels

One-sided fixation is the main challenge for the over-cladding of sandwich panels and therefore, also for the in-situ reuse of buildings with an envelope made out of sandwich panels. The application of over-cladding systems on existing buildings requires knowledge about two certain points. First, the general load bearing behaviour of one-sided fixation. Therefore, an assessment of each parameter, including the foam system, the steel layer and the fastener, must be undertaken. Second, the durability of sandwich panels, especially regarding one-sided fixing, has to be determined and evaluated.

Achieving the aim of the general application requires two steps for each point. The first step was a summary of the state of the art and the second one are investigations and tests on the basis of the state of the art. Furthermore, the knowledge about the load bearing behaviour of one sided fixations was necessary in order to do investigations on structural elements in Deliverable D4.3 [12].

The state of the art and research regarding the one-sided fixation of sandwich panels is given in Deliverable D4.2 [11]. Knowledge about the durability of sandwich panels is necessary for the over cladding of sandwich panels on existing buildings. Therefore, the factors that causes an ageing must be considered. Ageing means the effect of a decrease of material properties or mechanical performance over time. According to the factors, which are causing a degradation on sandwich panels, are the following:

- Long-term loading (self-weight and snow)
- Movement and forces caused by temperature differences
- Repeated loading
- Humidity
- High temperatures

Thereby, humidity and high temperature are the factors that have significant influence on the durability of core materials of sandwich panels. High temperatures are the decisive factor for sandwich panels with a polyurethane core. In the ageing of sandwich panels is measured by the degree of the tensile strength of core material. After an artificial ageing in a climate chamber, tensile test has to be done, so the degree of tensile test can be determined. For an approval of sandwich panels with a polyurethane core it is not necessary to do ageing test. State of the Art identifies a critical climatic condition, where the tensile strength highly alternates depending of the storage period. These conditions are defined by a humidity of 90 % and a temperature of 50 °C.

The test on connections were done on new sandwich panels and on sandwich panels which were artificially aged in a climate chamber with the critical conditions of EN 14509 [61]. To determine the influence of the profiling of the panels, three different sandwich panels with different profiled layers were used (in the following called P1, P2 and P3):

- P1: lightly profiled layer
- P2: micro profiled layer
- P3: flat layer.

The set-up for the tests on the sandwich panel specimens was designed to determine the load-bearing behaviour and resistance of only one layer under tensile load caused by a one-sided fixation. Therefore, the other steel layer is completely fixed. In order to ensure a pure tensile load, two joints were installed in the load introduction. The joints are orthogonal to each other. This guarantees that the fastener will not set in a tilting position and only tensile load occurs. The test set-up is shown in Figure 41. The dimension of 300 x 300 mm² excludes the load-bearing behaviour of the panel, so that the failure will only occur in one steel layer.

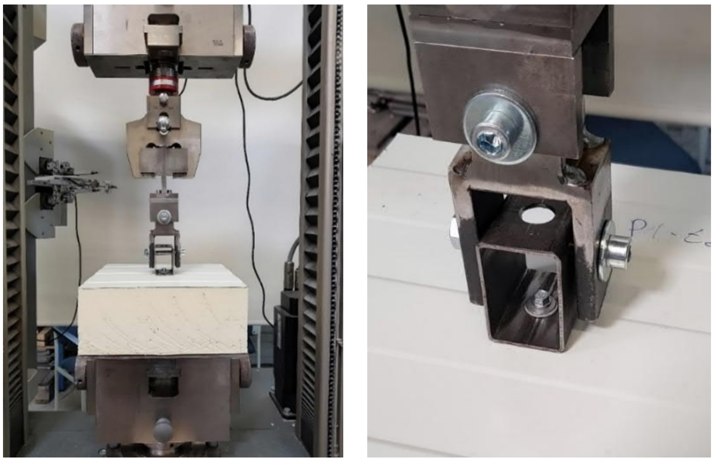


Figure 41 Test Set-up for one sided fixation

Figure 42 shows the climate chamber, which was used for the ageing of sandwich panels at the RWTH. The figure also shows the humidity and temperature conditions during the ageing preocess. The humidity was set to 85 % and the temperature to 50 °C. The specimens were stored for 28 days and tested every 7 days.

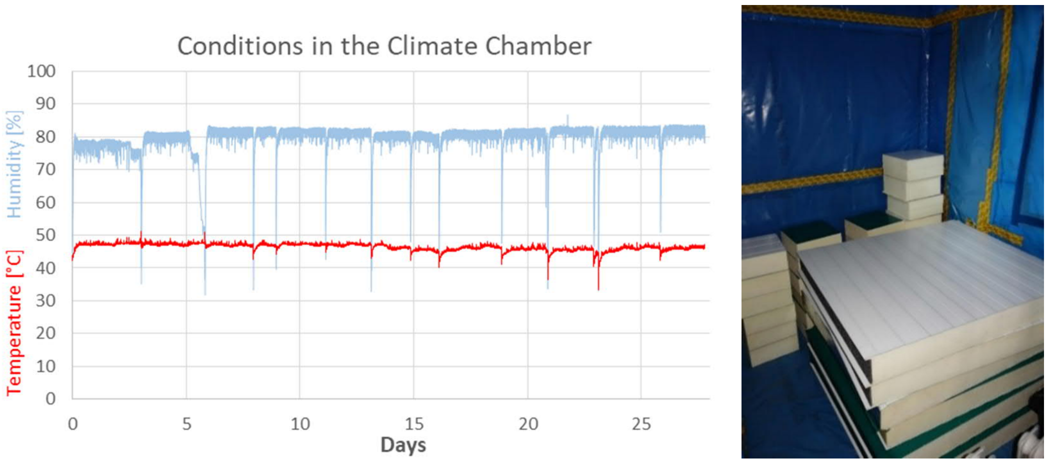


Figure 42 Conditions in the Climate Chamber

Furthermore, the maximum water absorption of each foam element was measured. Therefore, three small foam specimens (50 x 50 x 50 mm) of each product were stored in the climate chamber until the maximum water absorption was reached. The summarized results of the tests are shown in Figure 43. It is recognizable that the artificial ageing has not a major influence on the load bearing behaviour of the fastener. The degree in strength can be equalized with common safety factors.

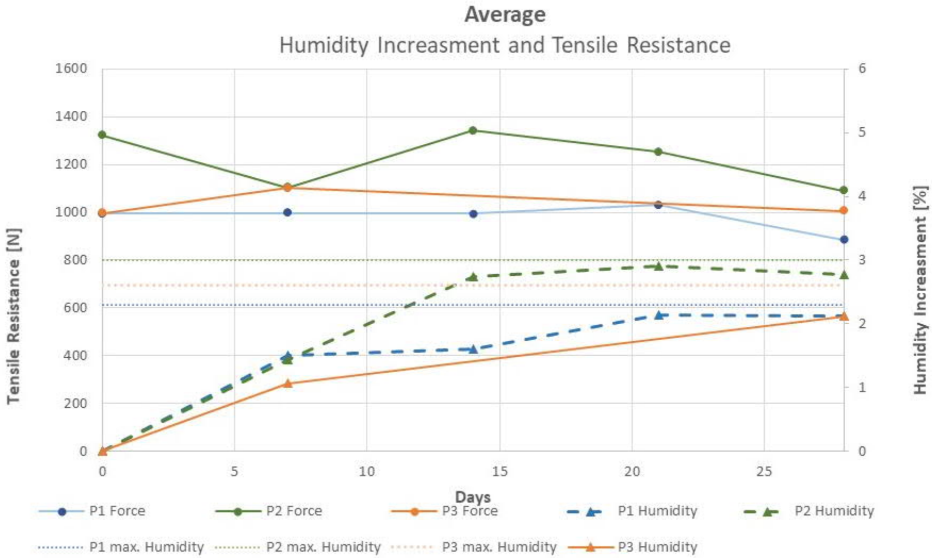


Figure 43 Results of tensile tests

Furthermore, first tests with real aged sandwich panels were done. Thereby, two different types of sandwich panels were used. The first ones are mineral wool panels provided by Ruukki Construction, which were manufactured in 2007 and used on the south side of a test building in Finland. The steel layer is flat. The test specimen are shown in Figure 44.

Figure 44 Specimens from used sandwich panels with a mineral wool core

The second type of specimen are made out of panels, which has a polyurethane core and were installed on an industrial building in Germany in 2001. Different from the other specimens, the specimen of this panels were 230 x 230 mm due to strong profiling of the steel layer. The specimens are shown in Figure 45.

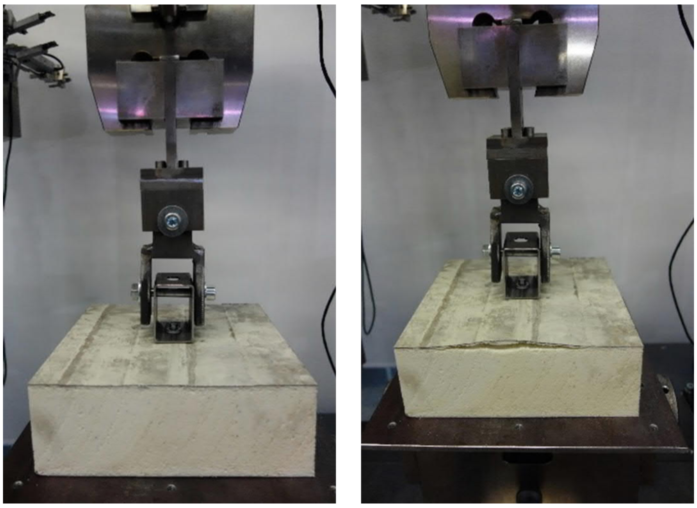


Figure 45 Specimens from used panels with a polyurethane core

The scope of these investigations exceeds the tests described in the Technical Annex. RWTH was working on the determination of the effect of repeated loading. Furthermore, an analysis which evaluates the main parameters of the connection-system was carried out.

Adapter profiles for sandwich panels

The development and testing of the Smart Flashing Connector is the main part of D4.2 [11]. Thereby, the focus is on the connector itself. The load bearing behaviour of the overall system consisting of substructure, *Smart Flashing Connector* and sandwich panel is determined in D4.3 [12]. Figure 46 shows a schematic sketch of the connector. In the following, the theoretical development, the development of the prototype and the testing of the connector will be shown.

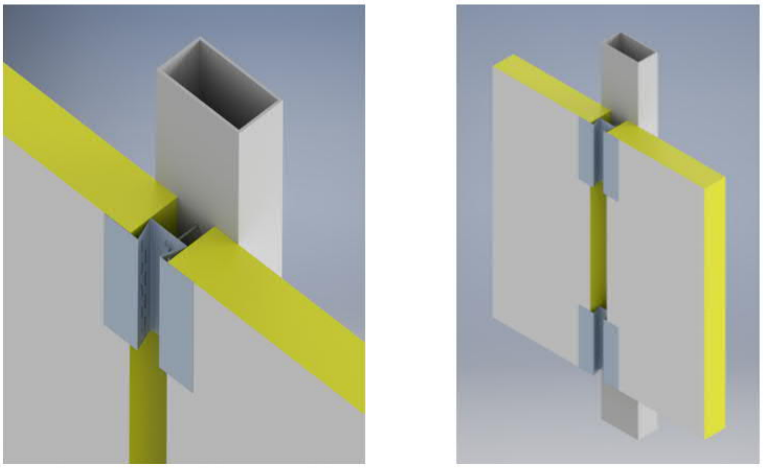


Figure 46 Schematic sketch of the new
Smart Flashing Connector

The *Smart Flashing Connector* needs to meet certain requirements to ensure the possibility of an unrestricted use. Therefore, the following requirements were defined and taken into account during the development of the connector.

- General applicability
- Dimensional tolerances
- Easy assembly
- Financially competitive
- Statically sufficient
- Sufficient building physic properties

In the following a short description of the production of the Prototype is given. Thereby, the individual components were ordered from different companies and assembled at the RWTH Aachen University. First, the adapter profiles with oblong wholes were made of S235. The dimensions are shown in Figure 47. The length of the profile is 190 mm. The installation on a HEB 300 leads to a support width of 55 mm. According to the oblong wholes, which have a length of 30 mm and allow a horizontal adjustment of the connector up to 15 mm in each direction, the minimum support width is 40 mm.

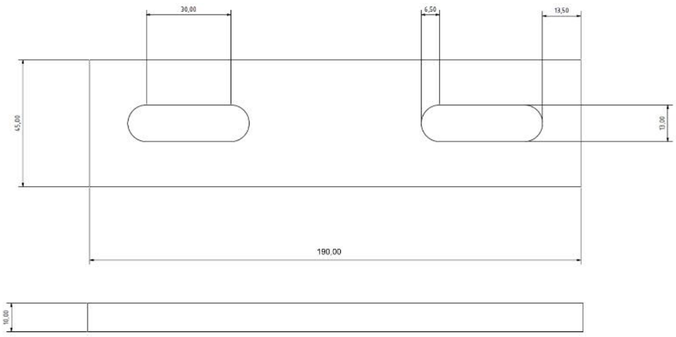


Figure 47 Drawing of the adapter profile

The rail, which ensures a vertical flexibility, is welded on the adapter profiles. The length of the rail, and therefore also the length of the *Smart Flashing Connector*, is 200 mm. This ensures a vertical flexibility of ±100 mm. Due to different width of sandwich panels (usually 1000 to 11000 mm) the flexibility is also important to use all kinds of sandwich panels. Figure 49 shows the system of adapter profiles and rail, which is connected to an HEB 300. Therefore, M12 x 30 bolts were used for the connection.

The anchor bolt, the threaded sleeve and the regular bolt were chosen to secure the fixation of an element with a height of 120 mm. Therefore, the clamping sheet should not exceed a certain height. To secure a “clamping way” of 5 mm the maximum height of the sheet was set to 23.50 mm. The design and the dimension of the sheet are shown in Figure 48. The Material used is a S320GD+Z275.

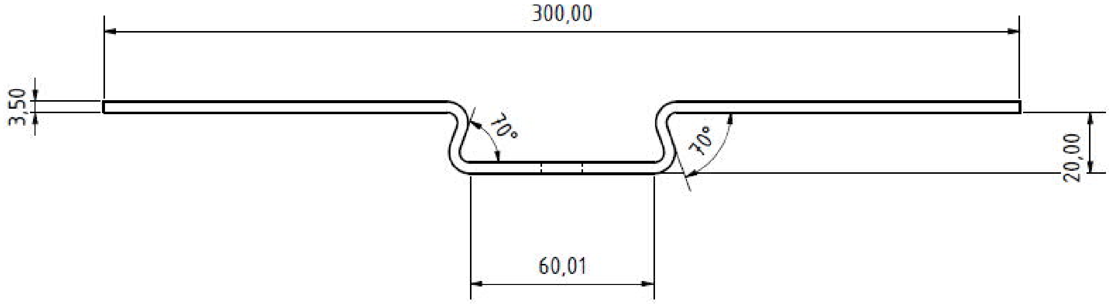
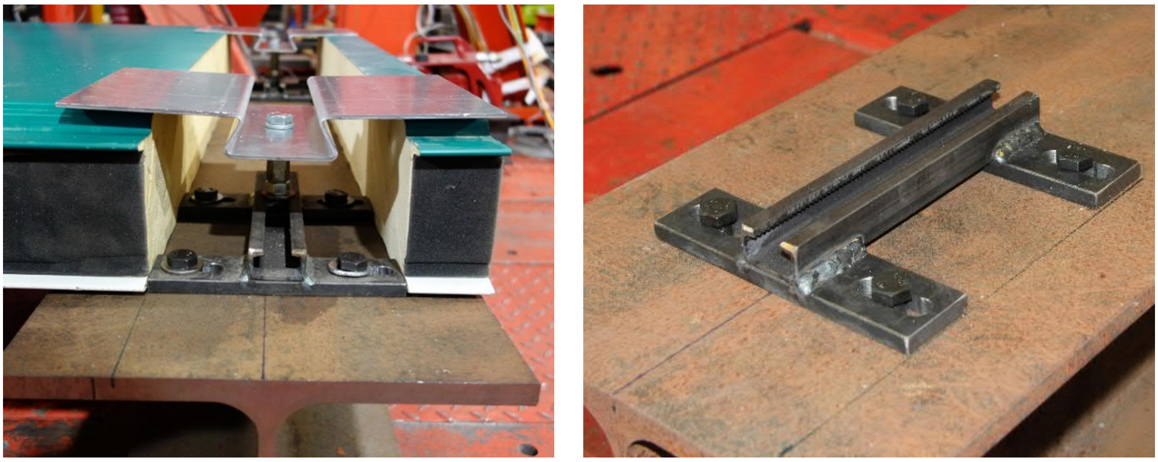


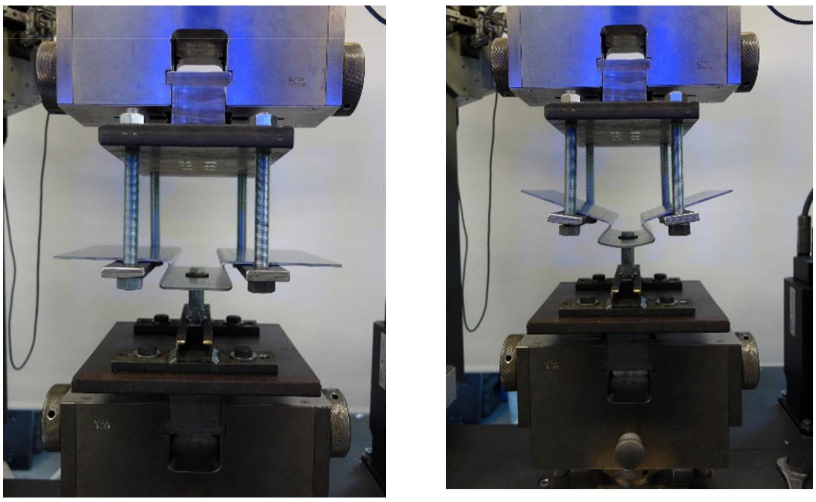
Figure 48 Design and dimension of clamping sheet



(a) SFC (b) Rail of SFC

Figure 49 Smart Flashing Connector

In the following, the testing of the Smart Flashing Connector is presented. Thereby, the Connector itself was tested. The system consisting of Smart Flashing Connector and panel was tested in D4.3 [12]. Due to thickness of the adapter profile of 10 mm, the thickness flange of the HEB 300 of 19 mm and the strength class of the M12 bolts of 8.8 it is unlikely that the connection to the substructure might be the weakest part of the connector. This is even the same for the connection of anchor bolt, threaded sleeve and the regular bolt. To ensure this, tensile test were done. The test set-up is shown in Figure 50. Thereby, the *Smart Flashing Connector* is fixed on a plate with high stiffness and the tensile load is initiated in the clamping sheet. However, the load is not introduced completely externally, as is the case in reality, but close to the flanges of the sheet metal. This is the more favourable case for the sheet metal and therefore the less favourable for the rest of the construction. In the probable case that a failure of the sheet occurs nevertheless, it can be assumed that in reality only the sheet becomes relevant for the design and static proof.



(a) Test Set Up (b) SFC under Tensile Load

Figure 50 Smart Flashing Connector – Tensile Test

The test results show that the failure occurs only in the clamping sheet. This confirms the presumption, that the sheet is relevant for design and static proof.

Figure 51 shows the Load-Displacement-Curve of the tensile tests. The average maximum load of 11.57 kN occurs with a displacement of 11.77 mm. In the first place, these results are sufficient and it can be expected, that the full-scale test will be sufficient as well. Furthermore, Table 22 shows the results of each test and the average of all tests.

The development and test results of the Smart Flashing Connector are satisfying. It can therefore be assumed that the full-scale tests will also lead to satisfying results. With the full-scale tests, the results must be examined not only with regard to the load-bearing behaviour of the *Smart Flashing Connector*, but also with regard to the behaviour of the sandwich panels. Further investigations took place within the scope of D4.3 [12].

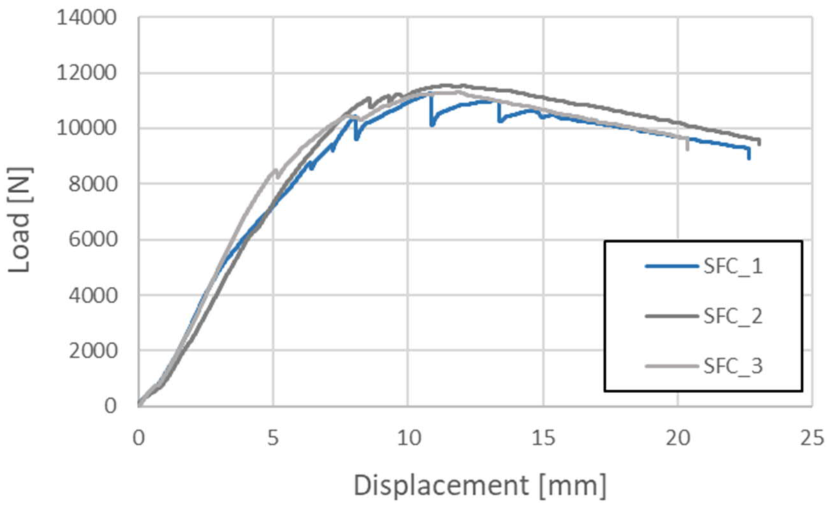


Figure 51 Load-Displacement-Diagram of tensile test

Table 22 Smart Flashing Connector test results

Specimen	**max F** [kN]	**Displacement** [mm]
SFC_1	12.50	12.16
SFC_2	10.86	11.25
SFC_3	11.35	11.90
Average	11.57	11.77

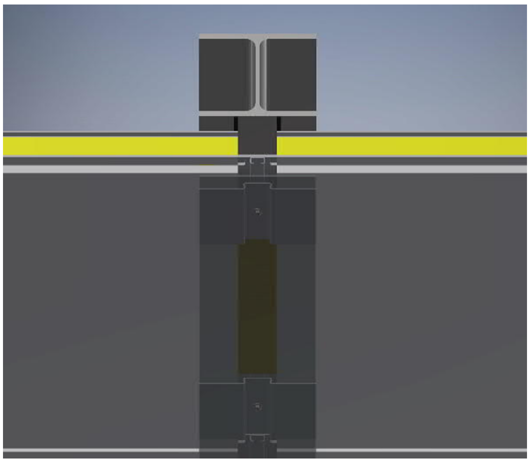
Conclusion

The design of the Smart Flashing Connector meets all the requirements that have been defined in advance. It offers maximum flexibility and easy handling at the same time. Thereby, the manufacturing and the installation process are suitable in terms of effort. Static tensile tests have also shown that the Smart Flashing Connector will probably be able to absorb sufficiently large forces to realize large spans of the sandwich panels. Static and structural component tests took place in D4.2 [11]. Thereby, the whole system, consisting of sandwich panel, SFC and substructure was tested.

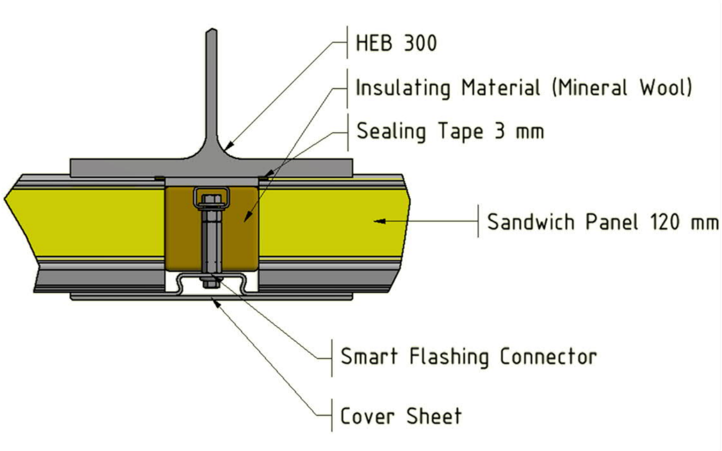
4.3 Production and testing of prototypes

Clamped solution with adapter profiles

The Smart Flashing Connector (SFC) was developed to enable the reuse of sandwich panels with a clamping solution. The SFC replaces the screws that are usually used to connect the sandwich panels to the substructure. Figure 52 shows a detailed view of the Smart Flashing Connector mounted on a HEB 300 including the clamped sandwich panels. The hollow space at the vertical joint between the panels is filled with thermal insulation and is covered by a cover plate.



(a) Sketch of installed panels on HEB 300



(b) Deatils of the connection

Figure 52 Smart Flashing Connector

First, the manufacturability of the prototype was evaluated. The prototype was manufactured at the RWTH Aachen. Great importance was attached to ordering the individual components in such a way that they can be adapted before assembly. The rail was ordered in sufficient length and the final cutting was then carried out at RWTH Aachen University. The adapter profiles were delivered as flat steel and the long holes were drilled afterwards. The clamping plate was manufactured by an external company, as this was the only way to ensure that the high quality of workmanship could be achieved. Once all the individual parts have been manufactured, the assembly is easy and can be done either in the factory or directly on the construction site.

Another important requirement is the easy assembly on the construction site. The current method of fastening sandwich panels to the substructure with screws is a very quick procedure without much effort. The Smart Flashing Connector should also avoid high efforts of installation due to be competitive to existing systems. To ensure that this is the case, the Smart Flashing Connector was first mounted on a substructure consisting of a HEB 300.

As expected, the Smart Flashing Connector is very easy to attach to the HEB 300. There are no unexpected difficulties or problems. Based on the first good experience with the installation, a prototype wall was built for the structural tests. Again, the attachment of the sandwich panel to the substructure worked as expected. Figure 53 shows the structure of the whole system consisting of the Smart Flashing Connector, substructure and sandwich panel.

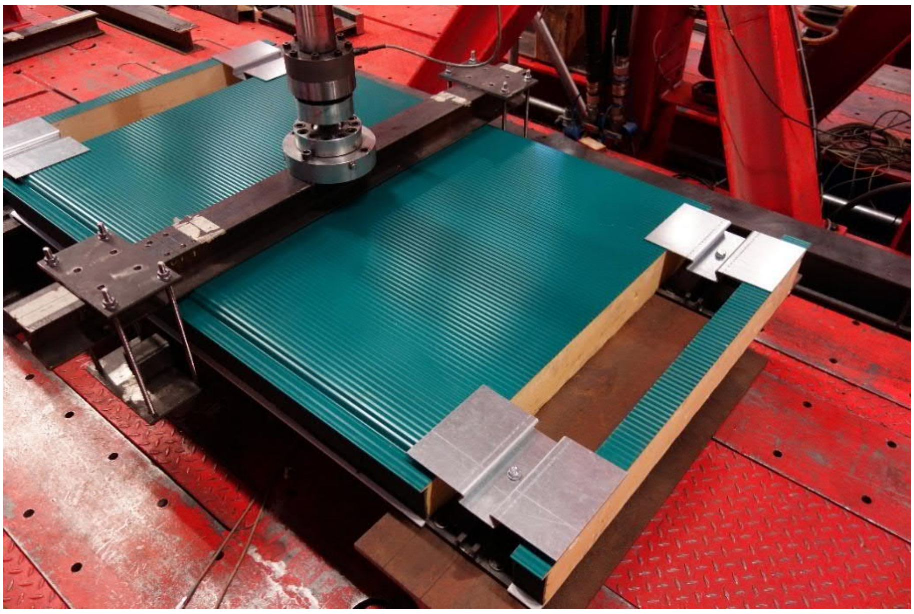


Figure 53 Prototype of clamped wall system

The theoretical considerations about the installation of the Smart Flashing Connector and the wall system, which took place in D4.2 [11], could be confirmed by the practical setup. It was particularly pleasing that no additional difficulties were encountered. The construction of the wall system therefore does not pose any difficulties for the usability on the market.

The evaluation of the load-bearing behaviour of the Smart Flashing Connector was carried out in these deliverables on a component test. A wind suction load was simulated, which acts on the sandwich panel and has to be absorbed by the Smart Flashing Connector. The panel is fixed horizontally and held by four Smart Flashing Connectors. These are each attached to the outer corners of the element. This means that two SFCs are installed per running meter for the joint that is created at the support. In this test, unlike the test in D4.2 [11], the SFCs are not symmetrically loaded. Since the wind load is simulated on only one element, this means for the SFC that only one flank of the clamping plate is loaded at a time. To ensure that the SFC remains stable throughout the test, the subsequent panels are simulated by small strips of the elements. The structure of the enclosure has already been described above. Below are detailed images of the SFC during and after the test. Figure 100 shows the deformation behaviour of the Smart Flashing Connector during and after the test.

During the test, the load-bearing behaviour was as initially expected. The loaded flank of the clamping plate is plastically deformed, while the other side, which is aligned with the panel strip, is loaded in compression and thus does not deform. The remaining part of the Smart Flashing Connector is hardly stressed by the arising forces and remains perpendicularly fixed to the substructure as expected. The load-deformation diagram is shown in Figure 101. The results of the tests are shown in Table 41.

The results show that the load bearing capacity of the Smart Flashing Connector is at a very satisfactory level. This means that it is possible to use the Smart Flashing Connector as a connecting element for reusable sandwich panel systems. The maximum loads are definitely comparable with conventional screw connections. A sample calculation has shown that a building to be erected in Niedersachsen, Germany is designed with wind suction loads of 0.81 kN/m². Taking into account the necessary safety factors, sandwich panels can be safely installed up to a span width of 4.8 m. This means that in some cases the maximum span width is not dependent on the Smart Flashing Connector but on the load bearing capacity of the sandwich elements. The joint created in the area of the Smart Flashing Connector has an influence on the heat transfer coefficient of the entire outer wall construction. Analogous to the classic, planar joints of sandwich constructions, the joint leads to an increase in the nominal value of the heat transfer coefficient. Regularly occurring thermal bridges must be taken into account as part of the heat transfer coefficient. Individual components can be neglected in numerical thermal insulation calculations according to EN ISO 6946, provided that their influence on the heat transfer coefficient is less than 3 %. Therefore, elements such as fasteners are often not taken into account in numerical investigations, as their effect on the thermal behaviour of the entire component is usually only marginal. According to EN ISO 14683, the influence of punctiform thermal bridges (as far as they result from the intersection of linear thermal bridges) can be neglected. Three-dimensional numerical FEM calculations (finite element method) according to EN ISO 10211 are used to determine the heat flows in the thermal influence area of the various constructions. Based on these calculations, the design values of the area-related heat transfer coefficients can be determined. Sections through the joint area insulated with mineral fibre and through the screw of the SFC are shown in Figure 54.

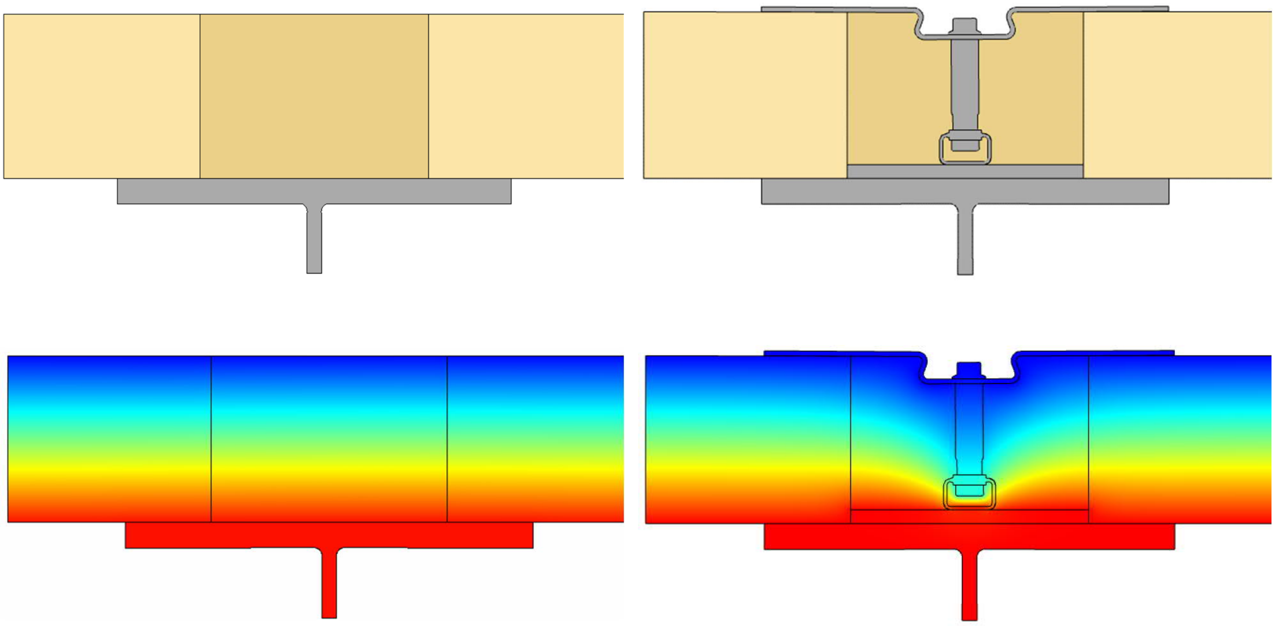


Figure 54 Thermal Performance of Smart Flashing Connector

The nominal value of the heat transfer coefficient of the sandwich elements is 0.197 W/(m²·K) with a 12 cm thick thermal insulation core. The Psi-value of the mineral fibre joint determined by FE simulation is Psi = 0.03 W/(m·K) and must be taken into account with a length of 0.8 m. The length corresponds to the clear dimension between two SFCs with a construction width of the sandwich elements of 1 m. The Chi value of the SFC is 0.05 W/K. One sandwich element is held by four SFCs. Thermally effective is the half of one SFC, which results in a calculated number of two SFC per sandwich element. With a maximum span width of 4.5 m, this results in the rated value of the heat transfer coefficient of U_d = 0.23 W/(m²·K).

Hybrid System

The manufacturability of the hybrid system was evaluated during assembly in the hotbox at the RWTH. In the following, the construction is described in the individual steps of the assembly. Figure 55 shows a sketch of the hybrid system.

Two test specimens in the dimensions of w=1.30 m and h=2.50 m were manufactured. These dimensions correspond to a sandwich element of the usual construction width of 1000 mm with two "edge pieces" to illustrate the longitudinal sandwich joint and in height to four of the selected liner tray profiles (600/100 mm). This represents for the sandwich panel the static system of a four-span beam with a span length of 600 mm.

The four liner tray profiles (600/100, length 1.30m each) are screwed onto a steel beam HEB 120 in order to ensure a setup as close to reality as possible.

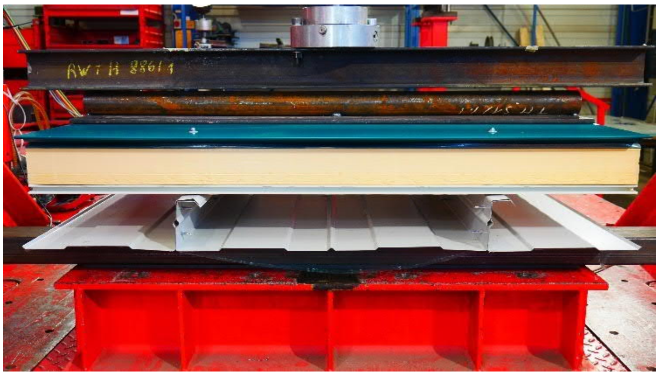
The cassette profiles are screwed together using self-drilling screws. The recommended maximum distance between them is 1000 mm. In the tests carried out, this distance is selected at 600 mm. This corresponds to three drilling screws per cassette web. The cassettes are filled with mineral wool (λMW=0.035 W/(mK)).

Figure 55 Sketch of hybrid system (left) and its installation from inside (middle) and outside (right)

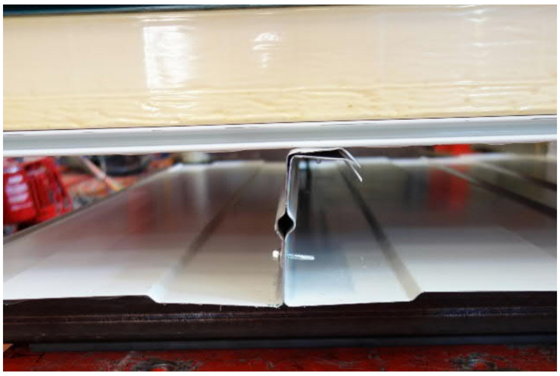
The sandwich panels are fixed to the webs of the liner trays. In case of direct fixation, the distance between the fasteners is limited to d≤200 mm. Therefore, the distance between the fasteners is set at 200 mm. The use of load distribution plates prevents the failure of the surface layer. Figure 55shows the front and back of the completed hybrid system

The test setup for investigating the load-bearing capacity of the end bearing is shown in Figure 56. Previous investigations have shown that the end support has a low load bearing capacity compared to the rest of the hybrid structure and must be investigated separately **Error! Reference source not found.**. The support to be investigated is installed on a fixed bearing and represents the end support of the actual construction. The second support in the test only describes the centre of the beam and is therefore fixed on a roller bearing. The load is introduced at a distance of 300 mm from the fixed bearing. This ensures that the majority (2/3) of the load is transferred to the end support.

The installed test specimen for the structural test series of the hybrid system is shown in the following. The load is applied via the sandwich element.



(a) Test Setup



(b) Detail of Liner Tray Web

Figure 56 Hybrid System Specimen

The failure of the test specimen is shown in Figure 102. The expected load-bearing-behaviour of the bars was clearly shown in the test. After reaching their maximum load-bearing capacity, the webs start to buckle. This failure should be significantly delayed or eliminated by the reinforcements in the hybrid FRP system.The load-deformation diagram is shown in Figure 103. It can be seen that a linear progression can be seen until the specimen fails. Table 42 shows the individual results of the five tests performed. It can be seen that the scattering is extremely small, both in terms of load and displacement. Since the load is distributed differently over the two supports, this must be taken into account when determining the maximum load capacity. The load arrives 2/3 in the end support. Furthermore, in the actual installation situation only the outermost web is loaded in compression, so that here too the load distributed over each web must be considered individually. To determine the design value of the heat transfer coefficient as a measure of thermal quality, it was first checked by means of numerical methods whether the values determined with a simplified manual calculation method were sufficiently accurate. For a liner tray wall with a thickness of 90 mm and insulation of WLS 035 and a sandwich element with a thickness of 60 mm with WLS 025 (joint type I), a finite element model of the hybrid element was created and then the exact heat transfer coefficient was determined. The numerically determined design heat transfer coefficient is $U_{HYB,d}$= 0.283 W/(m²·K). For comparison between manual calculation and FEM calculation, all steel profile sheet thicknesses are assumed to be 0.75 mm.

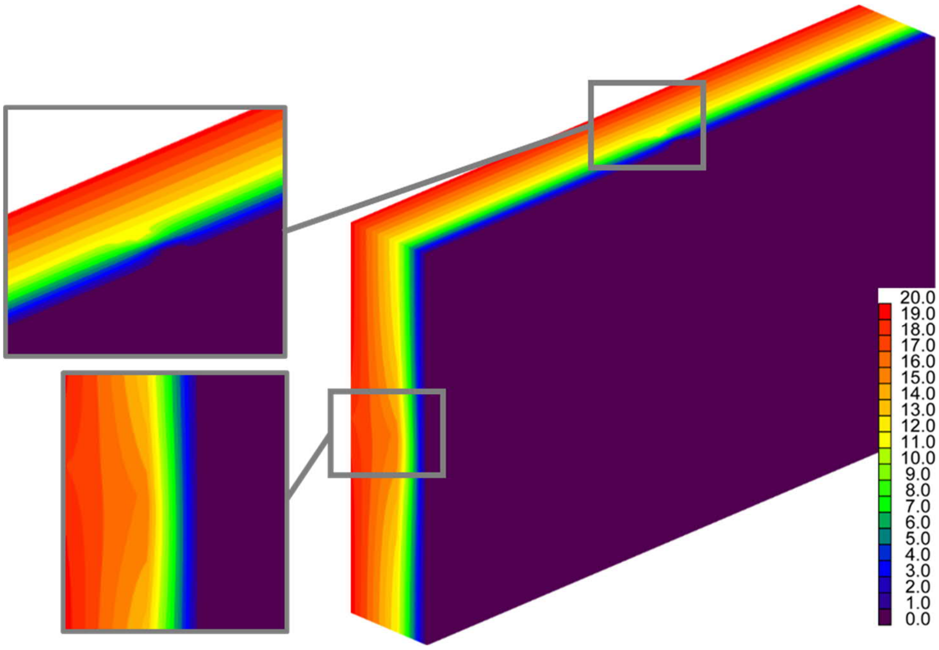


Figure 57 Temperature distribution of the hybrid element

For the existing liner tray wall, a heat transfer coefficient of $U_{LT,d}$ = 0.727 W/(m²·K) can be assumed based on the separating strip variant. From this a thermal resistance of the liner tray wall of R_{LT} = 1.206 m²·K/W can be determined. With the help of EN 14509 [61] a heat transfer coefficient of $U_{SP,d}$ = 0.431 W/(m²·K) (when using a joint coefficient f_{joint} = 0.083) can be determined for the sandwich panel. This corresponds to a thermal resistance of the sandwich element including the joint of R_{SE} = 2.148 m²·K/W. Based on the thermal approach of the series connection of the thermal resistances, the hand calculation method yields a thermal resistance of the hybrid element of R_{HYB} = 3.354 m²·K/W. From this, in conjunction with the heat transfer resistances, a rated value of the thermal transmittance of $U_{HYB,d}$ = 0.284 W/(m²·K) can be determined. The comparison of the numerically determined with the simplified calculated heat transfer coefficient shows that only very small deviations occur. Therefore, the manual calculation method is used in the following to assess the thermal quality since the achievable heat transfer coefficients of the different hybrid elements.

Due to their modular construction, liner tray profile facades are ideally suited for reuse combined with energy-efficient refurbishment without complete demolition. If the existing outer shell is replaced by standard sandwich panels, the facade is referred to as a hybrid facade. When planning hybrid facades with vertically installed sandwich panels, it must be taken into account that if the sandwich panelss are not visibly fixed in the longitudinal joints, the distance of the lateral support of the narrow liner tray flanges, which is permissible according to the general building authority approvals of many liner tray profiles installed in the existing building, is exceeded. In addition, the load case temperature difference at the sandwich panel must be considered when designing hybrid facades. Previous design approaches for this load case lead to a clear overestimation of the constraining forces occurring in hybrid facades, which means that the static proof of the liner tray profiles often cannot be provided. Suitable approaches for recording the constraining forces actually occurring in hybrid facades due to temperature differences at the sandwich element have been provided within the framework of this research project. Due to the small sheet thicknesses of the liner tray profiles, the installation of the sandwich elements on the liner tray profiles is prone to errors. It should therefore always be carried out very carefully. The new construction of hybrid facades is also possible from a static point of view.

Due to the complexity of the component "hybrid element", it seems to make sense for further research approaches not only to examine the combination of several components, but also to examine fundamental aspects of the isolated individual components - in this case sandwich elements or liner tray profiles - in detail.

The direct fastening of sandwich elements to liner tray profiles with conventional sandwich fasteners is technically possible, but is not yet covered by the general building authority approvals for sandwich fasteners, because in this case the fastening is carried out on two narrow liner tray belts per crossing point. Consequently, the general building authority approvals of the sandwich fasteners should be extended for fastening to two components.

In order to consider possible aspects of the application, the façade of the testing laboratory of the Institute for Steel and Metal Lightweight Construction at the RWTH, consisting of cassette profiles and trapezoidal profiles, was partially replaced by a sandwich panel Relevant points in this case result from the circumstances which would arise in contrast to an assembly in a new building.

Dismantling usually involves few complications, as the trapezoidal profiles are fastened with self-drilling screws and rivets and can therefore be removed almost non-destructively by unscrewing/drilling the fasteners. Attention should be paid to connections on roofs, corners, window reveals and similar.

For the installation of the sandwich panel various complications have to be considered, which can be caused by the existing situation. In order to ensure the impermeability of the building envelope, any old dirt from insulation, weather and other circumstances on the cassette profiles must be removed to allow the sandwich panels to be fitted. In the case of trapezoidal profiles, this occurs when the insulation material slips into the profile. In addition, when positioning the new elements, it must be taken into account not to use the same screw pattern. If the fasteners are placed in the area of existing drill holes, problems in the exact positioning of the element can occur because the fasteners "slip" into old drill holes. If the above-mentioned aspects are taken into account during installation, the sandwich panel can be easily attached to existing structures. Figure 58 shows the existing wall and the process of installing the new sandwich panel, up to the finished building situation.

Figure 58 Installation of hybrid system

Hybrid System with FRP Profiles

The experimental setup of the hybrid system with the first version of the FRP V1 reinforcement is shown in Figure 59. The resource-saving punctual attachment of the FRP profile is clearly visible. The easy and handy installation of the reinforcement makes precise attachment possible. Figure 104 shows the failure of the specimen after the test. It can be clearly seen that the FRP profile stabilizes the lower part of the webs. No deformations are visible up to the area of the bead. Above the bead area, however, the expected buckling sets in. Due to the behaviour of the test specimen observed in the test, the reinforcement can be interpreted as a success confirmed by the recorded data.

Figure 59 Reinforcement with FRP profiles V1 test setup (left) and detail (right)

The load-deformation diagram is shown in Figure 105. A linear progression can be seen until the specimen fails. Table 43 shows the individual results of the five tests performed with extremely small scattering (both in load and displacement) and the increase in the load capacity of the reinforcement. The FRP profile achieves an increase in load-bearing capacity of 31.7%, which is remarkable since FRP profiles are a reinforcement with low material and installation costs. The test setup of the second variant of the reinforcement of the FRP profile V2 is the same as previous series (see Figure 60), but the FRP profile extends over the entire height of the web.

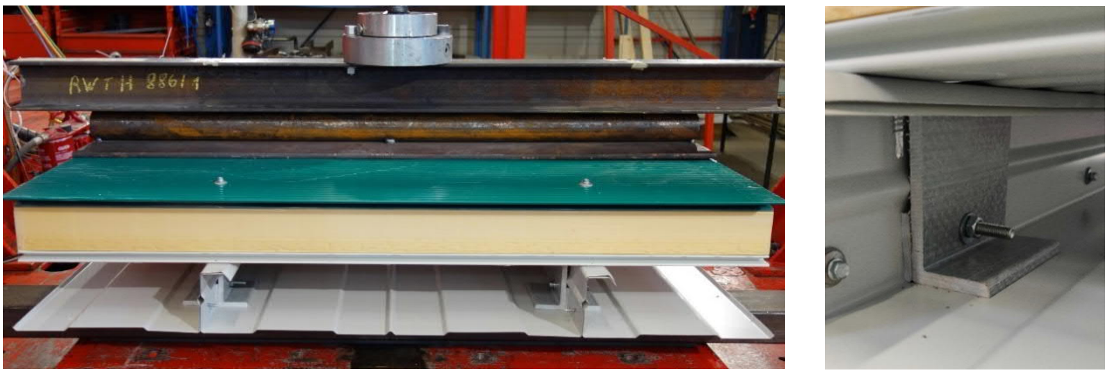


Figure 60 Reinforcement with FRP profiles V2 test setup (left) and detail (right)

Figure 106 shows the failure of the specimens reinforced with FRP profile V2. This failure is different from the two types of failure of the previous test series, because it was not determined by buckling of the web. After the test, the web including the FRP profiles did not show any significant deformations or other characteristics indicating failure or overstressing of the web. However, the sandwich panel placed on the liner tray is stressed to such an extent that shear fracture of the core material occurs between load introduction and end support. It shows the typical failure mode of a sandwich panel tested for shear for the approval according to EN 14509 [61]. The shear fracture develops across the specimen from the load introduction to the support and leads to delamination of the cover layers similar to the failure reported in D7.1b [19] but in the transverse direction of the panel. The average shear strength determined in the tests is here 0.158 MPa and its declared design value is 0.13 MPa. The results of all five tests are significantly higher than the declared shear strength value with very low scattering (see Figure 107). Therefore, the design may be based on the shear strength of the sandwich panel from the approvals.

Table 44 shows the individual results of the tests. The results of the tests on the end support of the hybrid system consisting of liner tray and sandwich panel are very successful. In the first series of tests, the reference values of the load-bearing capacity of the hybrid system at the final support were determined. The second and third series of tests were carried out with components of the hybrid system additionally reinforced with FRP profiles. The first variant of the FRP Profile V1 consisted of angles that reinforced the lower half of the web to reduce the buckling length. In the second variant V2, the FRP profiles extended over the entire height of the webs. The V2 reinforcement resulted in a 32% increase in the load-bearing capacity and the V2 reinforcement even resulted in an increase of 111% with a new failure mode in the sandwich panel. Therefore, the design based on the declared shear strength from the approvals of the sandwich panels can be possible.

Over-cladding

A prototype building envelope was constructed with the developed over-cladding system. First six profiles were mounted on the vertically laid south wall, then six profiles on the horizontally laid west wall. Special profiles were used to attach the sidings. After the profiles were fixed, the sidings could be mounted. Two lifting platforms and a vacuum suction cup were used for this purpose. Finally, angle profiles were attached to the west-south corner of the building. This completed the construction project. In principle, the amount of work required to apply the over-cladding system is relatively low. Since the profiles used as the substructure for the sidings are light, they are also easy to handle. It is only necessary to ensure that the substructure is absolutely straight. To ensure this, the use of a water trolley is sufficient. The profiles are fixed in the sandwich panel by the one-sided fixing. The screw spacing was 300 mm. This corresponds to the geometry of the specimens from the tests in Deliverable 4.2. The attachment of the profiles to the sandwich panel is shown in Figure 61.

Figure 61 Installation of profiles with one-sided fixation

4.4 Assessment of improvement of the overall building performance

This section presents a theoretical study on new hybrid solutions for claddings regarding their contribution to the improvement of the overall performance of buildings design from reclaimed elements.

The purpose of the study was to compare indicators such as environmental, economic or energy efficiency of rehabilitated envelope solutions, quantifying the savings achievable by retrofitting common envelope systems used in single-storey steel-framed buildings (SSBs). For the assessment were carried out and compared several case-scenarios. The solutions presented in the theoretical study-cases were rehabilitated in order to fulfil the modern standards of thermal performance:

- **Built-up wall system** (see Figure 62(a)): the built-up wall system is consisting of an external and an internal trapezoidal steel sheet; both fastened to the side rails, having insulation in-between the side rails. An additional layer of vapour barrier foil stands enclosed by the internal steel sheet and the thermal insulation. In this study case a 0.5 mm thick steel sheet (S250 GD+Z) was considered for both internal and external trapezoidal steel sheets, while the thermal insulation was a 100 mm thick mineral wool (density: 20 kg/m3).

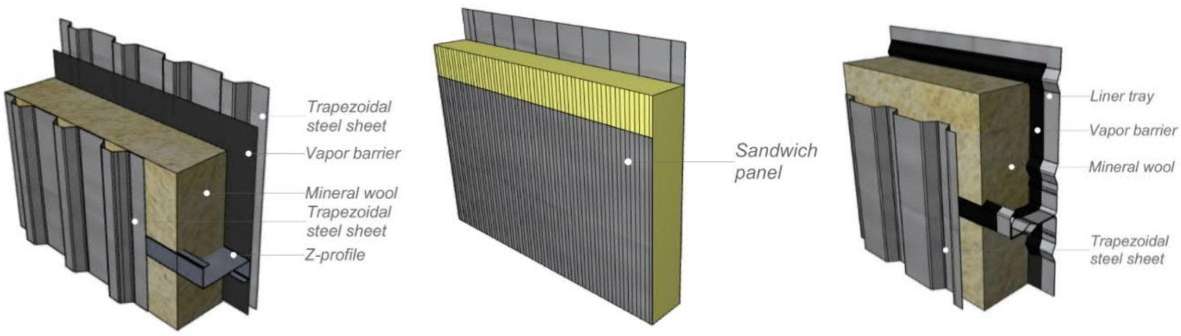


Figure 62. Built-up wall system (left), sandwich panels wall system (middle) and liner tray wall system (right)

- **Sandwich panels wall system** (Figure 62 (b)): the envelope system resides in sandwich panels (an insulating foam-core with two steel sheets skins) attached vertical to the thin-walled steel side rails (Z-steel profiles) or horizontally to the main structure. The sandwich panel weighted in the study case was a PUR (polyurethane insulation) based sandwich panel (density: 30 kg/m^3), with a 60 mm insulation core and 0.5 mm steel sheets skin (S280 GD).
- **Liner tray wall system** (Figure 62(c)): a built-up wall system consisting in an external trapezoidal steel sheet installed on the flanges of a liner tray attached to the load bearing structure. An encased insulation core layer is used, and a vapour barrier foil stands between the load bearing structure and the thermal insulation. For the study it was considered a 0.5 mm thick trapezoidal steel sheet with 20 mm high rib (S250 GD+Z), with 100 mm mineral wool insulation (density: 100 kg/m^3) encased in a 0.75 mm thick liner tray (S320GD+Z).
- **Built-up roof system I** (Figure 63): a built-up roof system consisting of an external and an internal steel sheet both fastened to the Z-purlins, having insulation in-between the purlins. Additional layer of vapour barrier foil stands enclosed by the internal steel sheet and the

thermal insulation. In this study case a 0.4 mm thick trapezoidal steel sheet with a 20 mm high rib (S250 GD+Z) was considered for the internal face, a 0.5 mm thick trapezoidal steel sheet with a 45 mm high rib (S250 GD+Z) for the external one, while the thermal insulation was a 100 mm of mineral wool (density: 20 kg/m^3). The purlins counted in the study were 150/2.5 mm Z-steel profile (S350 GD+Z).

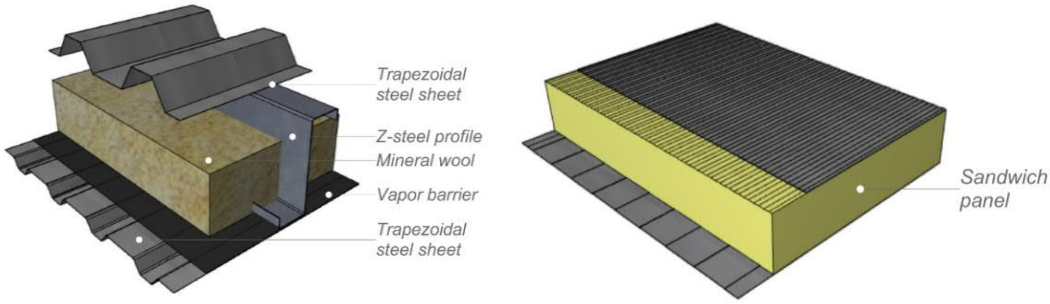


Figure 63. Built-up roof system I (left) and sandwich panel roof system (right)

- **Sandwich panel roof system** (Figure 63(b)): the envelope roof system resides in sandwich panels attached to the thin-walled steel purlins. The sandwich panel considered in the case study was an 80 mm PUR insulation sandwich panel (density: 30 kg/m^3), with a 0.5 mm steel sheet (S280 GD) for the internal steel sheet and a 0.6 mm thick steel sheet (S280 GD) for the external one, while the purlins were 150/2.5 mm Z-steel profile (S350 GD+Z).
- **Built-up roof system II** (Figure 64(a)): built-up roof system consisting of two-layers of thermal insulation installed over a liner tray fastened to the thin-walled steel purlins. Additional layer of vapour barrier foil stands between the liner tray and first layer of insulation. The outer skin is a trapezoidal steel sheet. For the case study it was taken into consideration a 0.75 mm thick liner tray with a 70 mm height (S320 GD) and a first layer of 70 mm rockwool insulation (density: 100 kg/m^3). A 50 mm high steel spacers stand between the two layers of thermal insulation. The second layer of insulation consists of 50 mm rockwool insulation, while the external steel sheet considered was a 0.5 mm thick trapezoidal steel sheet with a 20 mm high rib (S250 GD+Z). The purlins counted in the study were 150/2.5 mm Z-steel profiles (S350 GD+Z).

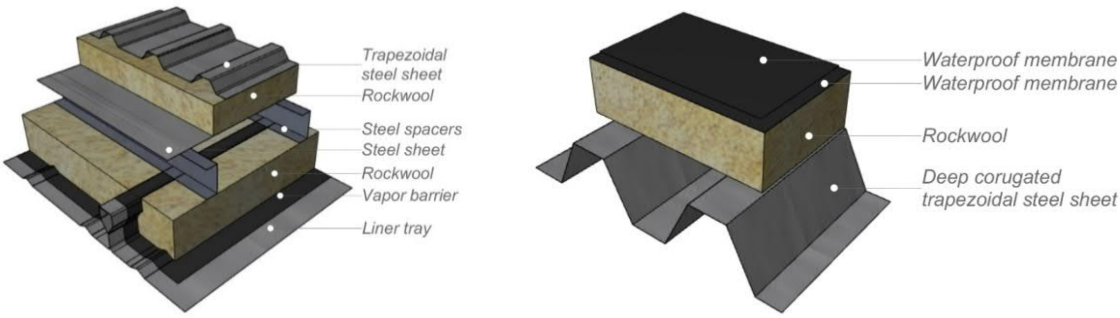


Figure 64. Built-up roof system II (left) and deep corrugated trapezoidal roof system (right)

- **Deep corrugated trapezoidal roof system** (Figure 64 (b)): The roof system consists of trapezoidal steel sheeting, vapour barrier, insulation layer and hydro insulation membrane. The deep corrugated trapezoidal roof system is connected to the main frame with screws or shooting nails. In this study case a 0.8 mm thick high-rib steel sheet (with a rib height of

135 mm) was considered, on top of which stands 120 mm thick rockwool (density: 100 kg/m^3). The outer skin consists of two-layer single ply membrane (3 mm).

Rehabilitated solutions for walls and roofs of the envelopes systems presented above are:

- **Case 1:** Built-up wall system (Figure 65(a)). Option (a) The external steel sheet is removed from the existing envelope system and a new 80 mm thick sandwich panel is installed over the remaining original built-up wall system. The sandwich panel is a PUR insulation-based sandwich panel (80mm, density: 30 kg/m^3), with a 0.4 mm thick steel sheet (S280 GD+Z) skins. Option (b) Over the existing envelope system is attached a sandwich panel. The existing trapezoidal steel sheet(*) is not removed. The sandwich panel has the same characteristics as in case 1(a).

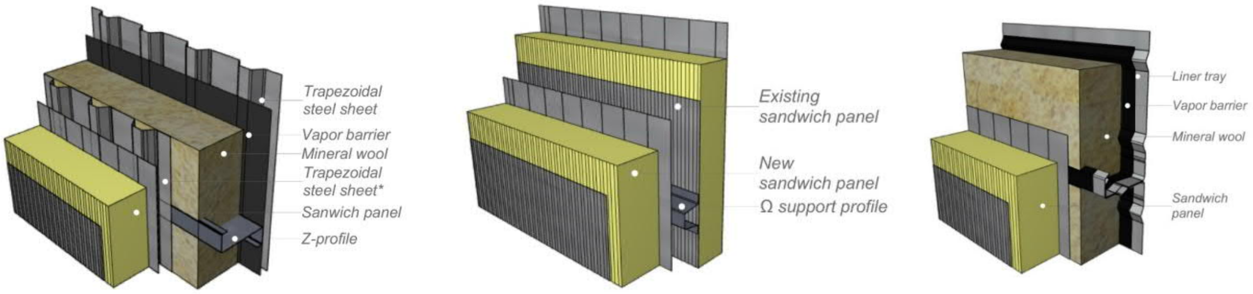


Figure 65. Rehabilitated built-up wall system (left), sandwich panels (middle) and liner tray wall system (right)

- **Case 2:** Sandwich panels wall system (Figure 65(b)). Over the existing envelope system are installed 50 mm height Ω (35/2.5 mm) steel rails (S235) and an 80 mm PUR sandwich panel (density: 30 kg/m^3), with a 0.5 mm thick steel sheet (S280 GD+Z) skins.
- **Case 3:** Liner tray wall system Figure 65(c). the outer trapezoidal steel sheet is removed from the existing wall envelope system and a sandwich panel is installed over the remaining original built-up wall system. The sandwich panel is an 80 mm PUR insulation-based sandwich panel (density: 30 kg/m^3), with a 0.5 mm thick steel sheet (S280 GD+Z) skins.
- **Case 4:** Built-up Roof System I (Figure 66(a)). Option a) The external steel sheet is removed from the existing envelope system and a sandwich panel is installed over the remaining original built-up roof system. The sandwich panel is a PUR insulation-based sandwich panel (80mm, density: 30 kg/m^3), with a 0.4 mm thick steel sheet (S280 GD) skins. Option b) Over the existing envelope system is attached a sandwich panel. The sandwich panel has the same characteristics as in case 4.a.
- **Case 5:** Sandwich panel roof system (Figure 66(b)): over the existing envelope system are installed 50 mm height Ω (35/2.5 mm) metal rails (S235) and an 80 mm PUR sandwich panel (density: 30 kg/m^3), with a 0.5 mm thick steel sheet (S280 GD) skins.
- **Case 6:** Built-up Roof System II (Figure 67(a)). The external steel sheet is removed from the existing roof system and another layer of 100 mm thick rockwool is installed to the remaining original built-up roof system. On top of the rockwool insulation are attached two layers of hydro insulation membrane (1.5 mm thick single-ply membrane).
- **Case 7:** Deep Corrugated Trapezoidal Roof System (Figure 67(b)). the external layers of hydro insulating membrane are removed from the existing roof system and another layer of 100 mm thick rockwool is installed to the remaining original built-up roof system. On top of the rockwool insulation are attached two layers of hydro insulation membrane (1.5 mm thick single-ply membrane).

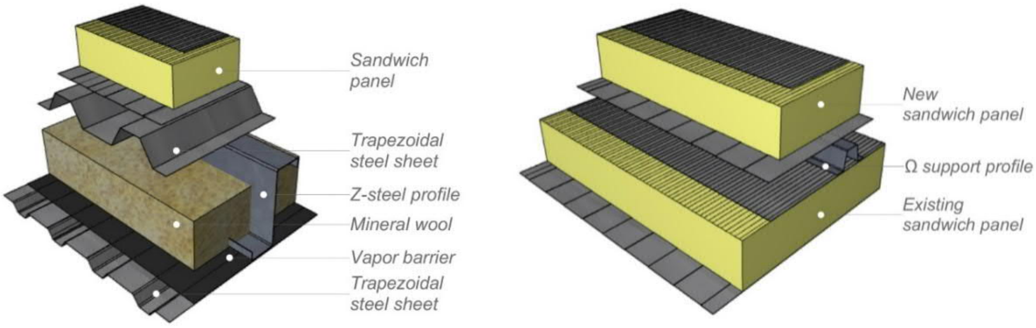


Figure 66. Rehabilitated built-up roof system I (left) and sandwich panels-based roof system (right)

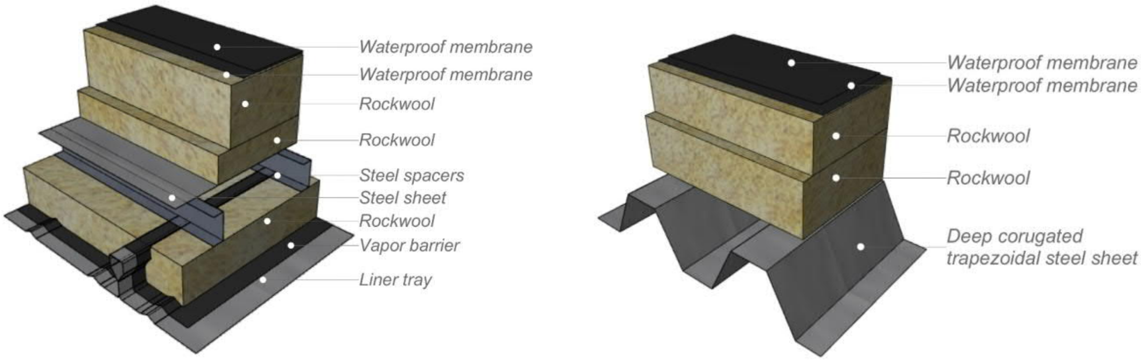


Figure 67. Rehabilitated built-up roof system II (left) and deep corrugated trapezoidal roof system (right)

Energy efficiency assessment

The envelope systems have been compared using the dedicated online Ubakus software [75]. The external and internal temperatures were considered at the values of -5°C and 20°C respectively. Also, a similar heat transfer coefficient for all systems after the rehabilitation process was targeted. Table 23 shows the final values for each system before and after the rehabilitation process.

Table 23: Overall U-values for systems

Solution	**Envelope system**	**U -initial-** [W/ m²K]	**U -upgrade-** [W/ m²K]
Case 1a	Built-up wall system (option A)	0.303	0.155
Case 1b	Built-up wall system (option B)	0.303	0.155
Case 2	Sandwich panel wall system	0.360	0.156
Case 3	Liner tray wall system	0.300	0.150
Case 4a	Built-up roof system 1 (option A)	0.306	0.155
Case 4b	Built-up roof system 1 (option B)	0.305	0.155
Case 5	Sandwich panel roof system	0.276	0.144
Case 6	Built-up roof system 2	0.279	0.155
Case 7	Deep corrugated trapezoidal roof system	0.279	0.155

To evaluate the energy consumption, an industrial hall model 10 meters by 30 meters, with no openings has been considered. The simulation was carried out using the built-in Energy Evaluation Design tool of Graphisoft Archicad 21 [76]. Considering the resulted thermal coefficient values, two cases have been considered for the energy evaluation: built-up wall and roof system and sandwich panel wall and roof system.

Environmental benefits

The Life Cycle Assessment (LCA) has been calculated using openLCA software [77] together with Ecoinvent 3.6 database [78]. The evaluation of the environmental impact follows the rules of ISO 14044 [79], EN 15804 [80] and EN 15978 [74]. The benefits beyond the system boundary were reported separately, as claimed by CEN/TC 350 methodology [80] for the approach of accounting of recycling in LCA. The indicator for the environmental performance of the rehabilitated solutions was considered Global warming potential (GWP 100).

Assessed scenarios for the environmental impact

The declared unit is 1m^2 of rehabilitated envelope solution; the averaging was computed based on an envelope of a 30 x 10 m industrial hall (426.45 m^2 of wall envelope and 357.49 m^2 of roof envelope). In this study the end-of-life scenario for each one of the seven cases studied involved deconstruction/dismantling of the materials which constituted the rehabilitation solutions previously installed. Table 24 shows the end-of-life scenarios considered in the study case for each component of rehabilitation solutions analysed.

Table 24: End-of-life scenarios for products used in envelopes rehabilitation [20]

Component	End-of-life scenario		
	Reuse	Recycle	Landfill
Sandwich panels	90%	7%	3%
Metal rails (spacers), screws	0%	96%	4%
Steel sheet	0%	89%	11%
Rockwool	0%	0%	100%
Hydro insulation membrane	0%	0%	100%

Life Cycle Assessment results

Figure 68 presents the total LCA results of the assessed scenarios. The LCA savings are reflected as negative values. According to the results, smallest environmental impact is shown by the case when on a built-up wall system is installed a new sandwich panel (34.37 kg CO_2 e/m^2 – case 1b), without removing any other components from the existing envelope. The highest rate of emissions (37.59 kg CO_2 e/m^2 – case 2) is registered when on an existing envelope consisting in sandwich panels are installed metal rails (spacers) and an additional layer of sandwich panels.

Regarding the benefits (reflected in the assessment as negative values) calculated in Module D, the highest potential benefits appear in cases 1a and 3 (33.82 kg CO_2 e/m^2), due to the fact that in these case scenarios, along with the reuse of the sandwich panels, the rehabilitation solution requires the dismantling of an existing steel sheet which is recycled.

The emissions of scenarios which include the rehabilitation of roof envelope systems show the smallest environmental impact by the built-up wall system II case. Despite the additional workload of this case scenario, reflected in the construction stage emissions, the total LCA results (28.38 kg CO_2 e/m^2 – case 6) are the smallest among the other rehabilitation solutions for roofs, in behalf of the relative small environmental impact in the production stage (23.36 kg CO_2 e/m^2) of the Case 6's components, in comparison with the construction materials integrated by the other case scenarios (31.05-33.80 kg CO_2 e/m^2).

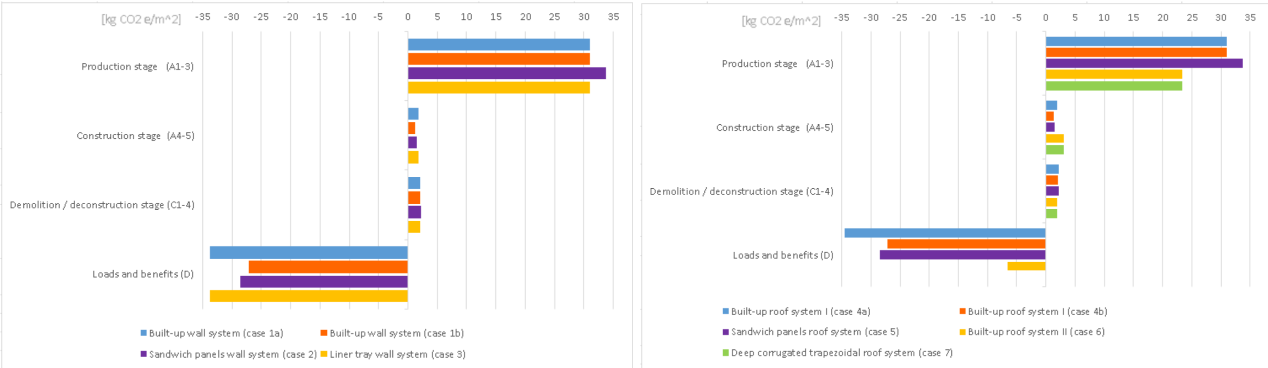


Figure 68. LCA results of the rehabilitated wall systems (left)
and rehabilitated roof systems (right), including loads and benefits beyond the system boundary

The highest potential benefits of rehabilitated roof case scenarios, calculated in Module D, analogous with the benefits of retrofit wall solutions, appears in case 4a (34.47 kg CO_2 e/m^2), due to the fact that, along with the reuse of the sandwich panels, the rehabilitation solution requires the dismantling of an existing steel sheet which is recycled and recorded as a benefit for the environment. On the opposite side is registered Case 7 with no potential benefits figured in Module D, as a result of generating 100% waste materials in the end-of-life.

Economic assessment

The calculation of economic indicators is based on the same scenarios and modules as in the LCA analysis, referring to envelope rehabilitation solutions, to which were associated time and financial costs. The assessment of the economic performance of studied cases follows the rules described in EN 16627 [90].

Assessed scenarios of the economic impact

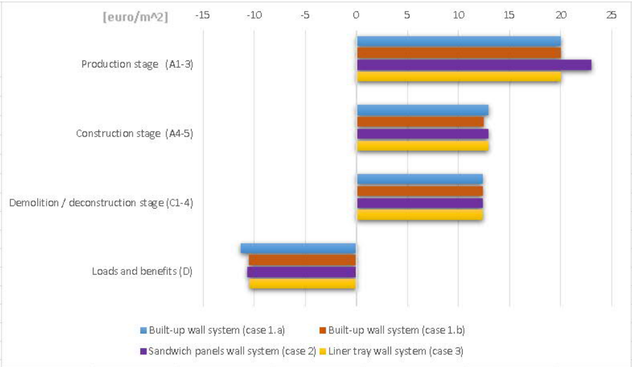
Recovered materials and recycled steel scrap can generate earnings as benefits and savings. Potential cost savings includes revenues for recycled steel (earnings from the sold steel scrap) and revenues from the sold sandwich panels. The returns considered in case of the sold steel scrap were of 180 euro/ton, while the gains from the sold sandwich panels were calculated at a value of 11.5 euro/m^2.

Life Cycle Costs results of the assessed cases

The results of the life cycle cost assessment show that the highest LCC (modules A-C) is shown by Case 2 - the Sandwich panel wall system rehabilitation (48.34 €/m^2) and by Case 7 - the Deep corrugated trapezoidal roof system rehabilitation (61.30 €/m^2).

The lowest LCC for rehabilitated wall systems (44.84 €/m^2) is registered by the cases 1.b (Built-up wall system) when the external steel sheet of the existent envelope it is not removed before installing the new sandwich panel, avoiding as such additional workload. In case of rehabilitated roof systems, the lowest LCC (49.54 €/m^2) is shown in Case 4.b (Built-up Roof System I).

Comparative LCC results of each case scenario are shown in Figure 69. When considering the loads and benefits from Module D only, the highest savings (11,31 euro/m^2 – case 1a and 4a) come when sandwich panels are deconstructed and sold for a future reuse in the end-of-life, along with the earnings gained from the sold steel scrap resulted from the recycling of steel sheets.



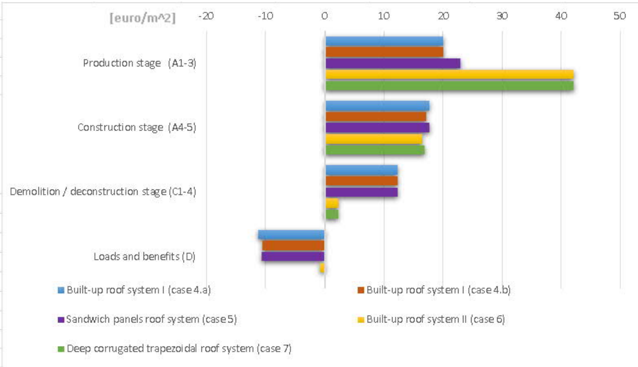


Figure 69. LCC results of the rehabilitated envelope wall systems (left) and rehabilitated envelope roof systems (right), including potential savings

The need to update building's envelope to current standards of thermal performance appears more and more often lately. Consequently, the building envelope needs hybrid elements, which allow an easy adaption to new requirements, an effortless dismantling and, by any means, to ensure a future possible reuse of the components and recycling of the materials. The present assessment considered seven study-cases, where rehabilitation solution to classic envelope systems for industrial facilities were analysed in order to approach energy efficiency, environmental impact and costs.

As the results showed, the environmental impact in construction and de-construction / demolition stages was negligible in comparison with the production stage, while in the case of economic impact, costs in construction and de-construction / demolition stages were as high as the costs in the production stage of even higher. Although the rehabilitation solutions are difficult to reuse in the very same layer stratification as presented in this study case (due to perforations occurred through cladding fixing), these layers could be reused for another life cycle as interior layers in an envelope system, allowing to integrate the existing claddings in the concept of circular economy.

5. Environmental and economic benefits of reuse (WP5)

5.1 Environmental assessment

This section presents a methodology to declare environmental benefits of reused elements and on the overview of the existing approaches to account for reuse and recycling. The complete results are presented in the report Deliverable D5.1 [14] and cover the following issues:

- Justification for the use of a Module D (EN 15978 [74] and EN 15804 [80]) approach to account steel for future reuse, in recognition of the need for longer term resource efficiency within the EU;
- Implementation of the calculated impacts in the legislation and certification systems.

Introduction

The European steel sector has played an important role in the development of life cycle assessment (LCA) methods and standards over many years. Lifecycle inventory (LCI) data, published by steel industry is based on the production of steel from iron ore and steel scrap. Steel inventory covers material mining and manufacture but also includes benefits and loads of recycling steel from products at the end of their life. In the same time, after intended life, reusability extends the steel life with less impacts compared to steel recovery through melting process. Several studies shown that a design approach featuring reused steel allows for 30% savings in energy and CO_2 reduction with respect to a new one. Therefore, the following initiatives were reviewed and summarized under this task:

- EU's Resource efficiency opportunities in building sector COM(2014) 445 [81]
- EU action plan for the Circular Economy COM(2015) 614 [82]
- Product environmental footprint (PEF) [83]
- ISO TC59/SC17: Sustainability in buildings and civil engineering works [84]
- CEN TC 350: Sustainability of construction works [74][80]
- World Resources Institute (WRI)/ World Business Council for Sustainable Development (WBCSD): The Greenhouse Gas Protocol (GHG Protocol) [85]
- PAS & GHG Protocol: Specification for the assessment of the life cycle greenhouse gas emissions [86]
- ILCD: The European Commission's International Reference Life Cycle Data System Handbook [87]
- Ellen MacArthur MCI methodology [88]
- McDonough C2C material reutilization approach [89]

The challenge of quantifying and declaring the environmental benefits of reusing and recycling structural steel is a controversial and contested subject within the LCA community. At the heart of this methodological debate is the incompatibility between different product life cycles and their scope of assessment. Steel (as a material) theoretically has an infinite life cycle, through multiple recycling loops, whereas building assessments are generally limited in scope, to the predicted design life of the building. Structural steel (as a product) also has the potential to be reused over several building life cycles. This yields some methodological challenges on which there is a lack of consensus; most notably, on how the initial and long-term environmental burdens and benefits are quantified and allocated over time. The calculation of environmental impacts of reuse should reflect the fact that the functional unit is (a) completely reused and its lifecycle is extended, or (b) its components are reused or designed for the future reuse. Since most of the lifecycle assessment methods do not take into account the extended durability of the product, the former situation is commonly solved by the assessment of each use cycle separately either as actual or average impact per use cycle.

Reuse is an alternative production process for the components otherwise produced from the virgin materials and recycled scrap in the blast oxygen furnace (BOS) or electric arc furnace (EAF), and therefore the impacts of reused steel should be allocated in the production stage of the lifecycle assessment. However, this approach does not reward the ability of the component to be reused in the future, and may discourage designers and facility owners to invest resources into reusable and dismountable buildings. For that reason, it is also important to declare the environmental impacts beyond the system boundary in the similar way as they are currently declared for the steel recycling. The following sections describe a methodology to quantify the environmental benefits of structural steel reuse and recycling based on the most up-to-date LCA standards and guidance, namely the standards developed by CEN/TC 350 and the PEF methodology developed by EU DG Environment.

Comparison of the existing methods

Two of the existing methods, CEN/TC 350 and PEF CFF-M, are already capable of calculating several simultaneous secondary material flows, and therefore may be considered for the assessment of the reuse and recycling of the constructional steelwork. Unfortunately, neither of them is able to take into account the efficiency of steel recycling in the format used by World Steel Association. Moreover, CEN/TC 350 method cannot distinguish between different unit impacts at the beginning and end of the product’s life and PEF CFF-M formula requires additional calculations of total flows and average unit impacts.

Table 25 Comparison of the existing methods to calculate impact beyond the system boundaries

	World Steel Association	CEN/TC 350	PEF
Input flow of secondary material	S	$M_{MR,in}$	R_1
Output flow of secondary material	RR	$M_{MR,out}$	R_2
Unit impact of the recovery process (e.g. recycling or reuse)	X_{re}	$E_{MRafterEoW,out}$	E_{rec} E_{recEoL}
Unit impact of the substituted primary production	X_{pr}	$E_{VMSub,out}$	E_V E_V^*
Efficiency of the recovery process	Y	n/a	n/a
Quality of the secondary material	-	$Q_{R,out}$	Q_{Sin} Q_{Sout}
Quality of the primary material	-	Q_{Sub}	Q_P
Allocation of impacts between supplier and user	100%	-	$1-A$

Proposed calculation

Our goal was to develop a formula suitable for the assessment of the constructional steel reuse that can be easily extended to other materials. For practical purposes, the formula should be compatible with the existing World Steel Association's LCI model to ensure the validity of the existing LCA calculations and with the modular CEN/TC 350 methodology that is used in the development Environmental Product Declarations. Therefore, the calculation of environmental benefits beyond the system boundary (Module D) proposed in this Task is based on the Equation (5) with the symbols described in Table 26.

$$X = \sum\left(M_{out,i} - M_{in,i}\right) \cdot \left(E_{MR,i} - E_{VM,i}\frac{Q_{MR,i}}{Q_{VM,i}}\right) \cdot Y_i \tag{5}$$

The calculation can be further simplified for the constructional steelwork by assuming that the impacts are not affected by the quality factors (closed loop recycling with theoretically infinite number of cycles), and the same points of functional equivalence for recycling and reuse ($E_{VM} = E_{VM,recycling} = E_{VM,reuse}$ is the impact of the final product made of virgin materials leaving the workshop gate). Then the LCI of material recycling $X_{recycling}$ in Equation (6) can be the same as the existing calculation by the World Steel Association, and the impacts of reuse is presented in Equation (7). The parameters required for the calculation are summarized in Table 26.

$$X_{recycling} = \left(M_{out,scrap} - M_{in,scrap}\right) \cdot \left(E_{MR,recycling} - E_{VM}\right) \cdot Y_{recycling} \tag{6}$$

$$X_{reuse} = \left(M_{out,components} - M_{in,components}\right) \cdot \left(E_{MR,reuse} - E_{VM}\right) \cdot Y_{reuse} \tag{7}$$

Table 26 Parameters of the proposed calculation method

	Eq. (5)	Eq. (6)	Eq. (7)
Input flow of secondary material	M_{in}	$M_{in,1} = M_{in,scrap}$	$M_{in,2} = M_{in,components}$
Output flow of secondary material	M_{out}	$M_{out,1} = M_{out,scrap}$	$M_{out,2} = M_{out,components}$
Unit impact of the recovery process (e.g. recycling or reuse)	E_{MR}	$E_{MR,1} = E_{MR,recycling}$	$E_{MR,2} = E_{MR,reuse}$
Unit impact of the substituted primary production	E_{VM}	E_{VM}	E_{VM}
Efficiency of the recovery process	Y	$Y_1 = Y_{recycling}$	$Y_2 = Y_{reuse}$
Quality of the secondary material	Q_{MR}	-	-
Quality of the primary material	Q_{VM}	-	-
Allocation of impacts between supplier and user	Not recommended		

The calculated impact X according to Equations (5) to (7) shows the hypothetical or potential environmental burden or credit caused by the future lifecycles, and therefore it is not recommended to aggregate it with the impacts calculated in the current lifecycle of the building or its component. This recommendation is also compatible with CEN/TC 350 modular approach. The graphical representation of the proposed method is provided in Figure 70.

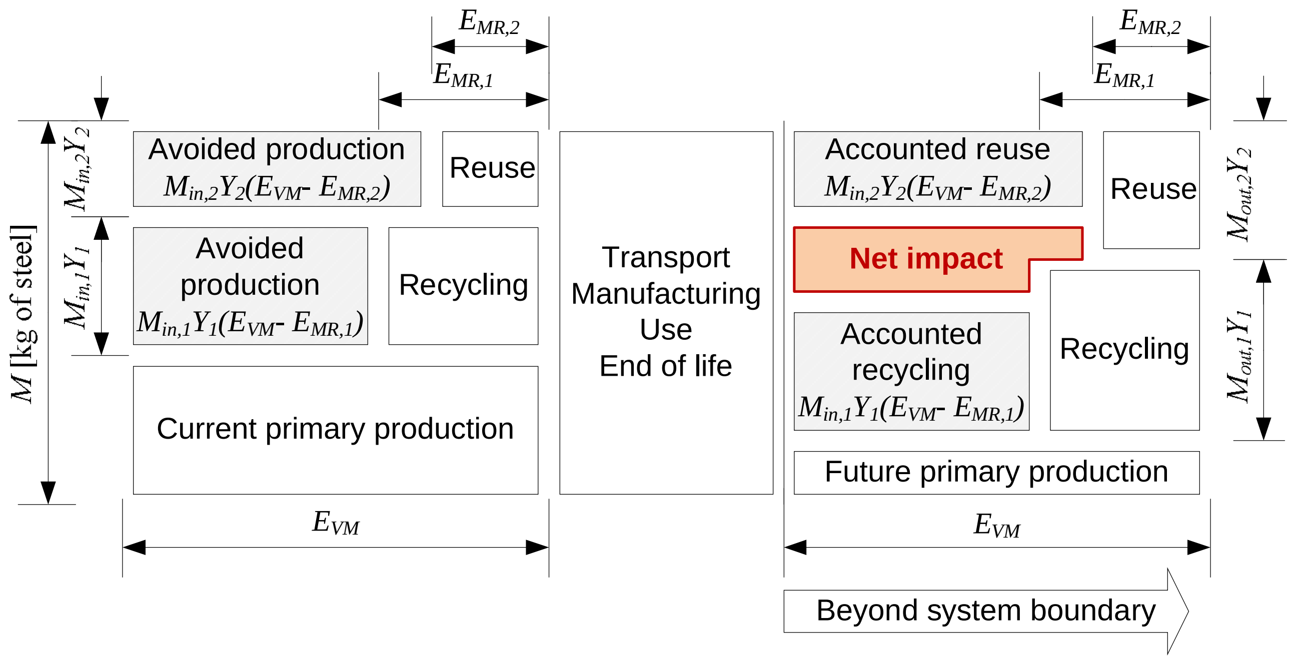


Figure 70 Allocation of net impact of recycling and reuse beyond the system boundary

In reality, reuse or remanufacturing of the product consumes a certain amount of new steel, and therefore part of the input flow of the scrap $M_{in,1}$ should be allocated to the processing of recovered components. At the same time, part of the recovered components can contribute to the output flow of the scrap $M_{out,1}$because they may be no longer suitable for reuse or remanufacture.

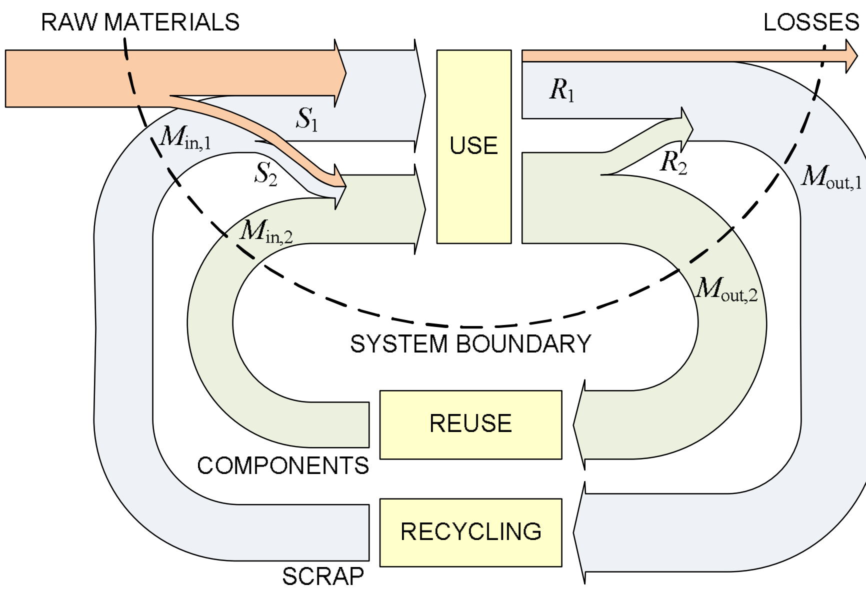


Figure 71 Material flows in reuse and recycling loops

These flows are illustrated in Figure 71, where the input scrap flow $M_{in,1}$ is the sum of scrap needed in steelmaking for the manufacturing of new components S_1 and scrap in steelmaking of products for remanufacturing and reuse S_2. The amount of scrap recovered from the building is R_1 and the amount of steel from recovered from the discarded reusable components is R_2in Figure 71. Their sum is the total scrap output flow $M_{out,1}$.

Compatibility with the existing methods

The proposed methodology is essentially an extension of the existing method developed by the World Steel Association for steel recycling. However, it produces the same results as the new CEN/TC 350 methodology and modular PEF circular footprint formula.

The formula in Equation (5) can be used directly to calculate Module D in proposed CEN/TC 350 methodology, because the unit impacts are equal (see Equation (8)) and material flows can be calculated according to the Equation (9).

$$E_{MRafterEoW,out,i} = E_{MR,i} \text{ and } E_{VMSub,out,i} = E_{VM} \quad (8)$$

$$M_{MR,out,i} = M_{out,i} \cdot Y_i \text{ and } M_{MR,in,i} = M_{in,i} \cdot Y_i \quad (9)$$

For the calculation of Module D according to the PEF CFF-M formula, it is necessary to calculate average unit impacts of the recovery at the input and output flows according to the Equation (10). However, due to the simplified and conservative assumption that the point of the functional equivalence is the same for all recovery routes, the unit impact of the primary production is always the same as demonstrated in Equation (11). Similarly as in the case of CEN/TC 350 methodology in Equation (9), material flows of PEF CFF-M formula have to take into account the yield factors Y_i (see Equation (12)).

$$E_{recEoL} = \left(\sum E_{MR,i} M_{out,i} Y_i\right) / \left(\sum M_{out,i}\, Y_i\right) \text{ and } E_{rec} = \left(\sum E_{MR,i} M_{in,i} Y_i\right) / \left(\sum M_{in,i}\, Y_i\right) \quad (10)$$

$$E^*_{V,in} = E^*_{V,out} = E_{VM} \quad (11)$$

$$R_2 = \sum M_{out,i} \cdot Y_i \text{ and } R_1 = \sum M_{in,i} \cdot Y_i \quad (12)$$

Conclusions

The example calculations provided in Deliverable D5.1 [14] demonstrate that the proposed method produces the same outputs as the new CEN/TC 350 equation and PEF circular footprint formula. Its advantage is that it is also consistent with the World Steel Association's LCI methodology that takes into account yield of the recovery process, Y. The PROGRESS method can be seen as an extension of the current methods and it is applicable to steel and other materials.

5.2 Economic potential of reuse

Economic benefits of reuse can be calculated if the costs arising in the product or building lifecycle are properly assessed. The basic principles of lifecycle cost assessment (LCC) are developed in ISO 15686-5 [98] and the most common LCC method in Europe is described in EN 16627 [90]. However, how the benefits are shared between the actors of the value chain depends mainly on the value of the component or the structure (i.e. how much is the buyer willing to pay for the constructional steel that may be fully functional, but otherwise less suitable than the new product for instance due to aesthetic reasons or because it is optimized for different external conditions).

The work on the Task 5.2 includes:

- Descriptions of the actors and stakeholders in the value chains around the reuse scenarios of SSB's, and their role in creating economic opportunities and constraints
- Qualitative evaluation of the economic potential of the reuse stages in various scenarios
- Review of the quantitative approaches to estimate the economic benefits and burdens of reuse cycles as presented in literature.
- Evaluation of existing case studies;
- Cost assessment methodology and example calculation;
- Summary and recommendations for each of the actors in the supply chain concerning design, deconstruction, maintenance, storage, handling, remanufacturing and other activities associated with the exploitation of the economic potential of reuse products.

Value chain and development of economic value

The value of the steelwork or steel-based components integrated in the building is here for the simplicity illustrated as the market price of such building or component in a given place and time. As can be seen in Figure 72, the value of the building designed for the specific purpose after fabrication and erection "A_5" depends on the costs of materials, manufacturing and assembly (including transport and storage costs). It is assumed that immediately after the erection of the building, the value may decrease to point "B_0" in Figure 72. This is caused especially by the customisation choices in building and product design that could not be fully exploited by the new owner. Then the value changes depending on the deterioration of the materials, surface finishes (aesthetic value) and development of the market prices of new buildings in the area. It is generally assumed that the value has decreasing trend until the decision about refurbishment or maintenance action is made to restore the value of the property. The single-storey steel structures are typically designed for 50 years according to the Eurocodes and their life can be further extended by testing and re-evaluation of structural integrity, stability and serviceability, and therefore the deterioration of value in the use phase "B" is expected to be rather slow. However, the real service life of such buildings is usually less than 30 years until they reach point "C_0" (end-of-Life) when the building as such cannot be used anymore.

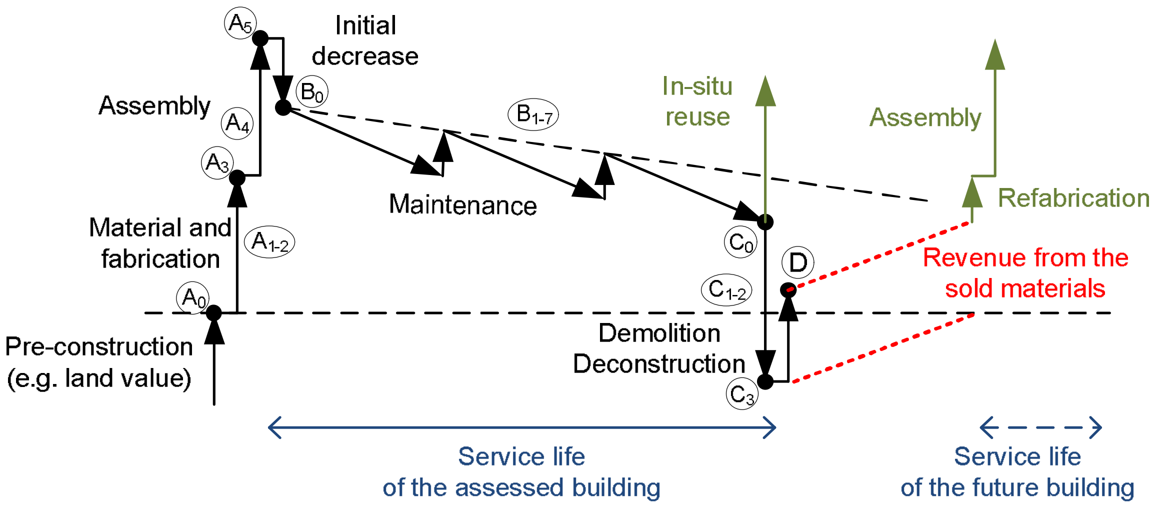


Figure 72 Development of the economic value of the single-storey building or steelwork and steel-based components integrated in such building

Typically, demolition in Europe is followed by construction of a new building on the same site. Therefore, one option for avoiding deconstruction or demolition of the whole building is “in-situ reuse” of the structure or its assembled parts. The new building is then built on the existing (reused) structure. In the case of demolition or deconstruction, the residual value of the building is calculated as the difference between demolition costs and revenue obtained for the sold secondary materials (e.g. steel scrap or reusable components). The calculation of the revenue for the reusable components is based on the assumption that, after re-fabrication and assembly of the future building, its value will correspond to the market value of the new building (see Figure 72 right). Deconstruction and separation of structural components can be divided into more stages (see Figure 73), since the components and envelopes can be recovered at different levels:

- **No deconstruction at all** will lead to in-situ reuse (D_0) without physically removing the component from the structure. The components can still be re-designed and modified.
- **Disassembly of the steelwork** will allow reuse of the whole structure or its part (D_1) that can act as the whole structure (e.g. single bay of the multi-span building)
- **Separation of the components of disassembled structure** for reuse of the components (D_2), is done typically by opening bolt connections e.g. when the sandwich panel, column or truss girder is cleaned, repainted, modified to fit the new design and installed again.
- **Extraction and reconditioning of the constituent products** will allow those products to be sold and reused also for different purpose (D_3).
- **Separation of steel scrap** to be recycled is the lowest level of recovery (D_4).

Different reuse or recycling process will result different residual value “D” as can be seen in Figure 73, where the residual values D_0, D_1, D_2 and D_3 are associated with in-situ reuse, reuse of the whole structure, fabricated components or constituent products respectively. D_4 is then the residual value of the baseline scenario with the steel scrap collected for recycling.

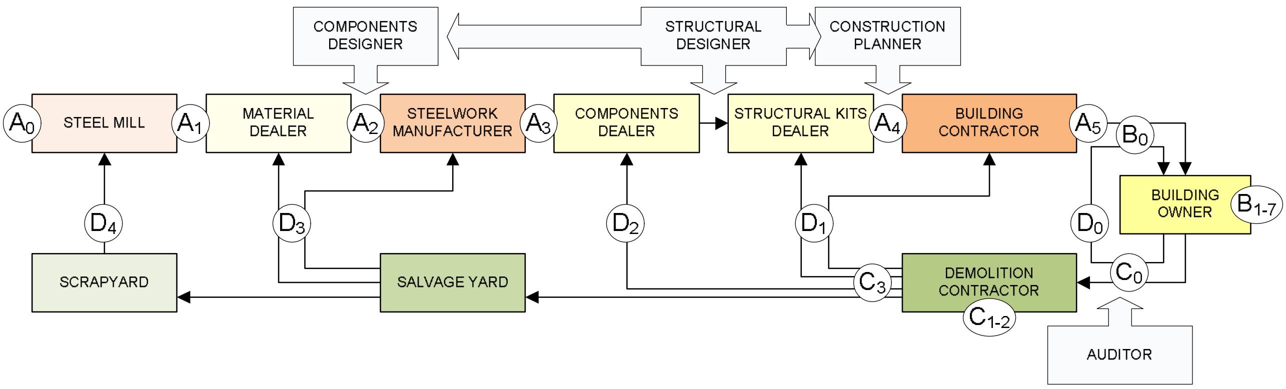


Figure 73 General description of different reuse flows and the actors in the particular lifecycle stages

Proposed cost model to be used in the case studies

The model is based on the collected data related to fabrication, construction and recovery of structural steelwork from single-storey steel buildings. Four scenarios are selected:

- D_4: New steel produced with 44% recycled scrap content
- D_3: Reused steel as reconditioned constituent products (e.g. sections and plates)
- $D_{1\text{-}2}$: Relocated and re-assembled steelwork or its parts
- D_0: Steel structure reused in-situ with major refurbishment

Costs in Product stage (A_{1-3})

The steelmaking process is considered in a simplistic way with the assumption of 0.44 t of steel scrap used to produce 1 t of steel. The cost scrap to produce 1 t of steel is assumed 200 € and the cost of raw materials to produce 1 t of steel is assumed 300 €. Additionally in the case of the reuse of reconditioned steel sections and plates, it is assumed that the stockist purchases the material for 524 €/t which is the price of new constituents decreased by the additional costs needed for reconditioning, shot-blasting and testing. In the case of reuse of fabricated sections the purchase price would be 984 €/t. The estimated costs are shown in the Table 27.

Table 27. Module A1-3 of the proposed cost model.

Information module	New steel (D_4 recycling)	Reused steel (D_3 reconditioning)	Reused steel (D_{1-2} re-erection)
A_1: Steel supply	788 €/t	524€/t	984 €/t
A_2: Transport	115 €/t		
A_3: Manufacturing	541 €/t	805 €/t	345 €/t

Construction process stage (A_{4-5})

The costs associated with the distribution and assembly of the steelwork are estimated in the following list. In the case of in-situ reuse, it is assumed that the steelwork is purchased for 1501 €/t, the price of erected structure without the additional costs of refurbishment:

Table 28 Module A4-5 of the proposed cost model

Information module	New and reused steel (D_4 recycling, D_{1-3} relocated reuse)	Reused steel (D_0 in-situ reuse)
A_4: Transport	115 €/t	0 €/t
A_5: Construction	460 €/t	2019 €/t

Demolition and deconstruction stage (C)

It is assumed that the building is conventionally demolished in the case of material recycling, but disassembled with 50% additional costs in the case of reuse. The costs of the demolition, deconstruction and material recovery process are:

Table 29 Module C of the proposed cost model

Information module	Demolition (D_4 recycling)	Deconstruction (D_{1-3} relocated reuse)
C_1: Demolition/deconstruction	288 €/t	403 €/t
C_2: Transport	46 €/t	

Benefits and loads beyond the system boundary (D)

Additional costs and incomes related to Module D is based on potential net income from the reuse of the components, steelwork, recycling scrap. It is calculated as the revenue minus additional costs of demolition/deconstruction and other processes to enable the reuse scenario. It is calculated as the net difference between current costs and potential savings in future.

Table 30 Module D of the proposed cost model (net value).

Recycling (D_4)	**Reuse (D_3 reconditioning)**	**Reuse (D_{1-2} reerection)**	**Reuse (D_0 in-situ reuse)**
-200 €/t revenue from the sold steel scrap	- 374 €/t 100 €/t additional cost of deconstruction 30 €/t additional cost for design for deconstruction 20 €/t profit - 524 €/t revenue from the sold recovered material	- 834 €/t 100 €/t additional cost of deconstruction 30 €/t additional cost for design for deconstruction 20 €/t profit - 984 €/t revenue from the sold recovered structure	- 1742 €/t 30 €/t redesign for reuse 5 €/t profit -276 €/t savings from demolition (including profit, transport) - 1501 €/t revenue from the sold structure before refurbishment

Results

The proposed cost model clearly shows that the residual value of the building can be greatly improved by different kinds of reuse. The most advantageous reuse is in-situ reuse with repair, refurbishment and upgrade of the existing structure. Also with the disassembly are re-erection of the building or its components, large part of the steel value is retained. More complicated would be reconditioning of steel constituents, but since the market of such products is much larger, it may lead to viable business models.

Table 31. Examples of estimated prices of different stages of building and reuse

Material source	**New steel**	**New or reused steel**		
End-of-life scenario	**Recycling[1] (D_4)**	**Reuse (D_3 reconditioning)**	**Reuse (D_{1-2} re-erection)**	**Reuse (D_0 in-situ)**
LCC (A-C)	2352 €/t	2467 €/t	2467 €/t	2076 €/t
LCC (D)	-200 €/t	-374 €/t	- 834 €/t	- 1742 €/t
Total LCC (A-D)	2152€/t	2093 €/t	1663 €/t	334 €/t
Estimated purchase price	Steel constituents: 788 €/t (new) and 524 €/t (reclaimed)			
	Fabricated components: 1444 €/t (new) and 984 €/t (reclaimed)			
	Structural steelwork: 2019 €/t (new) and 1501 €/t (used)			
Residual value	-134 €/t	75 €/t	535 €/t	1444 €/t
Depreciation rate[2]	3.95%	3.57%	2.72%	1.05%

[1] Not designed for reuse

[2] 27 years service life

Comparison of the proposed model with the existing data

The cost breakdown proposed for PROGRESS studies is compared to the existing cost models presented in the Deliverable report [15]. The compared data are from Ruukki Construction [91] (marked as FI in Figure 74 and Figure 75), lower and upper bounds of information from the UK study [92] (marked as UK low and UK high), costs based on the interview with the Czech consult [93] (marked as CZ). The proposed model is marked PROGRESS in the following graphs.

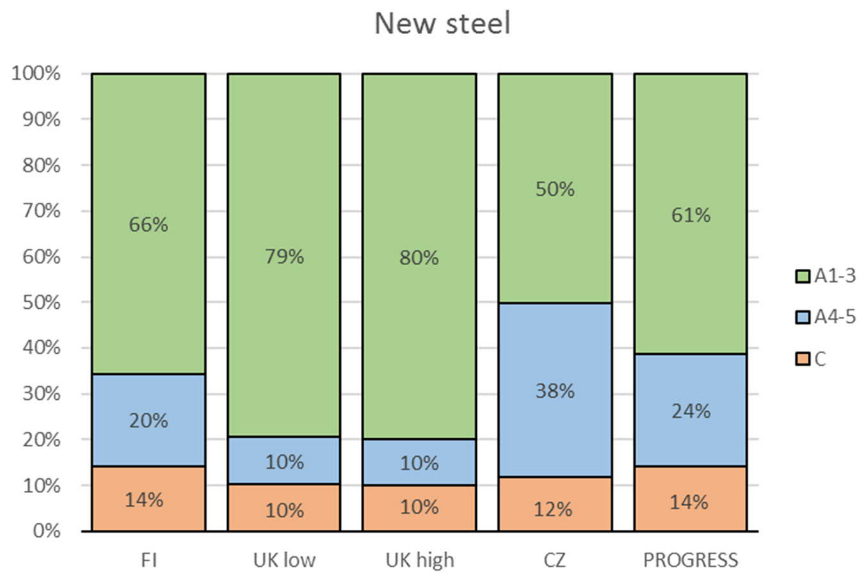


Figure 74 Costs of the LCC stages as % of total costs for the buildings with the new steel

The proposed model for new steel production and recycling is similar to CZ and FI data with roughly 60% of total costs in the manufacturing and production stage and 30% in the construction stage. The difference with the UK model is probably due to missing costs and profit margins in the construction and demolition stages.

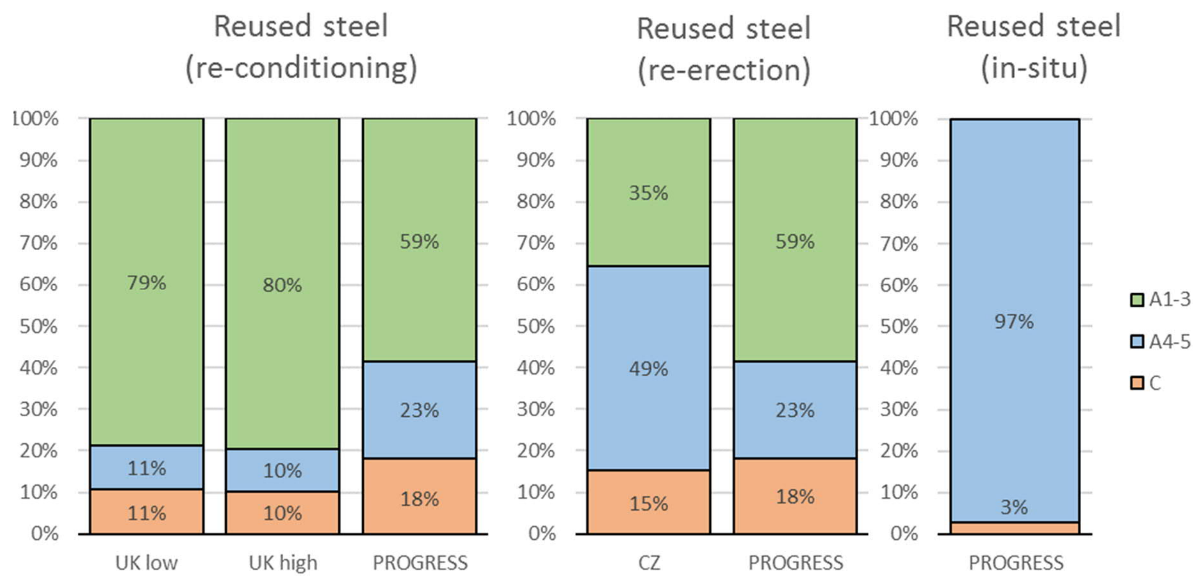


Figure 75 Costs of the LCC stages as % of total costs for different reuse scenarios

Case study: Life cycle cost for steel building hall

Constructional steelwork in the studied single-storey steel hall with welded portal frames represents 22% of the total investment costs, which is typical for similar small storage halls (see Figure 76).

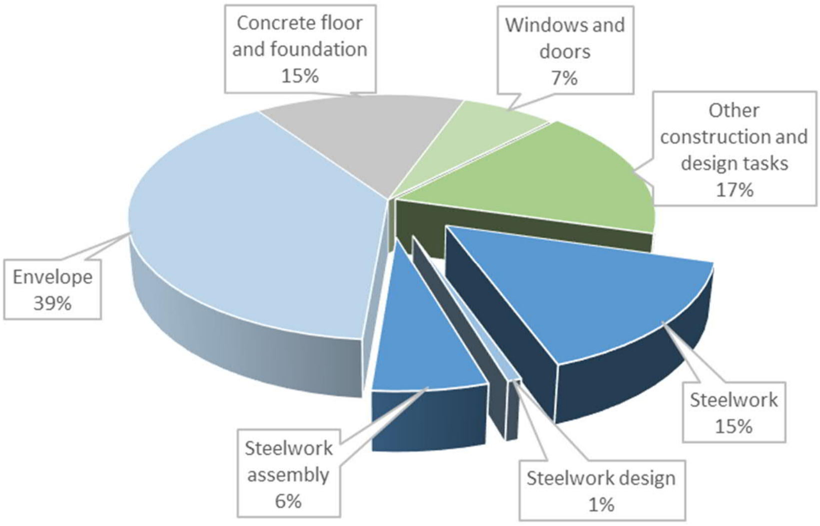


Figure 76 Costs related to the steelwork that will be affected by the reuse scenario

Life-cycle cost results are given in Table 32 for the life-cycle stages as described in the previous sections (CEN TC350 information modules A-C). Results take into account also potential savings coming from the stage beyond the system boundary D.

Table 32. LCC results for a single steel single-storey building

Material source	**New steel**		**Reused steel**	
End-of-life scenario	**Recycling[1] (D_4)**	**Reuse ($D_{1\text{-}2}$ re-erection)**	**Recycling (D_4)**	**Reuse ($D_{1\text{-}2}$ re-erection)**
Production ($A_{1\text{-}3}$)	108 191 €	108 397 €	102 670 €	103 876 €
Construction ($A_{4\text{-}5}$)	22 378 €			
Use[2] (B_6)	205 000 €			
Demolition ($C_{1\text{-}2}$)	12 569 €	17 144 €	12 569 €	17 144 €
Total costs (A-C)	348 138 €	352 919 €	343 617 €	348 398 €
Pot. savings (D)	-2 740 €	-11 549 €	-2 740 €	-11 549 €
Residual value	-9 829 €	-3 664 €	-9 829 €	-3 664 €

[1] Not designed for reuse
[2] 27 years service life

Building construction uses a substantial amount of materials and material manufacturing causes environmental and monetary impacts. Efficient way to improve impacts from construction is to replace virgin material with the materials disassembled from demolished buildings. However, this is not always possible, but when the steel structure is specifically designed for the reuse, like in the assessed case, economical benefits can be achieved.

5.3 Circular Economy business models

Task 5.3 addressed circular economy business models that are applicable (or potentially applicable) to the supply of reused and reusable single-storey, steel framed buildings and/or their component parts. This task builds upon the findings of several other tasks most notably Task 1.3 addressing market size and potential and supply chains for SSBs [2] and Task 5.2 addressing the economic potential of reusing SSBs and their constituent parts [15].

Under Task 5.3 new and developing circular economy business models were reviewed and their potential applicability to structural steel reclamation and reuse within single-storey buildings assessed. Where they already exist (and information is readily available), successful cases and business models were reviewed.

Types of circular economy business models

There are several studies reviewing and categorising CE business models. Some of these are reviewed in D5.3 [16]. Although these studies categorise models in broadly similar ways, the most relevant categorisation (to the scope of PROGRESS) is that provided by WRAP. The different categories are described below.

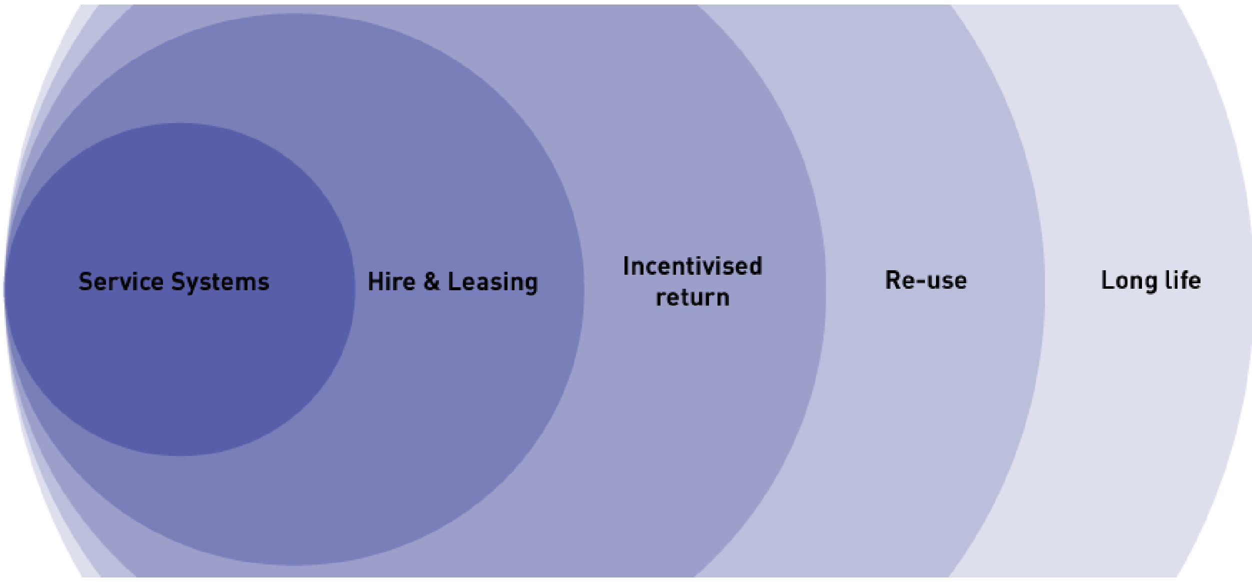


Figure 77 WRAP innovative business models map

- A **Product Service System** (PSS) is a service based upon delivering a mix of traditional product offerings and service contracts adaptable to market demand and service outputs. The business model is based on the idea that users of a product don't necessarily need or want ownership of a product, but they are in need of the function the product provides. By offering a Product Service System, businesses can offer these functions on a service contract, rather by selling the physical product. This allows businesses to increase their profits through ongoing service contracts, whilst simultaneously maximising the usable life of their products through servicing, continued monitoring and adapting to consumer needs and demands.
- **Dematerialised Services** model relies on providing a service that offers product benefits where the 'physical' product may not exist at all. Using collaboration, sharing and grouping

of product needs, this model looks at changing consumption patterns to deliver potential material saving through not producing a physical product for consumers. However, this must be balanced against the materials used in the service infrastructure.

- **Hire and leasing** models encourage long-term hire and leasing of products and drive a longer term approach to product durability, with longer service life, lower maintenance load and lower use of materials and CO_2.
- **Incentivised return and re-use** models encourage customers to return used items for an agreed value and customers gain value for unwanted items and return products via a convenient exchange system. Collected products are refurbished and sold for re-use on appropriate markets.
- **Long life** models are products specific designed to have a long life time with increased durability, and ultimately reducing consumption.

Circular economy business models in the steel and steel construction sectors

Production scenarios to meet the predicted global demand for steel face particular challenges from the immediate need to reduce greenhouse gas emissions. Although steel recycling rates are relatively high, particularly for construction products, to meet the predicted global demand, primary steel production will continue to be needed for some time. Improved circularity could however significantly reduce the need for primary steel production.

There is a recognition that supply-side (production) measures cannot simultaneously meet the predicted increase in global demand for steel while meeting carbon emission reduction targets such as the commitments of the Paris Agreement. Consequently, demand-side measures are also urgently required.

There are several observable trends influencing policy and opinion with respect to resource use, waste and the need to develop a more circular economy business models. These trends include:

- Growing awareness that current and predicted global resource consumption demand is unsustainable
- Public awareness on specific waste, resource and pollution issues, for example, plastic waste
- The need to decouple economic growth and resource consumption
- The need to reduce greenhouse gas emissions
- (Extended) Producer responsibility for waste and for their products at their end-of-life.

There are also challenges in applying some of the generic circular economy business models (as described in D5.3) to the construction sector. These include:

- Most of the successful CE business models have been applied to durable goods (e.g. cars, white goods) and energy consuming products (e.g. mobile phones) and consumable goods (e.g. clothing and textiles). Although construction products are durable goods (perfectly durable) their relatively long lifetimes makes the applicability of several of the generic CE business models difficult.
- The relatively long lifetimes of buildings and their component parts, mean that the whole-life cycle cost benefits of end-of-life scenarios such as deconstruction and reuse, yield low NPV (net present value) savings. Consequently, the economic case for circular economy buildings using tradition whole life costing methods, is not convincing for most clients.

In addition, the long life of buildings and their component parts, presents challenges to extended producer responsibilities.

- Within construction, the product (of greatest interest to the customer) is the building not its constituent parts such as a brick or a steel beam. Greater focus should therefore be placed on CE business models for buildings rather than at the construction product level
- Construction products are relatively low value products, consequently the economic viability of different business models, such as steel reuse, are generally low
- The construction industry, in general, is relatively risk adverse and mainly focussed on short-term objectives, i.e. the current and maybe the next project. As such, longer term and potentially more risky business models are not seen as attractive.
- Construction is principally concerned with producing physical products (buildings) whose primary functions are to provide shelter, be structurally robust and safe. As such, many of the innovative and disruptive business models that have successfully transformed other sectors are not applicable to construction. Examples include, Uber, Airbnb and Netflix. There are initiatives, such as AI, robotics and 3D printing, that could radically transform the construction sector but these technologies are not within the scope of PROGRESS.

With reference to the generic circular economy business models presented above, the following potential business models can be considered for the steel construction sector and particularly within the scope of PROGRESS.

Scenarios are considered for four different scenarios:

- Building level and product level scenarios
- Existing buildings or design of new buildings for future benefits.

Hire or leasing of products

Description - 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 see Figure 4.6.

Road plates

Steel piles

Small scale (Acro) propos

Props and formwork used for insitu concrete pours

Figure 78 Examples of temporary steel construction products based on a hire business model

The applicability of hire or leasing models appears more appropriate to buildings rather than construction products for use in permanent works. While there are many good examples of existing business models for steel temporary works' products, these do not appear to be applicable to permanent works because of the longevity of most buildings and consequently no realistic model by which building owners would be prepared to pay to lease or hire components (or indeed the entire building structure) over an extended and open-ended timescale.

The model for temporary, leased steel framed SSB is well established albeit for relatively short-term lease periods. The challenge is to extend this model into building sectors where building lifetimes are longer but still relatively short compared to most commercial and residential buildings. This model would seem most applicable to the retail and distribution sectors where building lifetimes are relatively short and, in general, clients are large often with multiple distribution and/or retails outlets and therefore greater scope for reusing and relocating their buildings.

Temporary storage building

Modular office building

Temporary event seating

Semi-permanent building extension

Temporary education building

Temporary storage building

Figure 79 Typical UK examples of temporary, relocatable steel-framed buildings

Product as a service or servitisation

Description - Servitisation is the innovation of organisation's capabilities and processes to better create mutual value through a shift from selling product to selling Product-Service Systems. A Product-Service System is an integrated product and service offering that delivers value in use. It is noted that most servitisation models has been developed in the manufacturing sector.

In such models, manufacturers can retain greater control over the items they produce and the embodied energy and materials, thus enabling better maintenance, reconditioning and recovery. Customers benefit too, as they only pay for the service they require and use, and often receive a better service as the manufacturer has a greater interest in providing a product that lasts.

Product-as-a-Service (PaaS) is a business model that allows customers to purchase a desired result rather than the equipment that delivers that result. In the context of construction, where the final product is a physical building that is required to resist forces safely, provide a comfortable and safe internal climate, etc. it is not immediately apparent how these functions could be servitised. In contrast, facilities management is a good example of servitisation that is relevant to the property sector and has been around for a long time. Product as a service is similar (within the PROGRESS scope) to a hire or leasing model, but based on a service rather than a product. For example, providing structural support to a building over a defined timescale or providing a secure, watertight and thermally efficient envelop to a building over a defined timescale.

Within construction, servitisation models are currently more applicable to building services, i.e. the provision of services such as lighting, heating, cooling, air conditioning within the building rather than, for example, structurally supporting or physically enclosing the building (envelope). The biggest challenge with respect to CE business models is that most construction product manufacturers produce components (or systems) which make up a final product (the building) which is the only product of real interest to the end client. Therefore, while it may be possible to conceive of a service agreement applicable to the building, having myriad such agreements for different elements of the building, e.g. the structure, the fenestration, the lifts, etc. does not seem viable.

Take back/buy-back model

Definition - A take-back scheme is an initiative generally established by a manufacturer or a sector, to collect used products or materials from consumers (generally at the end of the product life) and reintroduce them to the original processing and manufacturing cycle. A buy-back scheme is the same as a take-back scheme other than the manufacturer pays the consumer for returning the product.

Many sectors are increasingly adopting take-back schemes to improve waste management and resource efficiency. This is generally most common in the retail sector and for electrical and electronic goods (and batteries) under the WEEE directive. More recently, take-back schemes targeting plastic wastes have been introduced in response to the growing problems associated with discarded plastic waste. There appears to be growing appreciation by organisations of the public relations benefits of offering and operating take/buy-back schemes.

Examples of take-back schemes in construction are less common however there are some examples in the UK including mineral wool insulation and plasterboard. It is noted that, of the few construction specific schemes identified, these only relate to construction and not demolition waste. Again, it is the longevity of construction products that limits the viability of take-back/buy-back schemes to construction rather than demolition waste streams.

Steel products have the advantage over many competing, non-metallic construction products that their scrap value has always been sufficiently high to ensure that steel is recovered from construction and demolition waste streams for recycling. This has meant that steel producers have not been required (or voluntarily chosen) to introduce take-back schemes to improve recovery and recycling rates. The exception to this is deposit return schemes for drinks containers which includes steel cans.

Extended producer responsibility (EPR) is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. Assigning such responsibility can in principle provide incentives to prevent wastes at the source, promote product design for the environment and support the achievement of public recycling and materials management goals.

In the European Union, extended producer responsibility is mandatory within the context of the WEEE, Batteries, and ELV (vehicles) Directives, which put the responsibility for the financing of collection, recycling and responsible end-of-life disposal of WEEE, batteries, accumulators and vehicles on producers. The Packaging Directive also indirectly invokes the EPR principle by requiring Member States (MS) to take necessary measures to ensure that systems are set up for the collection and recycling of packaging waste. Additional waste streams for which producer responsibility organisations have been most commonly identified within the European Union include tyres, waste oil, paper and card, and construction and demolition waste.

A hybrid model of a take-back scheme in which the product is sold but the producer retains ownership of the product following demolition or deconstruction of the building maybe be applicable. This could be a 'shared ownership' model. Shared ownership models are becoming quite common in the property sector (for buildings) particularly for affordable housing.

Traditionally, buy-back schemes have been implemented to encourage producers to design environmentally friendly products by holding producers responsible for the costs of managing their products at end of life. In the context of structural steel, such an approach has not been required because of the high recovery and recycling rates already achieved. To encourage reuse however, as opposed to recycling, a buy-back scheme would seem to be relevant and appropriate.

In effect, such a model is not very different from today's model (of recovering and recycling steel for scrap) other than the original producer is rewarded or burdened by ownership of the product or the material in the future. This encourages the producer to develop their products and systems so that value is preserved. For example, standardised, demountable and reusable systems that will yield better future returns. It would also encourage traceability so that material properties are available to facilitate reuse and to ensure high quality recycling.

There is the question about the buy-back value but this would be agreed at the original sale point. Schemes are already running in which the buy-back value is based on a percentage of the initial cost. See for example, Desko https://www.desko.nl/ the Dutch office furniture company which has developed a three-tier buy back model to encourage reuse as followed:

A further significant aspect/benefit of such a model is security of future supply for steel producers and also certainty of the cost of raw materials (in the case of recycling) and products (in the case of remanufacture and reuse). Although raw material prices (iron ore and scrap) are volatile, resource use constraints and carbon taxation will inevitably lead to significantly higher raw material costs in the future. This may seem counterintuitive today with global over-capacity of steel running around 25%. Buy-back schemes would ensure certainty of supply of scrap and certainty of cost for steel producers. The challenge again, for a viable business model, is the longevity of buildings and their permanent components, e.g. the structure, in terms of establishing a via business model.

Reuse of structural steel elements or whole steel structures (or parts of)

The reuse of structural steel elements or whole steel building structures, is really just a variation on, or adaptation to, the existing, current business model for the supply of new structural steelwork. While the reuse business model has been studied several times and the barriers to its more widespread uptake have been well documented, the model itself has shown to be technically feasible and, as many examples demonstrate, also commercially viable, particularly at the whole building structure level.

The business models for the reuse of entire building structures and for individual structural components are quite different. The existence of both models in the market demonstrates the viability of both models albeit generally at small-scale (in the case of components) and in certain niche markets (in the case of whole building structures).

In the case of individual structural elements:

- Construction material exchange websites are available but none reviewed appear to be well used
- There are no metal or steel specific exchanges and generally, steel products are not commonly listed on (general) construction material exchanges
- ebay has listings of reclaimed steel sections and appears to be the most used portal for trading reclaimed structural steel. Most listings only offer small quantities however. Note that several of the small stockists that specialise in reclaimed structural steel trade via ebay.
- Some steel stockists sell reclaimed structural steel alongside new steel.

For the case of entire building structures, there are some companies that sell reused, single-storey steel-framed buildings, generally in the agricultural and industrial sectors. Many other property companies organise auctions of existing single-storey buildings for reuse, again generally agricultural and industrial buildings.

It is difficult to generalise about the commercial viability of whole building reuse. The costs of reusing structural steel are very project specific depending on a number of factors including location, local market conditions, scrap price, suitability of the structure, i.e. is it the right size, configuration, etc. for reuse for another owner and/or on a different site. The economic assessment data presented in D5.2 gives some idea of the likely cost savings achievable through reuse but it is difficult to provide definitive costings (and hence business models) due to the variation of costs on a case-by-case basis. It is clear that viable business models already exist for reusing SSB structures and that the challenge is more about increasing the supply and demand for such structures for example, using the guidance developed under PROGRESS.

In terms of component reuse, we have found no good examples of organisations successfully running a viable business trading solely in reclaimed sections for reuse be they demolition contractors, steel stockists or construction material exchange websites. ebay appears to be the most successful trading platform for reclaimed steel sections but listings are for small quantities and/or generally relatively small section sizes (typically RSJs in the UK). Although this model seems to be viable for the small-scale, e.g. domestic extensions, it does not represent a viable or scalable business model capable of delivering more mainstream reuse. Anecdotally, many demolition contractors and stockists do carry some reclaimed stock.

In terms of an improved business model to facilitate more widespread steel reuse some reconfiguration or consolidation of existing supply chains, for SSBs, makes good sense. With reference to Figure 80, which represents the current structural steel supply chain (red loop 1), and particularly the green loops shown, the following reconfiguring of the supply chain would appear to offer a more viable business model:

- Recovery of the structural elements for reuse eliminates the need for the scrap merchant (loop 3)
- The demolition contractor or the steelwork contractor is able to store reclaimed stock then the requirement for the stockist is avoided (loop 2)
- The demolition contractor has both space to store the reclaimed stock and is able to fabricate and paint the reclaimed steelwork (loop 4).

By consolidating supply chain partners in this way, profit margin is shared between fewer organisations making the business model potentially more commercially viable.

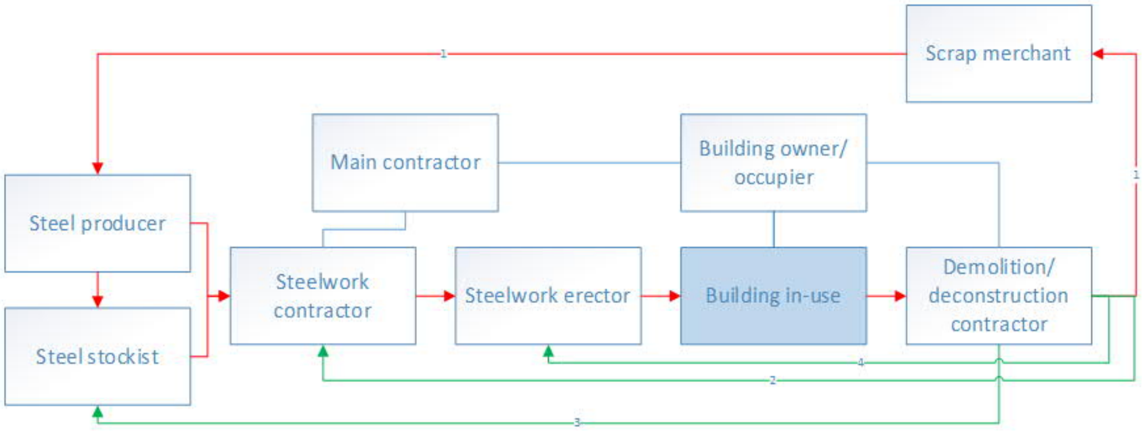


Figure 80 Configuration of stakeholders in the supply of new structural steelwork

3 above is likely to provide the most viable business model for reusing structural steel. An example of such a model is Cleveland Steel and Tube (CST) in the UK who sell surplus offshore pipe into the construction sector. The business model has many features of a potentially viable business model for reclaimed, open sections. Key to the success of their business includes:

- A large inventory of stock available on-line
- Significantly reduced lead times (compared to new products)
- On-site shot-blasting, fabrication and painting.

Crucial to the viability of any business model for reusing structural steel sections is to increase demand and to ensure sufficient supply to meet this demand. One model for doing this is a hybrid, buy-back model in which the demolition contractor is either mandated or incentivised to reclaim (intact) structural sections meeting certain specified criteria and returning these to a stockist of reclaimed sections. If not mandated, this could be incentivised through payment by the stockholder; with the price linked to the current scrap value, i.e. the price paid being current scrap price +10 to 20%. The actual price could be linked to the condition of the reclaimed sections, their age, provenance, transport distance, etc. Buy-back criteria could be mandated or set by individual stockholders. This could include, for example:

- Hot-rolled sections greater then 6m length
- In good condition without signs of corrosion
- Relatively free of attachments (details to be defined)
- Uncontaminated by any potentially hazardous coatings.

Such a model requires a suitably located stockholder site (relative to the demand) and of sufficient size to hold significant stock for a potentially long timeframe during which the stockholder can either sell the reclaimed steel for reuse or, as the scrap price varies, release unsold sections for recycling. As opposed to a physical inventory of stock, a virtual or cloud-based model may be an alternative, viable model – see deliverable D8.3 and below.

Information service to facilitate future building adaptation, deconstruction and reuse

The concept is to provide a commercial on-line service providing the facility to trade reclaimed structural steel components and buildings for reuse. In addition, the web service would include guidance and information about structural steel reclamation and reuse and associated services to support reuse including pre-deconstruction audits, testing and certifying the steel products.

The focus of such a model is existing buildings, scheduled for demolition but that could be reused or components from recently deconstructed buildings. In addition, the service would include the storage of structural models of new steel-framed buildings. Although a more comprehensive service (in terms of the ongoing management of the entire building), the Madaster Platform see https://www.madaster.com/en/our-offer/Madaster-Platform provides an example of this type of service offering. The Madaster business model is subscription based targeting property owners and their service providers as well as designers and constructors. It is principally a central repository for safely storing all relevant building information (including the material passport) over the long-term.

The concept for such a service has been explored under Task 8.3 and a prototype website developed. As conceived, within PROGRESS, the challenge for storing structural steel information until the building is to be demolished at some point in the future, is achieving revenue to run and maintain the platform during this time which, for most building types, is likely to be several decades.

Deliverable D5.3 [16] summarises the findings of the five generic circular economy business models reviewed in the section of the report within the scope of the PROGRESS project.

Conclusions

Of the various generic, CE business models reviewed, more seem potentially applicable to the building rather than the element (structure) or the component (section) level. Successful models already exist for steel temporary works' products and for temporary steel buildings therefore extending these models from temporary to semi-permanent buildings, typical of SSBs, would seem relatively straightforward. Standardisation and design for deconstruction are keys principles underlying such models. Property and investment experts should help the steel construction sector define new circular economy business models.

Models for reusing structural steel, both at the building and the component level already exist, albeit at small-scale and in certain niche markets. In the absence of legislation encouraging greater reuse, increasing economies of scale are required to stimulate demand and enable sufficient supply, both in terms of range and location of reclaimed sections.

Case studies of whole structure reuse demonstrate the economic viability today for some SSBs. The project specific nature and costs of reusing structural steel makes defining the business case for whole structure reuse difficult.

Structural steel reuse, particularly in SSBs, can become mainstream by relatively incremental change, greater demand from designers and clients and slight reconfiguration of existing supply chains. Legislative driver would help accelerate this shift.

Despite the current global overcapacity of steel-making, future raw material prices, material scarcity and environmental taxation may encourage steel producers to think more long-term and strategically about buy-back schemes that would enable them secure future supply. This would also encourage traceability and development of systems and products to facilitate future reuse.

Table 33 Summary of the applicability of different generic circular economy business models

Business model	Existing situation	Future opportunities/prospects
Hire & Leasing	Existing market for relocatable buildings in many building sectors (temporary applications) Many temporary works component examples	More challenging for longer-life or semi-permanent buildings Possible model for retail/distribution sectors Not viable for permanent works components
Servitisation	Some existing building services models	Possible models for whole buildings but not building sub-systems, e.g. structure. Possible model for envelope systems.
Incentivised return	Increasing uptake in retail sectors but not common in construction. Construction schemes generally limited to uncontaminated construction waste. End-of-life waste generally excluded. No specific requirement for steel construction products (only packaging, electrical and electronic goods) which are already highly recycled	Buy-back scheme to guarantee future supply for steel makers – commodity futures trading Incentivises traceability and product development to facilitate future reuse
Reuse	Small-scale, niche markets at both building and product level Proven technical and economic viability Constructional steel's high recycling rate means that reuse is not currently an objective for legislators	Need to increase demand (supply will follow) - Legislation would help this Reconfiguration of current supply chain to facilitate reuse Capture new building information to facilitate future reuse
Supporting services	Limited available information and support Limited trading via material exchanges which don't provide the required steel properties to facilitate reclamation and reuse	Designers need skills and support including advice on warranties and risk Testing and certification of existing reclaimed steelwork for reuse Secure capture and storage of BIM data to facilitate future reuse

6. Design recommendations on reusing reclaimed steel construction products (WP6)

Work under Tasks 6.1 and 6.2 summarizes all of the important conclusions, procedures and recommendations proposed under previous work packages. The deliverable D6.1-2 [17] is presented as a single guidance document, which is intended to have a direct applicability to practitioners. The guidance is split into four parts:

Introductory sections describe the scope of the guidance and the types of SSB included and their components. Benefits of reuse are described including different reuse scenarios. Environmental and economic assessment and benefits are described.

Part 1 provides recommendations for reusing existing single-storey buildings

Part 2 provides recommendations for designing and constructing new single-storey buildings so that they can be more easily deconstructed and reused in the future

Part 3 presents two case studies and various reuse scenarios, focussing on design issues and environmental and economic assessment.

The following topics that were addressed in other work packages, are covered in the design guide:

- Review of components in single storey buildings;
- Benefits of re-using constructional steel (reuse scenarios, LCA and LCC assessment, examples of successful case studies with reclaimed/existing steelwork);
- Historical review of codes of practice and product standards;
- Details guidance about evaluation of structural reusability of hot tolled products, hollow sections, cold formed elements and cladding (covering reclamation to CE marking);
- Practical guidance for the implementation of reuse: overview about the reuse practice in the current construction market, overview of the assessment of reclaimed steelwork prior to reuse, guidance for the reconditioning of products;
- Structural analysis and design of reclaimed elements: comprehensive guidance about the design with existing steelwork, covering ULS and SLS design, seismic consideration, approach for achieving desired reliability for existing buildings and possible remedial work for existing steelwork;
- Recommendations for new single storey buildings for reuse: best practice for analysis and design, member stability, SLS checks, durability, building information modelling and component tracking;
- Best practice for loading in new single storey buildings: typical load values, proposed European imposed load classes for wind and snow, action values for different return period and combination of actions;
- Reuse through design and better construction details: standardization for single storey buildings, best practice for connections, alternative solution for portal frames and trussed solutions, best practice for mezzanines, secondary steelwork and cladding;
- Practical case studies of buildings with reclaimed elements;
- Detailed testing protocol for hot rolled products and hollow sections, cold formed elements and cladding.

7. Case studies (WP7)

The outcomes of Work Packages 2 to 5 are applied in this Work Package and demonstrated on 15 case studies divided into 3 different groups:

- deconstruction and reuse projects with material testing (Cases 1-1 to 1-6)
- design cases concerning design from reused elements (Cases 2-1 to 2-4)
- design cases for improved reusability (Cases 3-1 to 3-5).

Deconstruction and reuse cases are reported as Factsheets 11 and 12 in Task 1.1 and one selected project in Task 7.1. Over 250 experiments were carried out to investigate the performance of deconstructed steelwork and envelope. The theoretical cases are divided into two reports. Deliverable D7.2 compares different design scenarios of an industrial hall with portal frames in four cases with reused steel (Cases 2-1 to 2-4) and two cases designed for optimum performance and future reuse (Cases 3-1 and 3-2). Deliverable D7.3 analyses in detail the possibility to re-design a single storey steel building with truss girders and its economic consequences (Cases 3-3 to 3-5).

7.1 Demonstration of the deconstruction and verification principles

The aim of the work summarized in two reports [18] and [19] was to demonstrate the process leading from the material audit to deconstruction and verification of the quality of recovered materials and components. Due to the complexity of the planned tests and demonstrations, the material tests were carried out on steel components and envelope panels originating from several different deconstruction projects in order to fulfil the Task goals (A) to (F) as described in Table 34. Case study 1-6 is reported in detail in Deliverable D7.1a [18] and the remaining studies are described briefly in the test report D7.1b [19] and factsheets [1].

Table 34 Overview of deconstruction and reuse cases

Case study		Contribution to the project outcomes
1-1	Deconstruction and reuse of steel roof from 1950s, Wuppertal, Germany	Mechanical testing (D) and chemical testing (E) of steel [19], factsheet 11 [1], cost analysis [15]
1-2	Deconstruction of envelope from 2012, Bückeburg, Germany	Investigation of basic material separation techniques described in D2.1a [4]
1-3	Deconstruction of envelope from the test building from 2007, Hämeenlinna, Finland	Panels testing (F) with mineral wool core [19]
1-4	Deconstruction of envelope from the test building from 2005, Aachen, Germany	Panels testing (F) with polyurethane core [19]
1-5	Partial deconstruction and in-situ reuse of restaurant building from 2008, Târgu Jiu, Romania	Mechanical testing (D) and minimum invasive testing (B) of structural steel [19], factsheet 12 [1]
1-6	Deconstruction and reuse of market hall from 2002 in Cologne, Germany	Pre-deconstruction audit (A) and detailed deconstruction process follow-up (C) [18]

(A) Pre-demolition audit

A suitable single-storey steel building for deconstruction and potential reuse of the steelwork was identified in great market, Cologne, Germany in spring 2020. The hall was erected in 2002, but not designed for deconstruction and reuse. As the structural steelwork was less than 20 years old, it was anticipated that its deconstruction and reuse would be relatively simple and cost efficient. Although, the owner did not declare his intention to reuse any of the deconstructed components, the goal of the audit was to identify obstacles for deconstruction and reuse of the primary and secondary structure and envelope. The audit report is attached to the Deliverable D7.1a [18] according to the template developed in D2.1a [4]. It revealed that deconstruction was possible, if several technical difficulties (such as frame columns grouted in concrete) were overcome. No dangerous particles (e.g. asbestos) were measured in the site, and therefore it was concluded that it is safe to start the deconstruction. The reuse of the envelope was not economical according to the preliminary calculations reported in [18]. The building was scanned by photogrammetric measurement taken from the drone and its 3D model was reconstructed (see Figure 81).

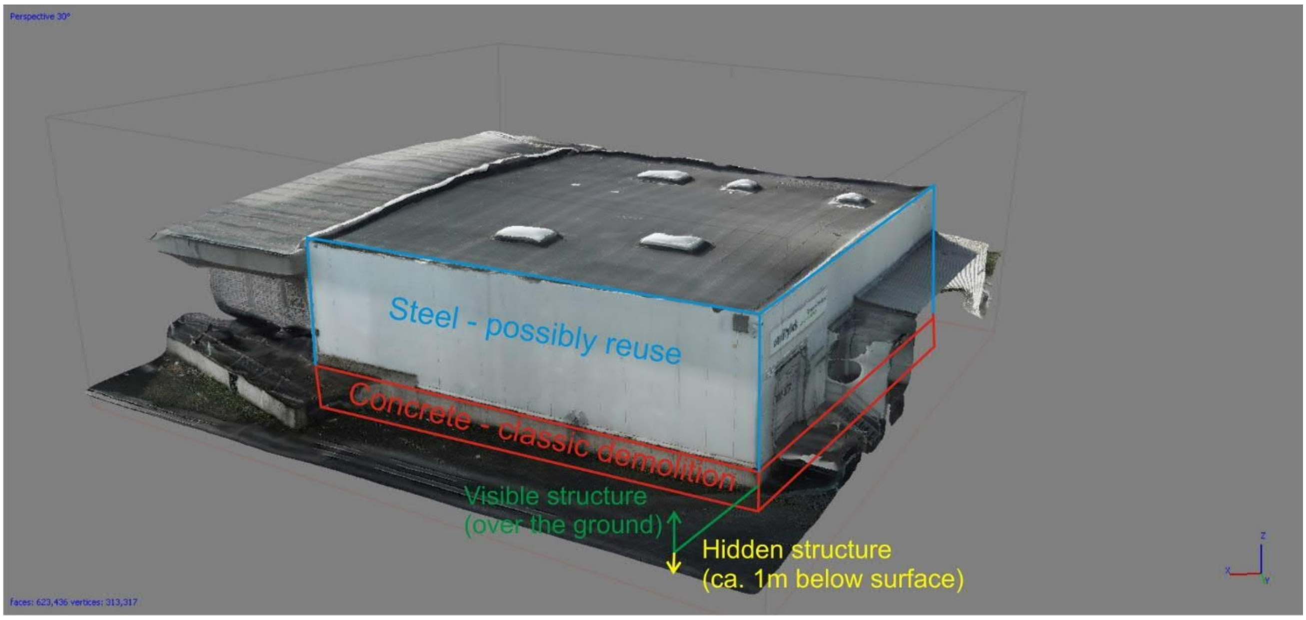


Figure 81 Overview of the SSB on a UAV model: The hall consist of a visible over the ground structure which is made of steel with attached cladding (blue), a concrete structure which ends ~1 m below the surface (red).

(B) Verification of the mechanical properties of the load-bearing structure (frames, secondary elements) before deconstruction

The demonstration of minimum-invasive testing of structural steel of existing single-storey building was carried out in autumn 2019, and therefore the material had to be obtained from a different deconstruction project than the market hall in Cologne, Germany. Two innovative methods for material strength and ductility identification were compared (small punch and instrumented indentation test) and it was concluded that the small punch testing is more mature and ready for use in similar situations. Additionally, sub-sized impact test was carried out and it was concluded that the material could be preliminary classified as S355JR. The full description of the experiments and their results was reported in Deliverable D7.1b [19].

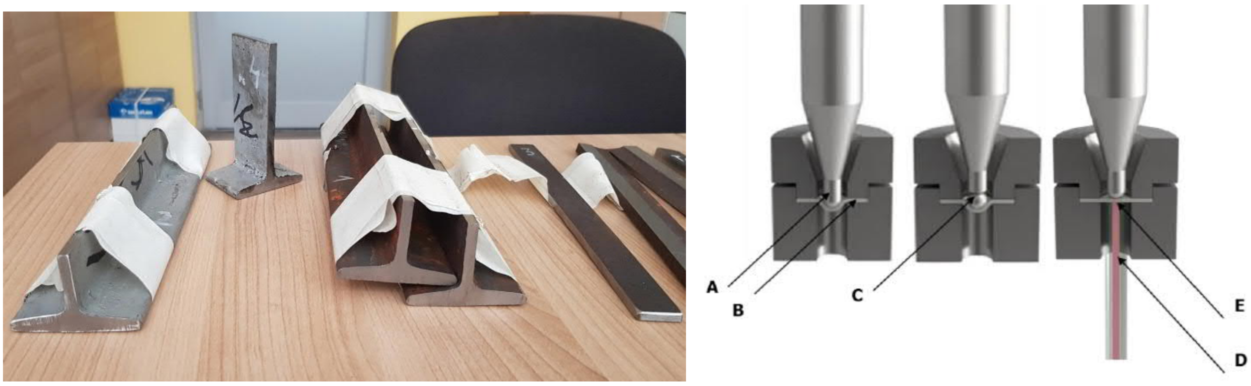


Figure 82 Material used for the demonstration of testing methods (left) and the schematics of small punch test (right)

(C) Deconstruction

The single-storey hall in Cologne, Germany was deconstructed according to the findings from the pre-demolition audit. Initially, there was no intention to reuse, and therefore the equipment and machinery was selected as for the traditional demolition. The decision to carefully deconstruct and reuse the steelwork was made later. This created a great opportunity to verify if the deconstruction of the steelwork can be performed using demolition excavators instead of the crane (see Figure 83). The demonstration was successful leading to economic savings in the process. Time, costs, labour work and on-site particles monitoring is reported in Deliverable D7.1a [18]. It should be noted that several additional partial deconstructions (or deconstructions of demo buildings) were used to obtain materials for the testing. They are described in Deliverable D7.1b [19].

Figure 83 Excavators removing the cladding (right) and pulling down the frame (left)

(D) Verification of the mechanical properties of the load-bearing structure (frames, secondary elements) after the deconstruction

Standard coupon tests were carried out on the material used for the minimum invasive methods for the verification of their results (see Figure 84). The Charpy impact tests were performed on sub-sized specimen, and therefore were reported among the verification methods that can be carried out before the deconstruction.

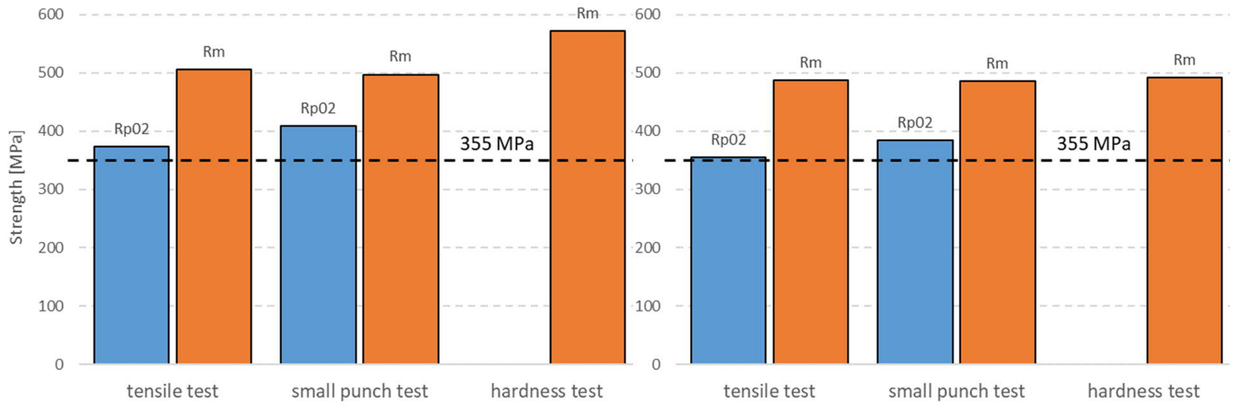


Figure 84 Comparison of predicted strength by standard tensile test, small punch test and hardness test on the web (left) and flange (right) of the I-section from the deconstructed single-storey steel building

(E) Verification of the chemical properties of the load-bearing structure

A sample from the reused steel truss fabricated in the first half of 20th century was sent for a chemical testing because of the doubts about its weldability. The results showed excessive amount of sulphur (0.07%) that may cause brittleness and reduce the weldability [19]. The following macrographic examination (sulphur print) of the cross-section didn't reveal any cracks, pores or other irregularities.

(F) Verification of the quality of the envelope

The extensive testing was carried out on sandwich panels with mineral wool and polyurethane (PIR) core. Mineral wool panels deconstructed from the test building in Hämeenlinna (Finland) after 11 years of service and PIR panels were deconstructed from Sandwich Demo House in Aachen (Germany) after 14 years of service. The mechanical properties of the panels were examined according to EN 14509, density, thermal conductivity and one-sided connections were also tested.

Conclusions

It was difficult to find a deconstruction and reuse project that would cover all the aspects of this Task, and therefore the experiments (parts B, D, E and F) were carried out and reported separately. The material for testing was obtained from several different buildings in Finland, Germany and Romania. Testing programme was extended, and at the end over 250 experiments were carried out to study the essential properties of the materials and components for reuse. The minimum-invasive Small Punch Test method showed promising results in steel strength prediction. The ageing effect was observed mostly in sandwich panels, while the main problems for structural steel components were the chemical impurities in the material fabricated before 1970s.

7.2 Theoretical studies of reusable building design

This section presents theoretical studies of building design from reclaimed elements to declare environmental and economic benefits of reused elements. It will cover the following six different theoretical case studies, presenting a comparative environmental and economic impact of the same steel building when the structure is build reusing an existing steel structure, using reclaimed elements or using new construction materials. The purpose of the study was to compare environmental and economic indicators (in terms of impacts such as GHG emissions and costs) of steel structures assessing structures made from elements using new materials along with structures made from reused steel components, quantifying the savings achievable by reusing construction materials. The study is based on an environmental impact assessment and on a life cycle cost assessment of a single-storey industrial hall erected in Romania. For the assessment were carried out and compared the following case-scenarios:

- Baseline scenario (Case 3-1) where the structure was designed as a new structure made with elements from new materials (optimal design).
- Second scenario (Case 3-2) where the structure was designed with elements from new materials, taking in mind the deconstruction at the end-of-life of the structure (a new structure made with elements from new materials designed for deconstruction) – covering also part of Deliverable 7.3 regarding Design for Deconstruction.
- Third scenario (Case 2-1) regarding a relocated steel structure; the scenario considered the reuse of an existing steel structure originated in Germany and reassembled in Romania (see Figure 85)

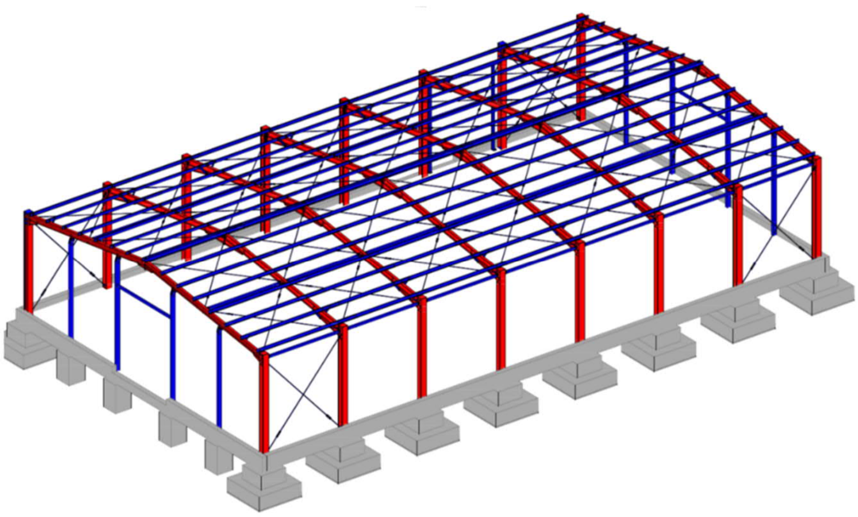


Figure 85. The steel structure rebuilt in Romania (reused steel in red, new steel in blue)

- In the fourth scenario (Case 2-2) it was weighed a steel structure made with reclaimed elements. Existing profiles for beams and columns have been identified in a storage yard in Germany deriving from other deconstructed buildings. All other components were made with new steel.
- The fifth scenario (Case 2-3) closeness Case 2-2, considering reclaimed elements such as columns and beams but also end plates for beams and columns. All other components represent new steel.
- The last scenario (Case 2-4) considered the reuse of an entire structure relocated from Germany. The percent of the reused steel in superstructure in this scenario is 100%.

The assessment was carried out having the following system boundaries:

- The heated floor area of the industrial hall is 525 m^2;
- Other materials and components considered:

    - concrete foundations and concrete floor: 185 m^3;
    - triple glazed windows: 22.5 m^2;
    - sectional sliding gates: 48 m^2;
- The U-value for the external walls is 0.56 W/m^2K, for roof elements is 0.34 W/m^2K, for ground floor slab is 0.76 W/m^2K while for windows and entrance-door is 1.3 W/m^2K;
- The operational lifetime of the building is 25 years;
- The assessment considers the main following building components: foundation and ground floor slab (concrete and steel rebars), steel load bearing structure (hot rolled and cold-formed steel elements), sandwich panels (steel sandwich panels with mineral wool insulation), triple glazed windows and sectional sliding gates.
- The steel rebars were counted as new material, with an input of 20% steel scrap in the process of manufacturing and an end-of-life scenario with 85% recycling potential and 15% landfilling or loss material after sorting.

Environmental assessment

Life cycle assessment method chosen for the evaluation of the environmental impact follows the rules of ISO 14044 [79], EN 15804 [80] and EN 15978 [74]. The approach for accounting of recycling in LCA is based on the modular building life cycle approach, where the benefits beyond the system boundary are reported separately. Global warming potential (GWP) was considered the indicator for the environmental performance. Each case from the four cases studied covered a view for "demolition and recycling" and one for "deconstruction and reuse" in the end-of-life module (except for the Case 3-1 which was considered for reuse only, as it included a design for deconstruction), see Table 35.

Table 35 Material flows in the assessed scenarios (incl. purlins)

End-of-life for steel in superstructure (reuse scenario)	Input			Output in recycling (reuse) scenario		
	New material	Reused material	Recycled material (scrap)	Waste	Reused material	Recycled scrap
Case 3-1	80%	0%	20%	10% (1%)	0% (90%)	90% (9%)
Case 3-2	80%	0%	20%	10% (0%)	0% (100%)	90% (0%)
Case 2-1	27.92%	65.10%	6.98%	10% (3%)	0% (72%)	90% (25%)
Case 2-2	35.61%	55.49%	8.90%	10% (4.45%)	0% (55.49%)	90% (40.06%)
Case 2-3	29.67%	62.91%	7.42%	10% (3.71%)	0% (62.91%)	90% (33.40%)
Case 2-4	0%	100%	0%	0%	0% (100%)	100% (0%)

LCA results of the assessed cases

Figure 86 presents the total LCA results of the assessed scenarios. The LCA savings are reflected as negative values while positive values define burdens of material utilisation. It can be seen that benefits and loads beyond the system boundary are not aggregated with the life cycle impacts (Modules A to C), as provided by the CEN/TC 350 methodology. According to the results, highest environmental impact is shown by the cases when structures erected with new elements are deconstructed for the next reuse case (1.24 t CO_2 e/m^2 – case 3-1 and 3-2) while the lowest rate of emissions are registered when structures are built with reused portal frames and at the end-of-life of the structure steel is recovered for recycling (0.97 t CO_2 e/m^2 – case 2-1).

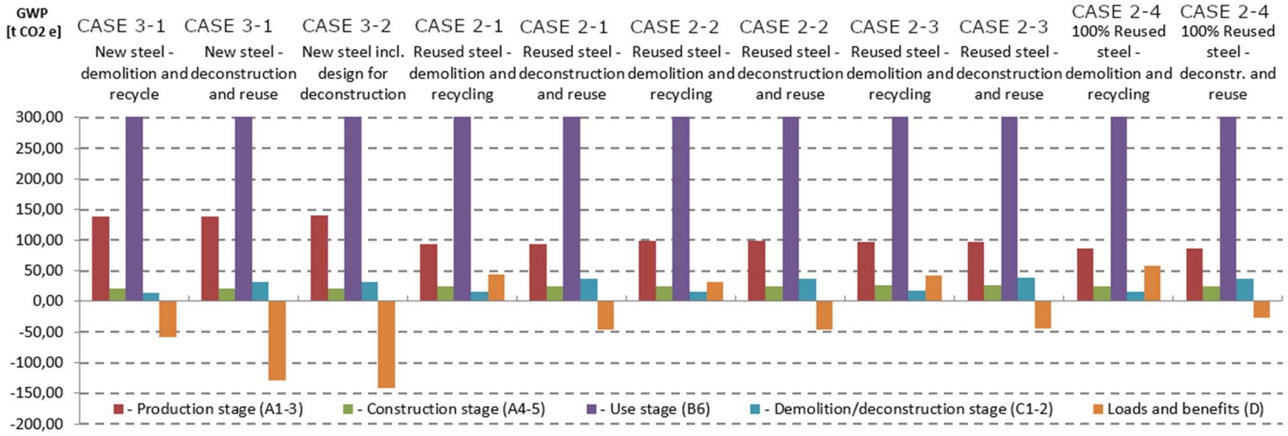


Figure 86. Total LCA results of the scenarios including loads and benefits beyond the system boundary

The results show that beyond the system boundary, in the scenarios where the structures built with reused elements and at the end-of-life steel is recovered for recycling, a burden is recorded in the assessment. The highest potential savings (0.244-0.269 t CO_2 e/m^2) appear in the scenario when the industrial hall was erected with new elements which are deconstructed for the next reuse case in the end-of-life.

Economic assessment

The calculation of economic indicators is based on the same scenarios and modules as in the LCA analysis, referring to new steel and reused steel structures, to which were associated time and financial costs. The assessment of the economic performance of studied cases follows the rules described in EN 16627 [90]. Potential cost savings includes revenues for recycled steel (earnings from the sold steel scrap), revenues from the sold steel elements or sold structure and revenues from the sold sandwich panels. Additional costs for expertise, redesign, testing, sandblasting, repainting were counted in cases where reused steel was involved.

LCC results of the assessed cases

According to the results, highest LCC (modules A-C) is shown by the cases when structures erected with reclaimed elements are deconstructed for the next reuse case (608 €/m^2) and lowest LCC by the case when construction uses new steel structures and after demolition recovered steel is sold for recycling (547 €/m^2). Figure 87 presents the total LCC results of the assessed scenarios, where the savings are reflected as negative values. When considering the loads and benefits from Module D only, the highest savings (34,70 euro/m^2 – 36,66 euro/m^2) come when the structure is deconstructed for a future reuse in the end-of-life, but when the total life cycle is considered, the costs of the structure built with reused construction materials (cases 2-1, 2-2, 2-3 and 2-4) exceed the costs of the structure designed with elements from new materials (case 3-1 and 3-2).

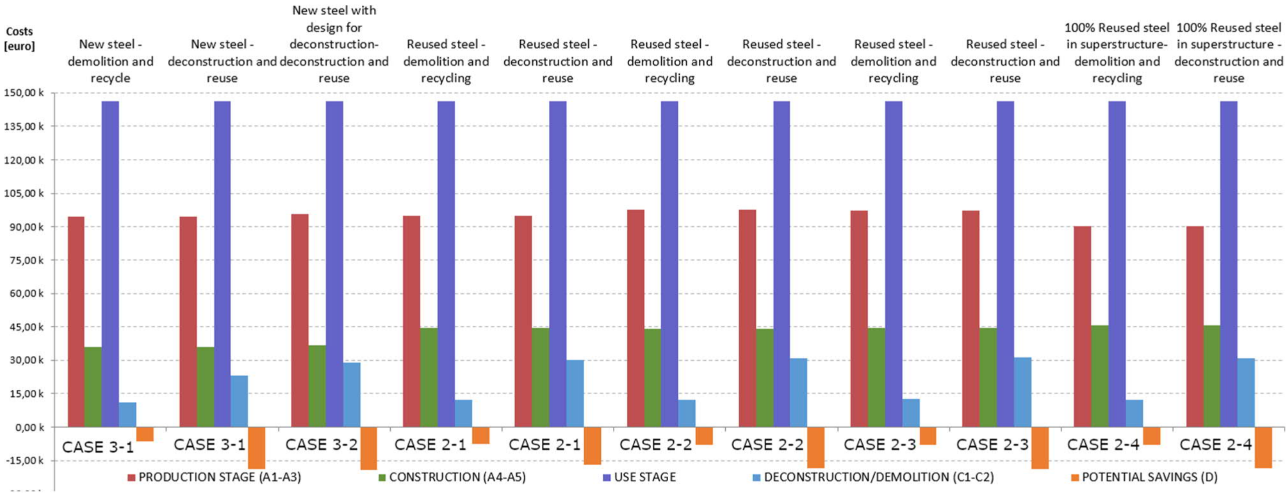


Figure 87. LCC results of the scenarios, including potential savings

The Life Cycle Assessment results showed that the reuse approach is a strategy that holds environmental benefits superior to recycling approach (modules A-C), the greatest gain being visible in the production stage ($A_{1\text{-}3}$) where GHG emissions are between 29-33% smaller when the structure is built with reused steel (188.51 kg CO_2 e/m^2 for structures built with reused steel in comparison with 266.26 kg CO_2 e/m^2 for structures built with new steel). According to the results, when it comes to economic potential of the reuse stages in various reuse and recycle scenarios, the scenario with reused steel elements resulted in higher potential savings (between 34.70 €/m^2 and 36.66 €/m^2) compared to recycling scenario (between 12.47 €/m^2 and 15.33€/m^2).

7.3 Design of building for improved reusability

Apart from the two case studies 3-1 and 3-2 discussed in the previous section, a thorough redesign of the existing storehouse building located in Tampere (Cases 3-3 to 3-5) was carried out to consider better reuse strategies [35]. The work on Case 3-5 continued later on with economical study for the reusability [36]. The building is rectangle shaped hall with length of 41.75 m, width of 31.5 m and height of approximately 10 m. Building has steel frame, with hollow sections as columns and hollow section trusses as main support in the middle and beams in the end of the building. In lateral direction, building is stiffened with rigid frames and in longitudinal direction, braces are used in both wall and roof to transfer horizontal wind loads. Building has load bearing corrugated sheets in the roof, which also act as a horizontal buckling support for top chords. Wall consists of sandwich panels that work both as an insulation and as façade. In addition to storage spaces, there are business premises inside the building. Business premises include meeting rooms, offices and social premises. Screen captures from existing building's information model is shown in Figure 88.

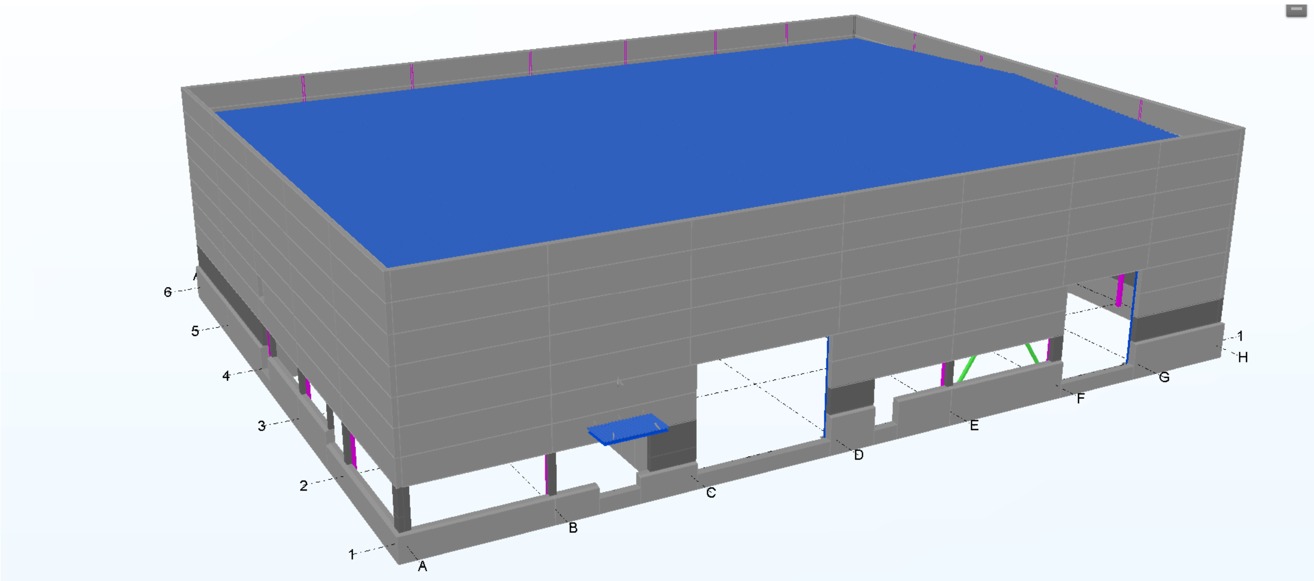


Figure 88 Screenshot of existing building's information model

In the first study, several re-use design options were presented to meet different levels of reusability of the building components (see Table 36). Finally, the last option "Case 3-5" was selected for more closely economical consideration. In this option, the total weight of the components was about 10% higher than in the original design.

Table 36 Steel quantities and fastener amount in different re-use options

	Original design	Case 3-3	Case 3-4	Case 3-5
Profiles	39 026 kg	50 846 kg	49 801 kg	42 760 kg
Plates	4 286 kg	7 983 kg	7 983 kg	5 992 kg
Sheets	17 680 kg	26 015 kg	17 680 kg	18 033 kg
Total weight	60 992 kg	84 844 kg	75 464 kg	66 785 kg
Fasteners	387	2749	2749	1315

The aim of the second, economical study was to resolve the feasibility of design for deconstruction and reuse in a case of commercial single-storey steel structure building. The viewpoint here is chosen especially for investors.

The research begins with a literature review on the reuse of buildings and their parts and investment / valuation calculations in the real estate industry. In addition, real-life examples of DfD and reuse are explored and analysed. This gives a backbone for the empiric part of the research. The empiric part consisted of a case-calculus which exploits the information collected from different sources. Relevant information was gathered, for example from the recent market reviews published by the major real estate companies in Finland, scientific articles and Ruukki Construction Oy. In addition to the basic calculus, a sensitivity analysis with different variables was utilised in order to solve the feasibility of DfD and reuse of building parts. After the empiric part, the results were evaluated, and conclusions were made about the economic feasibility of DfD and reuse of building parts. Lastly, recommendations and final thoughts about the subject were given.

From the literature it was found many barriers for using the DfD principles and reuse. As the DfD is likely to increase the initial construction costs and the benefits of it happens possibly far in the future, this is not a compelling equation for the investors, especially if it is not known when the building is thought to be deconstructed. There should be incentives that would force the investors, designers and builders to take the deconstruction phase of the building into consideration already in the design phase of the building. Means for this could be provided by for example, tightening legislation. This would then alleviate the reuse possibilities of building components. Of course, different designed service lives for different building parts questions the reusability of short-term building parts but for example, for the building structure designed service life is usually very long (50 to 100 years) so these parts should be designed and built in ways that enable reuse of them.

Building parts that are desired to be reused, must fulfil the quality requirements that are set to those. This means that their CE-markings and Declaration of Performances must be valid. Testing of reclaimed building components should be cost-effective and, in some cases, testing could be bypassed if the quality of the component can be assured in other way. Also, the customers mindset needs to change from neglecting reclaimed building parts to accepting those.

Calculations

In the first calculation the economic feasibility of DfD was explored by comparing the net present values (NPV) in 10-year discounted cash flow between two buildings: building not designed for deconstruction (Scenario 1) and building designed for deconstruction (Scenario 2). The only difference between buildings was that the DfD building was assumed to be constructed by applying the DfD principles which was reflected in slightly higher construction costs (initial investment) of 61k€ or 5,6%. Then by changing values in some parameters where the DfD was thought to have an impact, aim was to find favourable positions for the DfD building when comparing the NPVs.

In the first calculation an assumption was made that the buildings will stay in their current use after 10 year period, so the building would not be deconstructed in near future. The NPVs calculated were positive for both buildings: €148K for the traditional building and €88K for the DfD building. The initial difference of ca. €61K favouring the traditional building against the DfD building came from the higher initial construction costs for the DfD building.

After this basic calculus a sensitivity review and break-even analysis were performed. By changing the some of the parameters (yield, market rent, operating costs, construction costs), where the DfD principles can be thought to have an effect, aim was to discover positions where the DfD building (Scenario 2) would be a better option against the traditional building (Scenario 1).

Break-even points for the DfD building were yield of 6,67%, market rent of 8,28 €/sqm/mth and operating costs of 1,73 €/sqm/mth. The base level for these parameters were yield of 7,00%, market rent of 8,00 €/sqm/mth and operating costs of 2,00 €/sqm/mth. When changing two parameters simultaneously, for example yield of 6,90% and market rent of 8,20 €/sqm/mth would make the DfD building more profitable.

Studies have shown that for example, environmental certificates have a positive effect on the value of the building when compared to a building without a certificate and same kind of train of thought was used in this case. However, as the DfD does not yet have the same established “image premium” as the environmental certificates have, for example, remarkably lower yield requirements may be hard to justify for the investor. As the most tangible asset of the DfD occurs in the deconstruction phase of the building, this asset is hard to quantify, if the building will stay in its use more than 10 years.

In the second calculation it was assumed, that after certain time period (10, 20, 30 years) the building will either be demolished in case of the traditional building (Scenario A) or deconstructed in case of DfD building (Scenario B). The calculation compared the discounted residual values of demolition (where most of the steel is recycled) and deconstruction (where most of the steel is reused). In other word, this second calculation does not include normal real estate business incomes and costs from the use phase, but comparison is made only taking into account end of life costs. In the deconstruction option also the initial construction cost premium of ca. €61K was taken into account when performing the comparison. This can be thought as an extra investment for the DfD building which enables the reuse.

The discounted residual values calculated were negative for both buildings in every time period – naturally because calculation covers only the end of life phase without use phase. In the 10-year review with the base parameters, the discounted residual value when including the extra investment was ca. -€108K for the DfD building and ca. -€98K for the traditional building. So, with the base parameters the difference favouring the traditional building was ca. €10K in 10-year review but there was lot of uncertainty related to the biggest cost items (deconstruction/demolition costs, construction costs, resale price of the components).

For the DfD building with reuse (Scenario B) to break-even against the traditional building with recycle (Scenario A) when comparing the discounted residual values in 10-year review, for example the present value of vendible components should be ca. 13% higher than in the base case meaning their value should increase from the ca. €81K to ca. €92K. The construction cost premium should decrease from the ca. €61K to €50K for the Scenario B to become economically better option. If the other deconstruction costs for the Scenario B would decrease more than ca. 13% from the base figure of 119€/sqm to 103€/sqm, this would make the Scenario B a better option. As there was lot of uncertainty related to these cost items, these kind of changes favouring the DfD building with reuse could be plausible. On the other hand, changes to the other direction may also be possible.

When the time period is prolonged, this favours the traditional building with recycle option, as the benefits of reuse are weakened by the time and the effect of the initial construction cost premium becomes stronger. In the 20-year review the difference favouring the traditional building with recycle option when comparing the discounted residual values was ca. €42K. For example, for the DfD building with reuse to break-even in the 20-year review when comparing the discounted residual values, the present value of the components should be ca. €77K whereas in the base case their value was calculated to be ca. €35K. Anyway, all the residual values are relative low comparing to the total investment cost.

The calculation was also performed for the situation where the building is not designed for deconstruction but its parts (steel structure, roof structure and sandwich panels) are reused. The comparison was done between the reuse and recycle option for the traditional building. It can be speculated that the future tightening legislation may impose that some parts of the building must be deconstructed in a way that enables their reuse.

When compared to the DfD with reuse option, it was estimated that the deconstruction costs for the reusable parts were 25% higher and preparing for reuse costs were estimated to be ca. €12K higher. Other parameters were assumed to be the same. These assumptions were quite moderate, and it is possible that deconstruction and preparing for reuse costs could be much higher. However, with these assumptions it would make sense to deconstruct rather than demolish the building in the end of its life cycle even though it has not been designed for deconstruction.

Overall conclusions

With current practices it is hard to believe that DfD and reuse would spread wide across the construction industry in Finland purely by markets, when the building is thought stay in its place more than 10 years. The results from the DCF calculations support the view that when the possible benefits of DfD and reuse happen far in future this is not attractive for the investors. And as the costs of DfD incur in the beginning there is a clear imbalance of the profits and costs from the investor's point of view. This means that currently it is not profitable to choose DfD building over the traditional building at least when the time period is at least 10 years.

Two real examples were found in Finland with using the DfD principles (Hakaniemi's temporary market hall and shopping center Pikkulaiva). These cases show that DfD and reuse are utilised if the building is known to be transferred in 2-5 years after its completion. If the time span of the building is thought to be longer, using the DfD principles becomes more questionable from the economic point of view. The building parts that are reusable for example, after 30 years possibly include only the frame of the building. Overall it can be thought that the potential user group of DfD and reuse is at the moment user owners rather than investors.

It should be noted that there are lot of uncertainties on the real investment costs if building is designed for deconstruction. Even nowadays, at least the main frame of the building is quite easily reusable without any extra investments. Also the study showed that the differences in net present values in all studied cases are relative low between traditional and DfD buildings. This encourages to change design culture more for design for deconstruction direction. This could be also boosted by regulations without remarkable negative effect on current business.

8. Communication and dissemination (WP8)

The objectives of the Work Package 8 are to provide extensive and continuous dissemination through the internet (webpages, press releases, newsletters, social media and online tools) and discussions with the stakeholders via workshops and seminars. The following summary shows that the dissemination activities made during the first and second reporting periods greatly exceeded the original plans. The dissemination activities were organized in order to inform the wide audience across the whole value chain about the project outcomes and to get valuable feedback for the continuous implementation of the project. Therefore, the three main pillars of the dissemination were: the web presentation, workshops and seminars and the design guide developed in WP6. A prototype online tool for material exchange with implemented BIM functionality was developed to demonstrate the technological advantages of online marketing combined with machine-readable lifecycle information. The scientific community was addressed by several presentations at scientific conferences and papers published in scientific journals. Graduate and post-graduate students were involved in the project work and two master theses were completed within the project delivering the experiences from the consortium to the academy. The complete overview of the dissemination actions is provided in Table 37 and reported in more detail in the following sections.

Table 37 Overview of dissemination activities

Dissemination activities undertaken within the project	**Date and place**
Press release in SCI's "Connect" newsletter, Issue 69	March 2017, Ascot, UK
Press release by VTT Technical Research Centre of Finland "New life for steel waste structural components from old buildings", referred in more than 4 news servers in Finland and UK	16 May 2017 Espoo, FI
Demolition, Decontamination and Recycling (DDR) Expo: Panel discussion in the metals recycling session	14 Jun 2017 Brussels, BE
Demolition, Decontamination and Recycling (DDR) Expo: PROGRESS project roll-up in the exhibition area	14-16 Jun 2017 Brussels, BE
Eurosteel 2017: Conference presentation about reusability indicator for steel-framed buildings and application for an industrial hall	13-15 Sep 2017 Copenhagen, DK
Hradil, P., Talja, A., Ungureanu, V., Koukkari, H., Fülöp, L., Reusability indicator for steel-framed buildings and application for an industrial hall, ce/papers, Ernst & Sohn, Vol. 1, Issue 2-3, p. 4512-4521, 2018	13 Sep 2017 Copenhagen, DK
Danish Waste and Resource Network (Dakofa) meeting: Presentation of PROGRESS project	15 Sep 2017 Copenhagen, DK
Swedish Metals Producers Association (Jernkontoret) seminar about digitalization in metal industry: Presentation of selected topics from the PROGRESS project	1 Dec 2017 Stockholm, SE
Seppälä, J., Designing steel framed buildings for reuse: a case study, Master thesis, University of Oulu, Degree Programme of Civil Engineering	11 Feb 2018 Oulu, FI
EcoBuild 2018: Presentation of PROGRESS project	6-8 Mar 2018 London, UK
Metals in the Future: Presentation of PROGRESS project	19-20 Mar 2018 London, UK

World Steel Association meeting: Introduction of the new LCA calculation methodology for Module D of reusable steel	28 Mar 2018 (teleconference)
European Council for Construction Research, Development and Innovation (ECCREDI) meeting: Presentation of the project	3 May 2018 Brussels, BE
European Convention for Constructional Steelwork (ECCS) news about PROGRESS project in Steel Construction, Vol, 11(2), p. 172-176	16 May 2018 Brussels, BE
Euroconstruct 2018: Presentation of economic potential of reuse	7-8 Jun 2018 Helsinki, FI
Finnish Constructional Steelwork Association (TRY) seminar Teräsrakentamisen T&K päivät: Presentation of the thesis by Seppälä, J.	15-16 Aug 2018 Hämeenlinna, FI
IALCCE 2018: Organizing of special session dedicated to PROGRESS project	28-31 Oct 2018 Ghent, BE
Hradil, P., Fülöp, L., Ungureanu, V., Assessment of reusability of components from single-storey steel buildings, presentation in IALCCE conference and publication in conference proceedings	31 Oct 2018 Ghent, BE
Kamrath, P., Calculating the climate impact of demolition, presentation in IALCCE conference and publication in conference proceedings	31 Oct 2018 Ghent, BE
Vares, S., Hradil, P. Pulakka, S., Ungureanu, V., Sansom, M., Environmental- and life cycle cost impact of reused steel structures: a case study, presentation in IALCCE conference and publication in conference proceedings	31 Oct 2018 Ghent, BE
Kuhnhenne, M., Pyschny, D., Deconstruction, recycling and reuse of metal building envelopes, presentation in IALCCE conference and publication in conference proceedings	31 Oct 2018 Ghent, BE
Finnish Ministry of Environment seminar Circular economy in building sector, presentation concerning pre-demolition audits	7-8 Nov 2018 Helsinki, FI
European Construction Technology Platform (ECTP) Conference 2018, PROGRESS flyers in the exhibition area	13-14 Nov 2018 Brussels, BE
Hradil, P., Fülöp, L., Ungureanu, V., Assessment of reusability of components from single-storey steel buildings, Steel Construction, Ernst & Sohn (submitted manuscript)	19 Dec 2018
CircWaste networking seminar: Presentation of PROGRESS project to the Finnish municipal representatives.	13 Feb 2019, AM Lahti, FI
Built Environment Life Cycle Thinking Clinic: Organization of the PROGRESS workshop together with the Finnish Environmental Institute	13 Feb 2019, PM Lahti, FI
Futurebuild 2019: Presentation of PROGRES project	7 Mar 2019, London, UK
EcoBuild 2019: Presentation of PROGRES project	7 Mar 2019, London, UK
EGGA Annual Assembly: Presentation of PROGRESS project	11-12 June 2019 Antwerp, BE
The 16th National Conference on Steel Structures: Organization of the PROGRESS workshop	13-14 June 2019 Timisoara, RO
Construmat 2019: Organization of the PROGRESS workshop	16-17 May 2019, Barcelona, ES

The 16th National Conference on Steel Structures: Organization of the PROGRESS workshop	13-14 Jun 2019 Timisoara, RO
Finnish Constructional Steelwork Association (TRY) seminar Teräsrakentamisen T&K päivät: Presentation of the project.	18 Nov 2019 Helsinki, FI
Steel and Composite Construction conference: Organization of PROGRESS workshop	21-22 Nov 2019, Coimbra, PT
Organization of PROGRESS workshop in UK together with REDUCE project during the Steel Reuse Event	8 Oct 2019 London, UK
BILT Europe: Presentation of PROGRESS project	10-12 Oct 2019, Edinburgh, UK
Norwegian Steel Day: Presentation of PROGRESS project	31 Oct 2019 Oslo, NO
(CANCELLED) Organization of PROGRESS workshop in Netherlands together with Bouwen met Staal	*20 Mar 2020* *Amsterdam, NE*
(CANCELLED) Organization of PROGRESS workshop in France together with FFB and CTICM	*29 Apr 2020* *Paris, FR*
Webinar 1: Reusing existing, single-storey steel buildings	7 May 2020 12:00-13:30 CEST
(CANCELLED) Organization of final PROGRESS workshop and seminar together with ECCREDI	*12 May 2020* *Brussels, BE*
Webinar 2: Design of new single-storey steel buildings for reuse	14 May 2020 12:00-13:30 CEST
Webinar 3: Life cycle assessment and reusability assessment of single-storey steel buildings	21 May 2020 12:00-13:30 CEST
Webinar 4: Overview of the EU project PROGRESS	27 May 2020 12:00-13:30 CEST
Hradil, P., Fülöp, L., Ungureanu, V., Assessment of reusability of components from single-storey steel buildings, Steel Construction, Design and Research, 2019	Published in 2019
Vares, S., Hradil, P., Ungureanu, V., Sansom, M., Environmental- and life cycle cost impact of reused steel structures: a case study, Structure and Infrastructure Engineering (SIE), 2020	Published in 2020
Hradil, P., Fülöp, L., Vares, S., Sansom, M., Quantifying the environmental benefits of reusing and recycling constructional steel, The International Journal of Life Cycle Assessment	Submitted in 2020
Dissemination activities planned after the project end	**Date and place**
Press release by VTT Technical Research Centre of Finland informing about the final outcomes of PROGRESS project	June 2020 Espoo, FI
Final update of VTT's PROGRESS webpage with links to the project outcomes	June 2020 Espoo, FI
Presentation on IALCCE conference	27-30 Oct 2020 Shanghai, CN
Publication of the D6.1&2 [17] under ECCS Design Manual series	2021

8.1 Internet presentations

The webpage dedicated to the project PROGRESS was opened in November 2017 on the website of the European Convention for Constructional Steelwork on www.steelconstruct.com, under the “EU Projects” button in the menu (see Figure 89). The ECCS being a European federation of steelwork contractors’ associations, gathering 18 Full Members as national associations all over Europe and Associate Members among promotional organisations and research institutes, plus Supporting Members in the industry of metalwork and coatings. The Consortium members unanimously agreed to make the project widely visible through that channel in order to reach the most interested partners from the construction sector. ECCS is involved in a series of European projects, whether it is RFCS, FP7 or H2020 and is perceived as the ideal channel for wide dissemination.

The ECCS website was regularly updated with new information and further developed within the project every time the project required it. The webpage of the project is divided into public and “members only” access. The main public information is made visible through the project webpage but also through regular publications in the ECCS electronic newsletter distributed regularly to a database of 30.000 names from the sector (architects, engineers, design offices, contractors, students, professors…) and in the ECCS quarterly Journal, Steel Construction, Design and Research, distributed to professionals all over the globe.

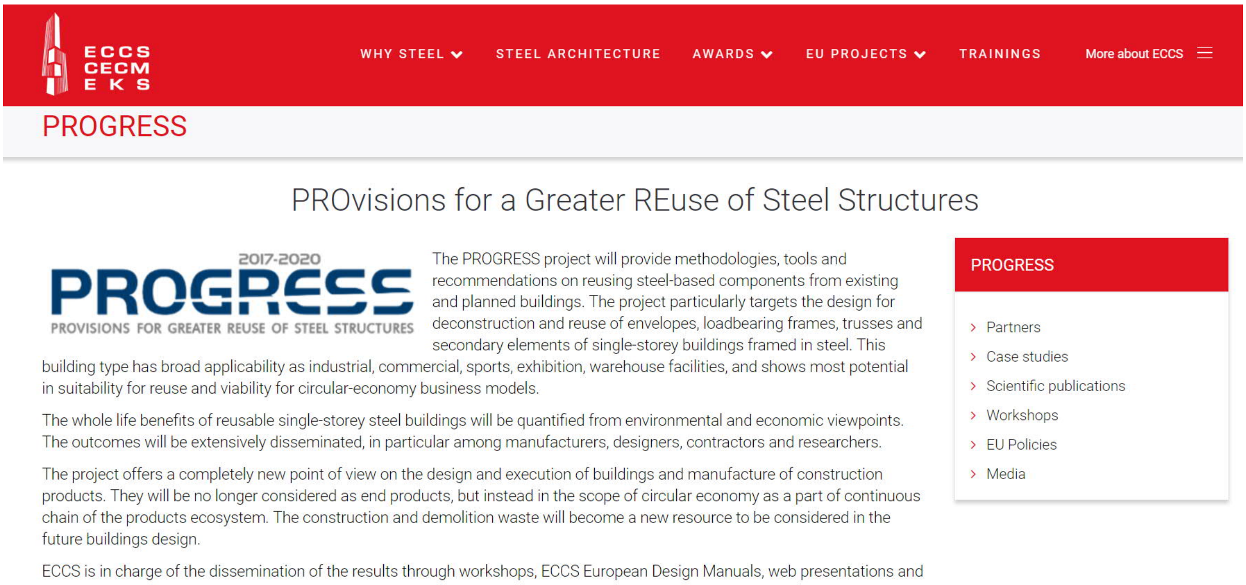


Figure 89 PROGRESS webpage (ECCS)

Additionally. VTT opened an informative webpage at http://www.vtt.fi/sites/progress/ and shared workspace accessible for the project members, advisory group and the Project Officer. VTT’s website contains basic information about the PROGRESS project and links to the documented case studies in Task 1.1 (see Figure 90).

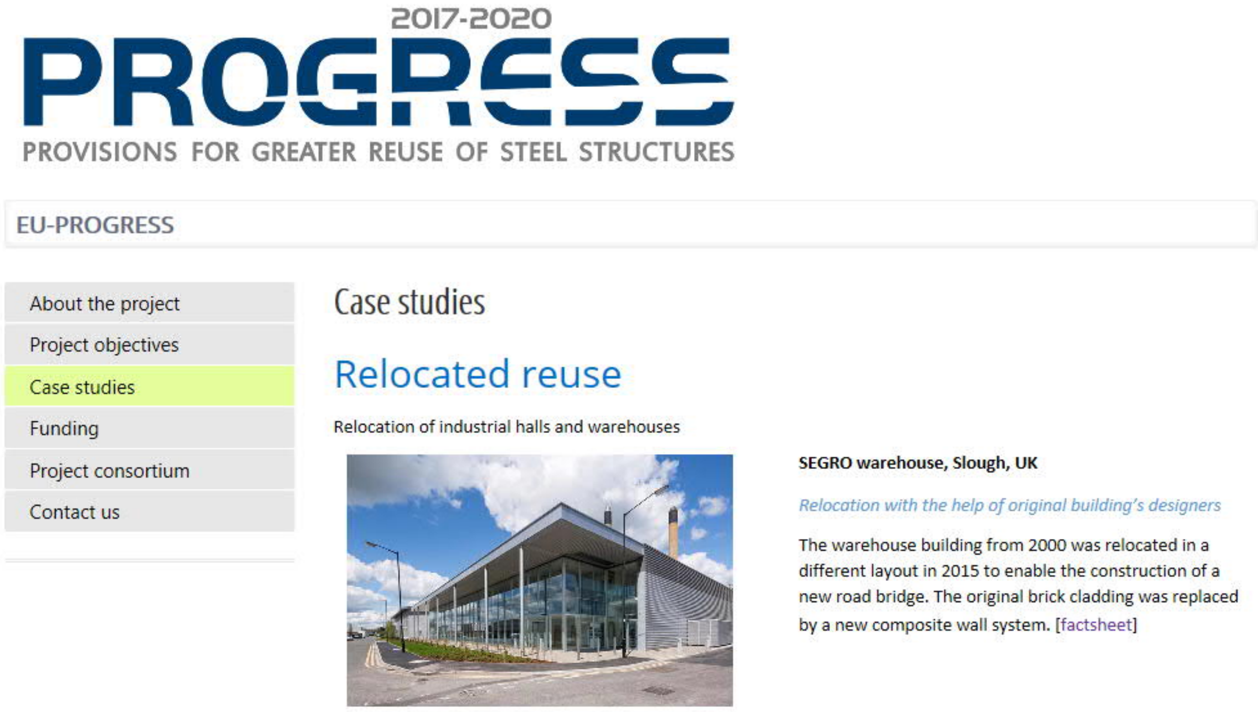


Figure 90 PROGRESS webpage (VTT)

The shared workspace contains:

- Project background (as agreed in the Consortium Agreement)
- Project official documents (restricted to project beneficiaries and Project Officer)
- Work documents (restricted to project beneficiaries and Project Officer)
- Meeting minutes and presentations (as agreed in Consortium Agreement)
- Deliverables (as agreed in the Consortium Agreement)
- Logos and templates for the project communication and dissemination
- Dissemination results

8.2 Seminars and workshops

As per commitment, the following workshops have taken place during the period 1.1.2019 until 31.5.2020:

Life Cycle Thinking Clinic Workshop (13 February 2019, Lahti, Finland)

The workshop was co-organized with the Finnish Environmental Institute (SYKE) on 13 February 2019 in Lahti. During this workshop, opportunities for CDW reduction by reuse of building elements were presented, and a CircWaste networking seminar was organized to present the PROGRESS project to the Finnish municipal representatives.

Barcelona Building Construmat (16 May 2019, Barcelona, Spain)

The Progress workshop was hosted by the Spanish member organization of ECCS, ASCEM, during the Barcelona Building Construmat, on 16 May 2019 in Barcelona. Construmat is the biggest Fair related with construction in Spain and is gathering all the actors of the built environment such as contractors, authorities, large public and audience.

During the event, the Progress project, which had been selected among 23 finalists, was awarded the First Prize in the category Innovative Project or Service. Mr Jordi Romanyà Ribé, President of ASCEM (Spanish Association of Steelwork Contractors) and CEO of SCS Culleré i Sala, Spanish steelwork contractor, was invited to present the advantages of steel solutions in construction and the potential of re-use in the circular economy concept.

Figure 91 From left to right: Construmat Organizer, Jordi Romanya (President of ASCEM), Petr Hradil (coordinator of PROGRESS), Elena Orteu, President of the Jury and architect. On the right, the Trophy itself.

National Conference on Steel Structures (13 June 2019, Timișoara, Romania)

The 16th edition of the National Conference on Steel Structures (CM16-2019) took place in Timișoara (UPT), during the period 13-14 June 2019, organized by the Faculty of Civil Engineering of the Politehnica University of Timişoara, Department of Steel Structures and Structural Mechanics (CMMC), together with the Romanian Academy – Timișoara Branch, Centre for Fundamental and Advanced Technical Research (CCTFA) and in collaboration with the Association of Metal Construction Producers from Romania (APCMR). In addition to the conference sessions, on 13 May afternoon, the results obtained in European research project PROGRESS were presented. The invited speaker is Markus Kuhnhenne from RWTH Aachen University with the title of the presentation entitled: Reuse of steel cladding systems.

Steel Reuse Event (8 Ocrober 2019, London, United Kingdom)

This specific workshop was held in London on 8 October 2019 and presented the findings from two EU-funded research projects (REDUCE and PROGRESS) investigating design for deconstruction and reuse of steel structures. The seminar covered a range of topics linked to steel reuse including demountable sheer connection systems, standardisation and demountable structural connections, sampling and testing protocols, legal and commercial aspects and guidance. It was also the occasion to launch the new Protocol for reusing structural steel.

XII Conference on steel and composite construction (21 November 2019, Coimbra, Portugal)

The XII Conference on Steel and Composite Construction was held in Coimbra - Portugal, on 21st and 22nd of November 2019.

The conference was organized by Associação Portuguesa de Construção Metálica e Mista (CMM), the Portuguese Member association of ECCS, and had as main objective the dissemination of the innovations and achievements in this type of construction, seeking to contribute decisively to the consolidation and expansion of the sector. This edition had as its special theme "**Steel Structures as the Answer to the Climatic Changes".**

During the conference, a special symposium was dedicated to PROGRESS. This special session covered the topics concerning the reuse of steel-based components from existing and planned buildings. It focused on methodologies, tools and recommendations to maximize the environmental and economic potential of the building components through their reuse.

Cancelled workshops

Due to the COVID 19 pandemic, ECCS together with the partners decided to cancel the last 3 workshops for safety reasons.

- PROGRESS workshop (20 March 2020, Hoofddorp, the Netherlands)
- Seminar Circular Construction with steel (29 April 2020, Paris, France)
- Circular Construction (Progress Final Workshop , 12 May 2020, Brussels, Belgium)

In order to compensate the cancelled workshops and continue the dissemination activities regarding reuse of steel structures, it was decided to organize a series of 4 webinars distributed on the month of May, i.e one seminar per week for a maximum duration of 90 minutes per seminar.

Thanks to the experience of SCI in the organization of professional webinars and thanks to the large network and database of ECCS (more than 30.000 addresses), the partners managed to replace the loss of the 3 workshops by four efficient and successful webinars, given for free. The success was immediate and quickly reached the maximum participation (100 delegates). It was felt necessary to buy and upgrade the Webex licence to accommodate up to 1000 delegates!

PROGRESS webinar 1: Reusing existing, single-storey steel buildings (7th May 2020)

- Introduction and context
- Pre-deconstruction audits (VTT)
- Reusability of existing structural steel including sampling and testing strategies, SCI Protocol P427 and CE marking (SCI)
- Reusing existing envelopes (RWTH)

PROGRESS webinar 2: Design of new single-storey steel buildings for reuse (14th May 2020)

- Introduction and context
- Current practice; building types, structural forms and regional practice (SCI)
- Good practice for design for future reuse (SCI)
- Demountable and reusable envelope systems (RWTH)
- Application of BIM to facilitate reuse (VTT)

PROGRESS webinar 3: Life cycle assessment and reusability assessment of single-storey steel buildings (21st May 2020)

- Introduction and context
- Reusability assessment (VTT)
- Environmental assessment of steel reuse and recycling (SCI)
- Economic assessment (VTT)
- LCA case studies (UPT)
- Business models for steel reuse and the prototype steel reuse portal (SCI)

PROGRESS webinar 4: Overview of the EU project PROGRESS (28th May 2020)

- Summary of the research project PROGRESS (VTT, Petr)
- Experiences and lessons learned from the past (UPT, Viorel)
- Good practices in design for reuse (SCI)
- Benefits of steel reuse for the construction industry and EU strategies (VTT, Petr)

8.3 Online tool prototype

The aim of Task 8.3 was to develop a prototype website portal for sharing information about the reuse of steel-framed SSBs and their constituent components. The portal provides information and guidance (from earlier WPs and particularly the Design Guide D6.1-2 [17]) but focuses on systems to trade steel buildings and products. In terms of the functionality of the portal, it has been developed to address both:

- Reuse today scenario, i.e. a traditional ‘sell-buy’ exchange but devoted specifically to reclaimed structural steel and steel-based envelope products from existing buildings
- Development of a database of new structural steel in newly constructed buildings, i.e. facilitating future deconstruction and reuse.

As set out in the proposal, the structure of the website was organised as shown in Figure A.

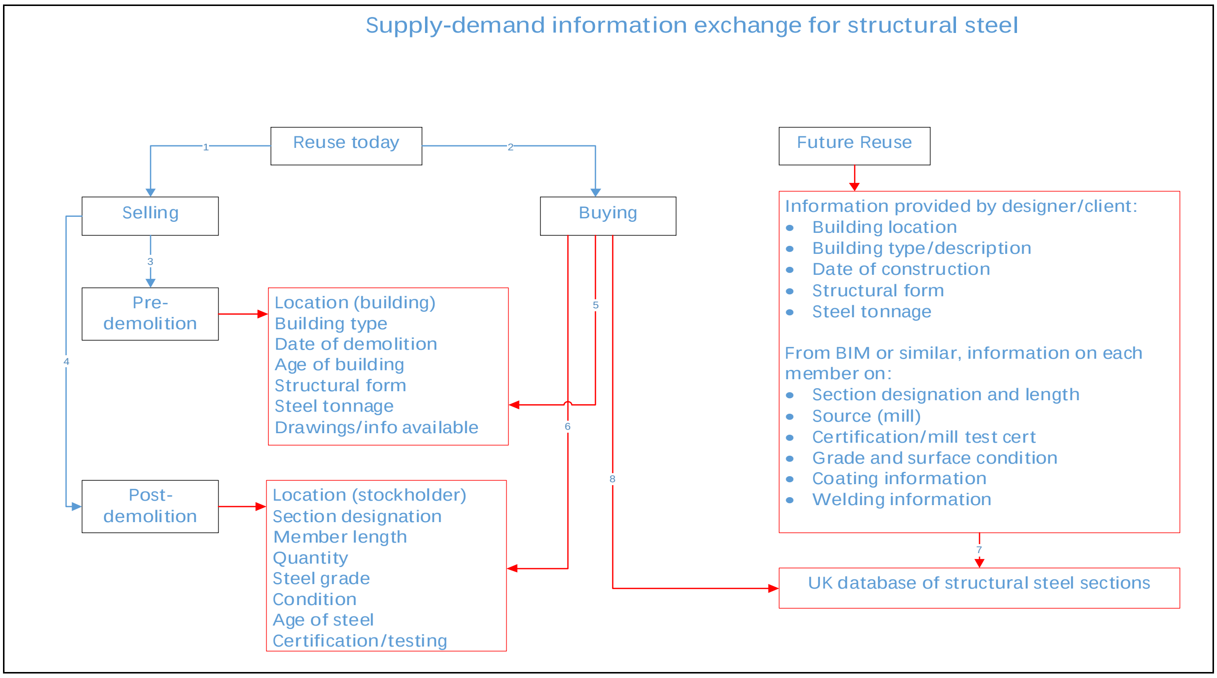


Figure 92 Framework of the prototype steel reuse portal

The prototype website was developed by SCI and IceBlue company. Although the website is intended to include all product groups within the scope of PROGRESS, the prototype development has focussed on hot-rolled, primary structural sections and on single-storey buildings.

Table 38 describes the different scenarios shown in Figure 92. Screenshots from the prototype are used to illustrate the website functionality.

Table 38 Information exchange scenarios and actors

Scenario	**Selling[1]**	**Actor**	**Buying[1]**	**Actor**	**Notes**
Reuse today, i.e. existing buildings	1	Building owner/Demolition contractor	2	Client/ designer	
Pre-demolition	3	Building owner/Demolition contractor	5	Client/ designer	General building information to link buyer and seller. More detailed information by negotiation
Post-demolition	4	Stockholder/ Demolition contractor	6	Client/ designer	Scenario in which either the entire building structure or an inventory of the structural elements are offered for sale
Future reuse, i.e. facilitating future reuse	7	Client/Demolition contractor	8	Client/ designer	Future scenario where BIM information is uploaded to a database to enable future reuse.

[1] Refer to the number shown in Figure A

Pre-demolition - Route 3/5 (see Figure A)

For this scenario it is assumed that, for most buildings, insufficiently detailed information is available, pre-demolition, to enable designers to plan for the reuse of the steel in sufficient detail. Information exchange therefore is limited to basic project/building information. The building information is posted (most likely) by the building owner or demolition contractor and if the building is likely to be of interest for reuse, the designer can make contact with the demolition contractor or building owner directly to discuss the potential for reuse in greater detail. This could include a more detailed pre-demolition audit and/or a review of existing design information and drawings, if these are available, or a more intrusive survey and testing.

Post-demolition - Route 4/6 (see Figure A)

This scenario assumes that the building has been deconstructed with a view to reusing the reclaimed members, i.e. care has been taken to deconstruct the building carefully with a view to preserving the structural steel members. Post-demolition, more information is more readily available, for example, section designation, length, etc. If testing is required, the results should also be made available.

For small-scale listings, information on individual elements can be uploaded manually using simple drop-down menus; as is the case for the current prototype. For larger inventories/databases, such as those held by stockists that currently trade in reclaimed sections, a means of uploading data (web service) to the website automatically would need to be developed.

Figure B shows the search facility to find buildings potentially available for reuse. The user inserts a postcode and search radius and selects either the ‘pre-demolition’ or ‘post-demolition’ scenario. Available buildings are shown on a map and are listed (left of screen). Clicking on ‘more details’ brings up further details about the building or the available sections depending on the scenario selected. All website users are able to search on the website but to list projects or to make contact with sellers, users are required to register and logon to the website.

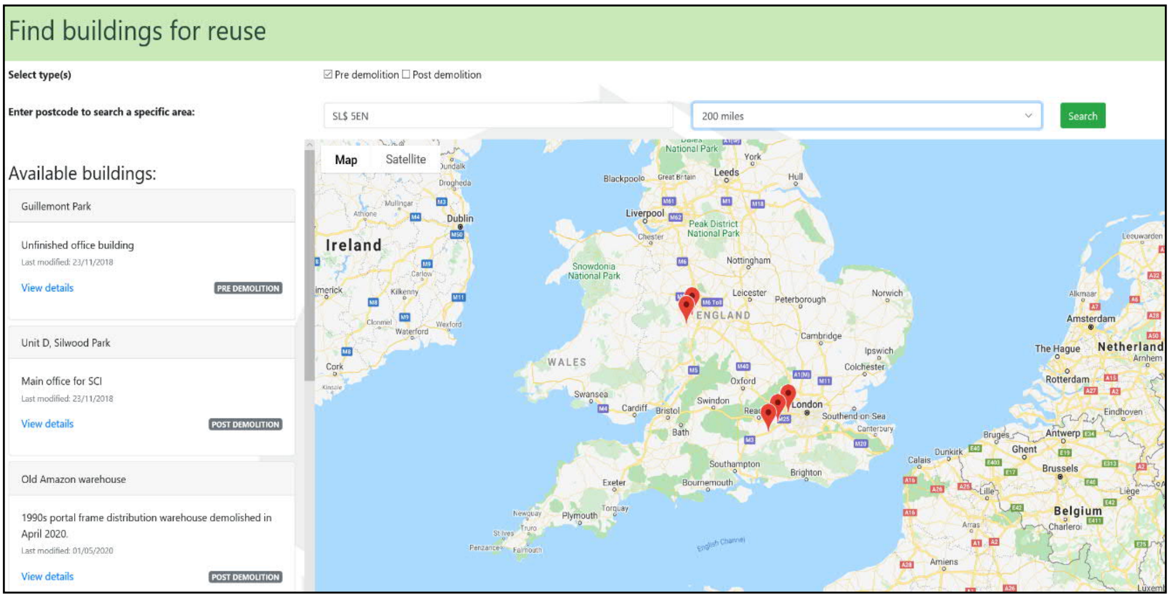


Figure 93 Search facility to find a steel building available for reuse

Figure C shows the building details returned for the pre-demolition scenario. Location details are provided together with details of the building including:

- Age of building
- Scheduled demolition date
- Size of building
- Overview of section sizes, grade, sub-grade, etc.
- Contact details to enquire about the building (only available to registered users).

Figure D shows the results returned for the post-demolition scenario. In addition to the project description and the location of the building/sections, an inventory of the available sections including their size, length, grade and quantity is provided. Contact information is available to registered users of the web site.

Project: NTS building, Thirsk

PRE DEMOLITION

Project description
dss

Address
120 Eldmire Lane,
Thirsk,
Yorkshire,
YO7 3HE.
United Kingdom

Project details

Building type
Industrial

Scheduled demolition date
31/05/2055

Age of building
1984

Structural form
Portal frame

Condition of steel structure

Number of bays
2

External column spacing
7.50

Column section range
0

Rafter section range
0

Steel Grade
S275

Steelwork coating
Shot-blasted

Is the steel structure CE marked?
True

Info regarding CE marking

Number of storeys
0 storeys

Footprint of building
0.00 x 0.00 m

Gross floor area
11700 m^2

Estimate of steel tonnage
0 tonnes

Height of building
11.00 m

Width of bay
30.00 m

Internal column spacing
7.50

Column section size
0

Rafter section size
0

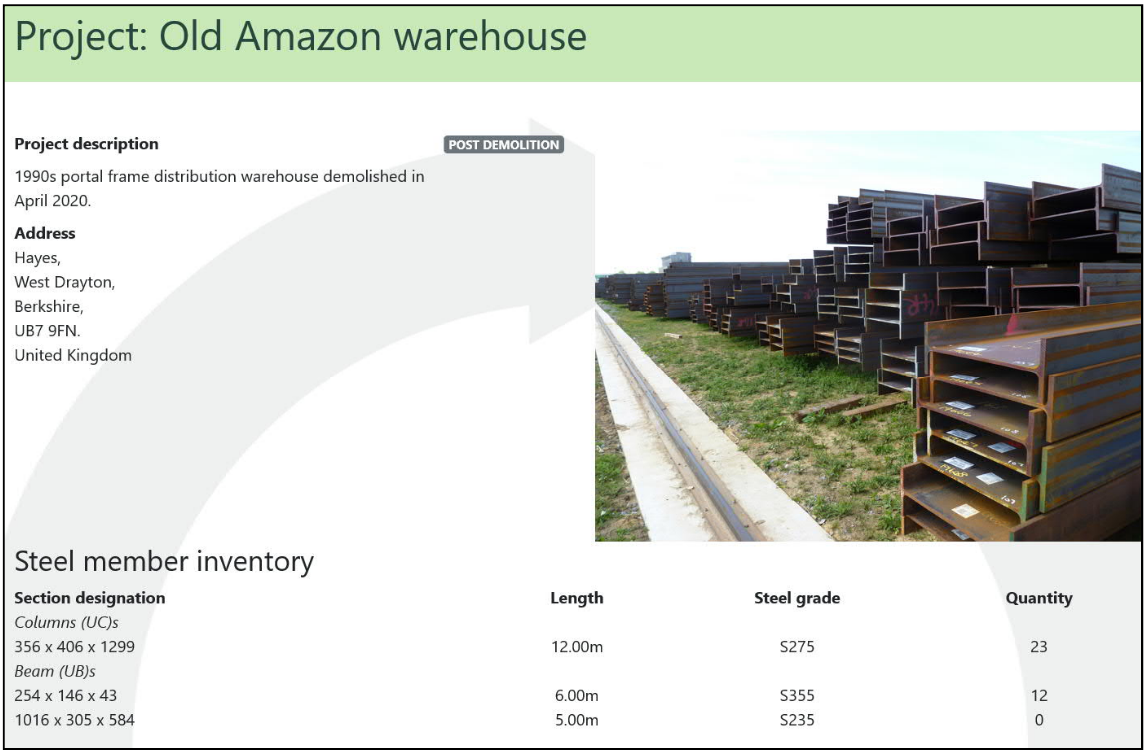
Steel Subgrade
J0

Roof pitch
3 degrees

Are building drawings/information available?
Yes

Other information

Figure 94 Pre-demolition project details



Project: Old Amazon warehouse

POST DEMOLITION

Project description
1990s portal frame distribution warehouse demolished in April 2020.

Address
Hayes,
West Drayton,
Berkshire,
UB7 9FN.
United Kingdom

Steel member inventory

Section designation	Length	Steel grade	Quantity
Columns (UC)s			
356 x 406 x 1299	12.00m	S275	23
Beam (UB)s			
254 x 146 x 43	6.00m	S355	12
1016 x 305 x 584	5.00m	S235	0

Figure 95 Post-demolition details

Alternatively, users can search the database of available reclaimed sections using the search facility shown in Figure E. Users input the following search criteria:

- Section type; currently UB, UC, PFC
- Postcode and search radius
- Section size from a dropdown menu of standard section sizes.

Note that the functionality to search for a range of section sizes has not yet been implemented in the prototype website.

Available sections are listed and clicking on 'view details' returns the information shown in Figure F.

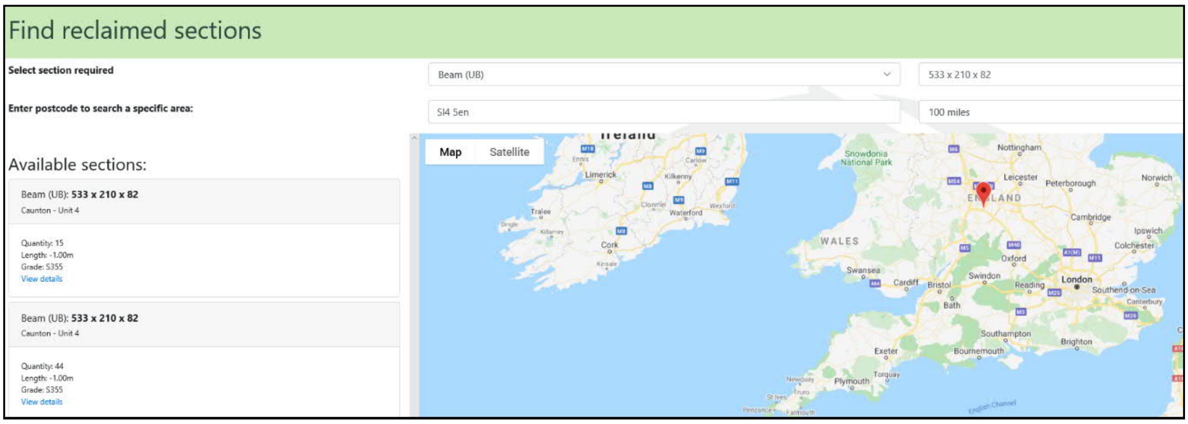


Figure 96 Search functionality for a specific section

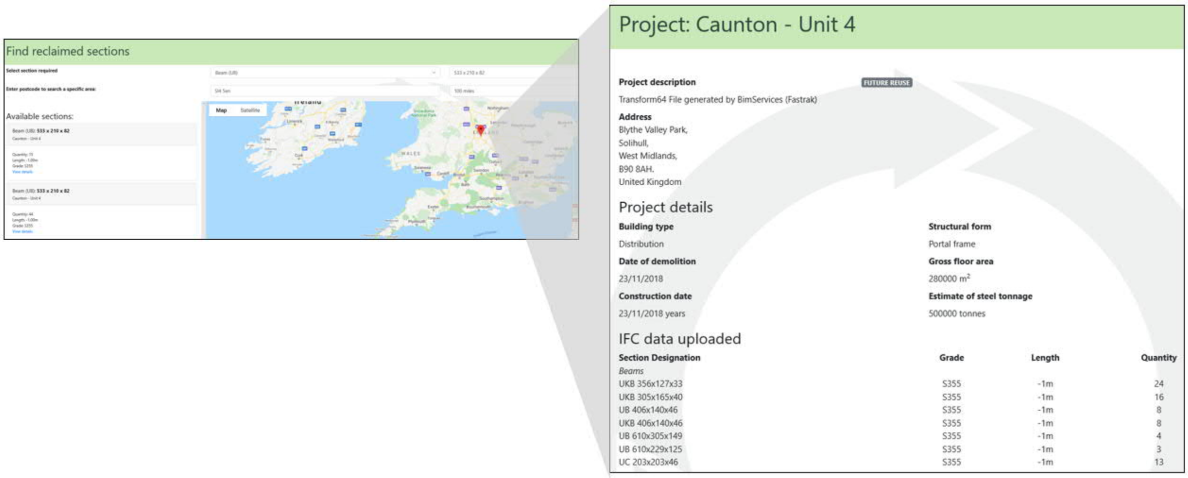


Figure 97 Returned results for a search for a specific section size

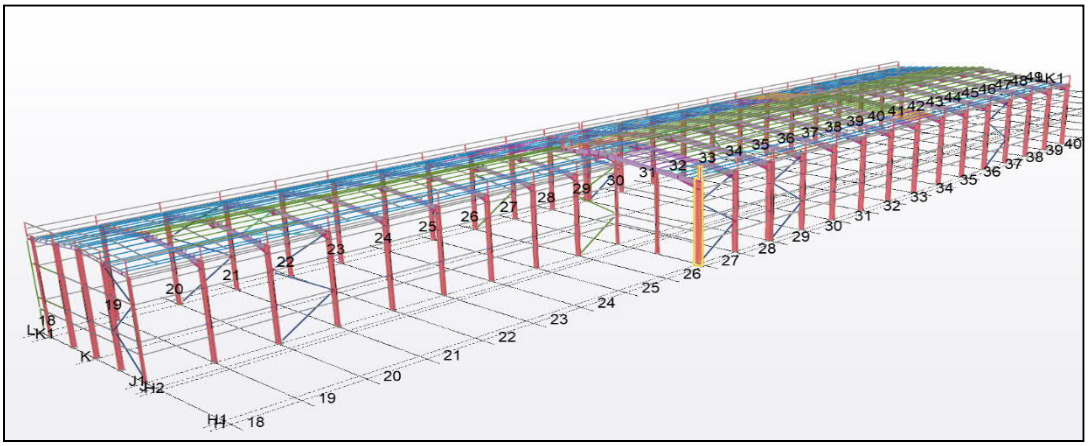
Future reuse - Route 7/8

This scenario relates to future reuse, i.e. enabling reuse of steel structures in the future. By capturing detailed information on buildings constructed today, this information will enable buildings to be refurbished or extended and potentially reused in the future. Data fields relate to:

- Building or project information, and
- Elemental information.

Project information is inputted manually and elemental or product information is provided to the portal via uploaded IFC files. The whole building structural models are held confidentially and securely until such point as they either due to be refurbished, structurally extended or when they are scheduled for demolition. At this time, the project/building information becomes searchable (as described in Figure B) and the elemental information will be placed in the database of reclaimed sections and searchable as shown in Figure E.

For the purpose of testing this functionality of the prototype website, a number of IFC models of steel SSBs have been provided by UK steelwork contractors to SCI – see Figure G which shows two examples.



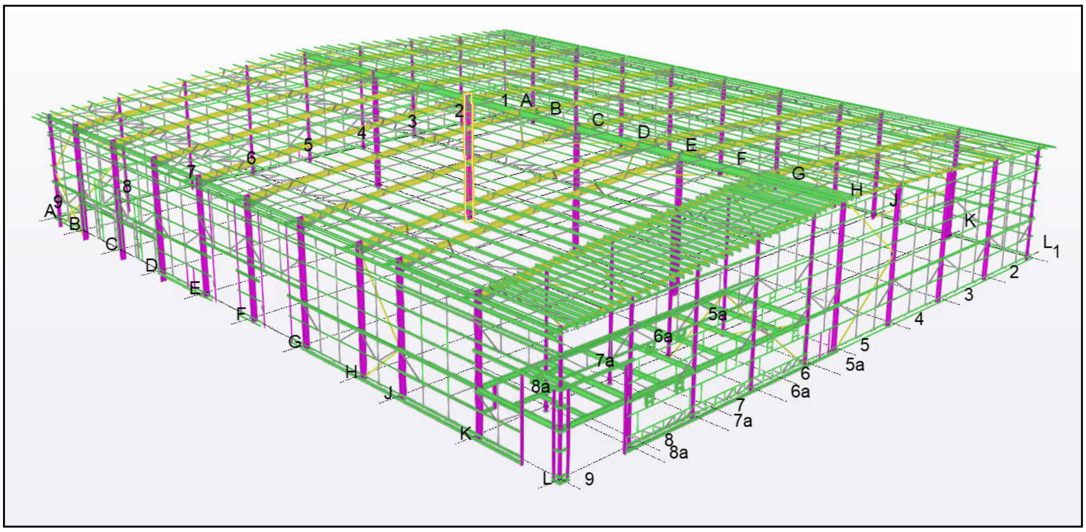


Figure 98 IFC files of single-storey, steel structures (models viewed using Tekla BIMsight)

Within the prototype, coding has been written to search through the IFC files and automatically select the elemental information and store this information in a searchable database. Figure H visualises this process using a screenshot for a UB 457 x 152 x 52 beam obtained from Tekla BIMsight. As shown, the section size, length, grade, sub-grade and weight are captured and stored in the database. Note that the example IFC files used during testing of the prototype, are in the format provided by the steelwork contractor. Although they contain the most important product information, it is recommended that a larger dataset is specified for the IFC file. This could include, for example, the mill certificate (or reference or link to this) and environmental information, for example in the form of an environmental product declaration (EPD).

One other challenge in automating the process of searching IFC files is the precise formatting of the product descriptions. For example, for section size, different steelwork contractors use either UB 457 x 152 x 52 or UB 457 * 152 * 52 similarly the way/format that the steel grade and sub-grade are recorded in the IFC file can vary. All of the IFC files tested within the prototype so far have been provided by UK steelwork contractors. This difficulty is likely to be greater with the inclusion of IFC files from other countries and other languages and reinforces the need for a clear standard on what information to include in the IFC model and the precise formatting of that information.

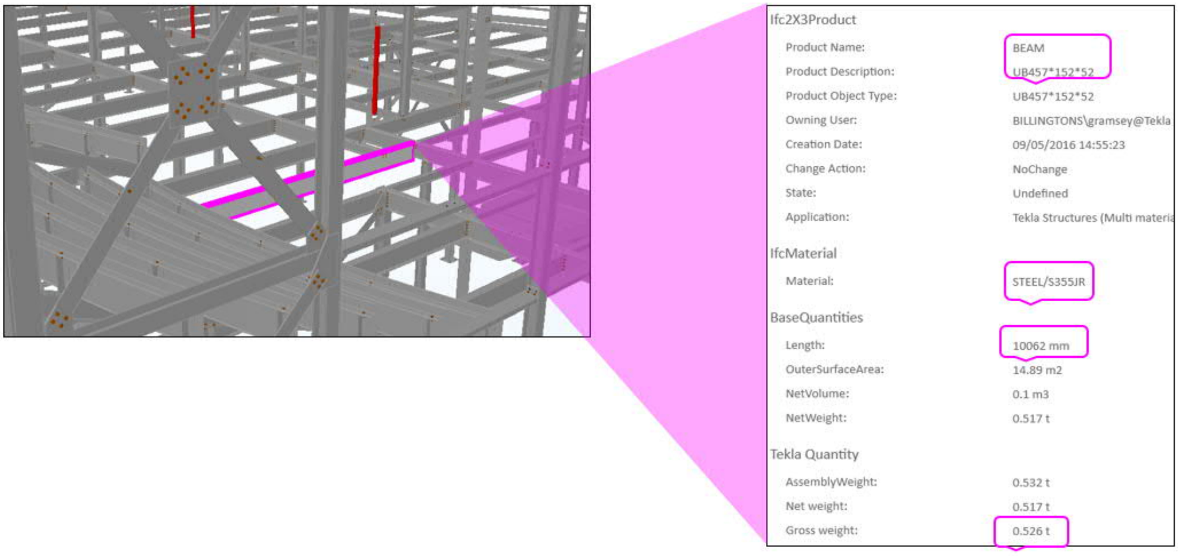


Figure 99 Elemental information extracted from IFC file

Summary and next steps

A prototype website for facilitating current reuse, i.e. of existing buildings, and future reuse has been developed and tested using example SSB projects. The scope of the prototype has been limited at this stage to primary structural steel elements however, the structure and functionality of the website can be easily extended to other structural steel products, including secondary steel elements and cladding products.

More work is required to take the prototype to a publicly available, fully functioning website however it is strongly recommended that this is done since no such material exchange is currently available providing the level of detail required to safely and cost effectively reuse reclaimed primary structural steelwork. Collating and securely storing structural models of new SSB is a very cost effective way of facilitating future reuse since these models are already routinely generated by European steelwork contractors and therefore generating these IFC files requires no additional effort or cost. Further work is however required to ensure the confidentiality of stored models and also to ensure that there are no security concerns for building owners particularly for some building types.

9. Project coordination (WP9)

This section presents the coordination activities on the project and Work Package level. The aim was to ensure effective project management by coordinating delivery of project results within planned budget and timescale, preparation of periodical reports and financial statements to the European Commission, promoting close interaction between partners and organising progress meetings with the whole consortium.

The delivery of the results was coordinated in order to follow the milestones and expected delivery dates indicated in the Grant Agreement of PROGRESS project. The deliverables submitted to the European Commission are listed in Table 39. Copies of all finished documents and drafts were stored in the shared workspace maintained by the project coordinator.

Table 39 Overview of project deliverables

Name of the deliverable		Submission
D1.1	Factsheets on review of existing deconstruction cases [1]	2.5.2020
D1.2	Report on the reuse potential of single-storey steel buildings [2]	31.8.2018
D1.3	Report on the legal barriers and opportunities [3]	28.2.2019
D2.1	Safe and efficient deconstruction (D2.1a) [4]	8.6.2020
	Deconstruction protocol for single-storey steel framed buildings (D2.1b) [5]	
D2.2	Suitability of materials and components in a new design situation [6]	2.5.2020
D2.3	Quality verification protocol including test results [7]	30.5.2020
D3.1	Summary of design practices for reusable buildings and products [8]	23.4.2020
D3.2	Building Information Model (BIM) implementation in steel reuse [9]	31.5.2020
D4.1	Report on new hybrid solutions and joining methods [10]	28.2.2019
D4.2	Test report on connections [11]	30.5.2020
D4.3	Production and Testing of Prototypes [12]	16.6.2020
D4.4	Evaluation of hybrid systems performance [13]	8.6.2020
D5.1	Methodology to declare environmental benefits of reused elements [14]	28.2.2019
D5.2	Economic assessment of reusing steel-based elements [15]	3.10.2019
D5.3	Circular economy business models [16]	4.6.2020
D6.1	European Recommendations for Reuse of Reclaimed Steel Products in Single-Storey Buildings [17]	19.6.2020
D6.2		
D7.1	Report on deconstruction of a single storey hall for reuse (D7.1a) [18]	16.6.2020
	Report on testing of materials and products (D7.1b) [19]	
D7.2	Case studies for the implementation of reclaimed elements [20]	23.4.2020
D7.3	Improved design solutions for better reusability [21]	23.4.2020
D8.1	Webpage [22]	28.11.2017
D8.2	Workshop materials [23]	31.8.2018
D8.3	Prototype information sharing portal [24]	4.6.2020
D9.1	Comprehensive overview of the project [25]	30.11.2017

In addition to the deliverables, two periodic reports were submitted to the Commission covering periods from 1 June 2017 to 31 December 2018 [26] and from 1 January 2019 to 31 May 2020 [27].

The Consortium agreed to organize 7 face-to-face progress meetings during the project (every 6 months) and review meetings by teleconferences between them. The initial review period of 3 months was shortened to 2 month after the 5th Consortium meeting in Timisoara because of the increased work effort planned in the second half of 2018. Due to the unexpected restrictions caused by the COVID-19 pandemic in Europe, the Consortium agreed to organize all the meetings in 2020 online. The overview of consortium meetings is in Table 40. Minutes and presentations from the meetings were stored in the shared workspace maintained by the coordinator. The particular work in the Work Packages and Tasks was discussed separately in teleconferences according to the needs of the Work Package leaders. Their plans were described in the minutes of consortium meetings.

Table 40 Overview of the Consortium meetings organized during the project

Meeting	Date and place	Attendants
1st	7-8 June 2017 in Espoo, Finland	23
2nd (online)	31 August 2017	10
3rd	29-30 November 2017 in Aachen, Germany	9
4th (online)	27 February 2018	8
5th	29-30 May 2018 in Timisoara, Romania	12
6th (online)	7 August 2018	7
7th (online)	2 October 2018	10
8th	26-27 November 2018 in Brussels, Belgium	10
9th (online)	18 December 2018	7
10th (online)	31 January 2019	9
11th	21-22 May 2019 in Ascot, UK	11
12th (online)	21 July 2019	9
13th (online)	3 October 2019	8
14th	20-21 November 2019 in Coimbra, Portugal	12
15th (online)	17 January 2020	9
16th (online)	31 March 2020	10
17th (online)	30 April 2020	11
18th (online)	26 May 2020	8
19th (online)	22 June 2020	10

The consortium vote was initiated in the beginning of 2nd Reporting Period about the need to support PKIR. The consortium decided to take over some parts of PKIR work. VTT organized reporting of the experimental work in Task 7.1, UPT and SCI formulated the deconstruction protocol in Task 2.1. The decision was communicated to the Project Officer and since the change of the budget was less than 10%, no amendment to the Grant Agreement was needed.

Exploitation and socio-economic impact of the research results

Socio-economic implications of steel reuse

The implementation of circular economy principles in construction sector is important for many reasons, mainly because it represents the highest priority in the waste recovery, it significantly reduces the environmental impacts of the manufactured building products and reduces the dependency on the non-renewable natural resources.

Although the recycling of steel is already very efficient, the generated amount of waste will be reduced if the products are continuously reused without being disposed first. Moreover, steel industry has a significant carbon footprint and the reduction of this impact will greatly contribute to the global efforts to mitigate the climate crisis. Reuse of components in buildings has a potential to avoid 20 Mt CO_2e yearly in EU with almost half of the savings directly attributed to steel components [97]. About 10% reduction of environmental impact of steel industry can be also expected if the reused content and reuse potential is properly declared on the product level [14].

From the economic point of view, the cost of the reusable steelwork is not likely to decrease significantly in the near future without any administrative intervention (such as recycling tax or reuse incentive) [21], but its value will be depreciating slower than the traditional steelwork [15]. Moreover, new local businesses will be emerging especially for stocking, trading and reconditioning of reclaimed material [24]. This will create a good opportunity for the territorial deployment of circular economy strategies. One of the important social effect of implementation of reuse concept is the growing acceptance and trust in second-hand materials in new buildings such as can be seen nowadays in reused consumer products with shorter lifecycles. This is typically coupled with the increased awareness of the property owners about the end-of-life value of their buildings.

Reusing of components from single-storey steel halls is a convenient starting point, as those structures are fairly simple, regular and abundant. Moreover, they are already many successful attempts to reuse such buildings [1] and develop a business concepts based on the circulation of reclaimed components and assemblies [2].

It should be noted that the research outcomes of PROGRESS project can be applied more widely. For instance, the innovations in steel connection technologies will have larger impact also in concrete, wood and composite construction. The most important conclusion of the PROGRESS project is that steel is the most suitable material for reuse at the moment, and therefore the steel sector should take the lead and pave the way for other, more complex, materials towards the circular and sustainable future.

Exploitation potential of the research results

The exploitation of particular outcomes of PROGRESS project can be summarized as:

- **Improvement of the overall design philosophy** of constructional steelwork supported by the European Recommendations for Reuse of Steel Products in Single-Storey Buildings [17] and master thesis at University of Oulu [35] (presented in Finnish Constructional Steel Association's conference).
- **Increased awareness about the alternative end-of-life options** with examples published in 14 Factsheets of the existing deconstruction cases [1] (PROGRESS webpage of ECCS and VTT webpage, presented to industrial stakeholders)
- **Possibility to avoid large waste streams** using the recommended rules for product/waste status [3] (presented to the Danish Waste and Resource Network, Dakofa and members of the Finnish municipalities) and material testing protocol for re-certification of steel products [7] (presented in PROGRESS webinars, May 2020)
- **Optimization of deconstruction and demolition process** with the reusable components identified and labelled in advance (Guidelines and template for pre-demolition audits [4] presented to the Finnish Ministry of Environment and industrial stakeholders) and guidance (deconstruction protocol as part of the deliverable D2.1 [5])
- **Systematic and transparent declaration of the environmental benefits** of steel reuse with the methodology to declare LCA beyond the system boundary [14] (presented to World Steel Association, developed into a case study and presented in IALCCE 2018, published in SIE journal)
- **Support for the larger sustainability strategies and single project-based decisions** with the simple metrics for the quick assessment of the reusability [2] (methodology presented in Eurosteel 2017 and IALCCE 2018, published in Steel Construction journal) and life-cycle costing model (master thesis at Aalto University published in 2019 [36])
- **Combination of energy and material efficiency** in buildings by the application of innovative joints for the existing envelopes [11] (presented in IALCCE 2018) and future envelopes [12] (Smart Flashing Connector presented in PROGRESS webinars)
- **Significantly decreased need for material testing** with product whole-life traceability supported by the recommendations for BIM/IFC extension to include CE marking, EPD and other relevant data [9] (part of the deliverable D3.2)
- **Development of new business areas** with the help of circular economy business models [16] and prototype online trading portal [24] (presented in PROGRESS webinars, May 2020)

List of figures

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List of acronyms and abbreviations

ACE	Architects Council of Europe
ASU	Apparent Steel Use
BCSA	British Constructional Steelwork Association
BIM	Building Information Model
BS	British Standards
BRE	Building Research Establishment
BREEAM	BRE Environmental Assessment Method
CA	Consortium Agreement
CE	Circular Economy
CEN	European Standardization Committee
CC	Consequence Class
CDW	Construction and Demolition Waste
CHS	Circular Hollow Section
CPD	Construction Products Directive
CPR	Construction Products Regulation
DDR	Demolition, Deconstruction, Recycling
DfD	Design for Deconstruction
DGNB	German Sustainable Building Council
DoP	Declaration of Performance
DT	Destructive Testing
EAD	European Assessment Document
EAG	Extended Advisory Group
EC	European Commission
ECCE	European Convention for Civil Engineers
ECCREDI	European Council for Construction Research, Development and Innovation
ECCS	European Convention for the Constructional Steelwork
ECTP	European Construction Technology Platform
EDA	European Demolition Association
EN	European Standard
ENV	European Prestandard
EOTA	European Organization for Technical Assessment
EoW	End of Waste
EPD	Environmental Product Declaration
ETA	European Technical Assessment

EU	European Union
EU-15	EU member countries prior to 1 May 2004
EU-28	EU member countries after 1 July 2013
FIEC	Federation of Construction Industries
FRP	Fibre-Reinforced Plastics
GA	Grant Agreement
GBM	Generic Business Model
GDP	Gross Domestic Product
hEN	Harmonized European Standard
IALCCE	International Association for Life-Cycle Civil Engineering
IFBS	International Association for Metal Building Envelopes
IFC	Industry Foundation Classes
IIT	Instrumented Indentation Test
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCC, LCCA	Life-Cycle Cost Assessment
LCI, LCIA	Life-Cycle Impact Assessment
LoD	Level of Detail
MW	Mineral Wool
NA	National Annex
NACE	The Statistical classification of economic activities in the European Community
NAD	National Application Document
ND, NDT	Non-Destructive Testing
NPV	Net Present Value
PEF	Product Environmental Footprint
PEFCR	PEF Category Rules
PKIR	Paul Kamrath Ingenieurrückbau
PO	Project Officer
prEN	Draft European Standard
prENV	Draft European Prestandard
PROGRESS	Provisions for a Greater Reuse of Steel Structures
PU, PUR	Polyurethane
RHS	Rectangular Hollow Section
RCA	Recycled Concrete Aggregate
RCC	Recycled Crushed Concrete
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals

RFCS	Research Fund for Coal and Steel
RWTH	Aachen University
SCI	Steel Construction Institute
SPT	Small Punch Test
SSB	Single-storey steel framed building
SVHC	Substance of Very High Concern
SYKE	Finnish Environmental Institute
TAB	Technical Assessment Body
TC	Technical Committee
TRY	Finnish Constructional Steelwork Association
UB	Universal Beams (British standard sections)
UPT	Polytechnics University of Timisoara
VDI	Association of German Engineers
VTT	VTT, Technical Research Centre of Finland, Ltd.
WFD	Waste Framework Directive
WP	Work Package

References

[1] Ungureanu, V., Fechete, H., Dubina, D., Factsheets on review of existing deconstruction cases, Deliverable D1.1 of PROGRESS project, Timisoara, Romania, 2020.

[2] Kuhnhenne, M., Pyschny. D., Hradil, P., Sansom, M., Kesti, J., Dubina, D., Ungureanu, V., Report on the reuse potential of single-storey steel buildings, Deliverable D1.2 of PROGRESS project, Aachen, Germany, 2018.

[3] Wahlström, M., Hradil, P., Sansom, M., Legal barriers and opportunities in structural steel reuse, Deliverable D1.3 of PROGRESS project, Espoo, Finland, to be submitted in February 2019.

[4] Kamrath, P., Ungureanu, V., Sansom, M., Wahlström, M., Hradil, P., Safe and efficient deconstruction, Deliverable D2.1a of PROGRESS project, Dortmund, Germany, 2020.

[5] Ungureanu, V., Georgescu, M., Grecea, D., Burca, M., Deconstruction protocol for single-storey steel framed buildings, Deliverable D2.1b of PROGRESS project, Timisoara, Romania, 2020.

[6] Ungureanu, V., Girão Coelho, A.M., Report on the suitability of materials and components to be used in a new design situation, Deliverable D2.2 of PROGRESS project, Timisoara, Romania, 2020.

[7] Pimentel, R., Girão-Coelho, A., Sansom, M., Hradil, P., Fülöp, L., Ungureanu, V., Kesti, J., Quality verification protocol including test results, Deliverable D2.3 of PROGRESS project, Ascot, UK, 2020.

[8] Pimentel, R. et al., Summary of design practices for reusable buildings and products, Deliverable D3.1 of PROGRESS project, Ascot, UK, 2020.

[9] Hradil, P., Mäkeläinen, T., Vares, S., Pimentel, R., Building Information Model (BIM) implementation in steel reuse, Deliverable D3.2 of PROGRESS project, Espoo, Finland, 2020.

[10] Kuhnhenne, M., Pyschny, D., Sansom, M., Girão Coelho, A.M., Kesti, J., Ungureanu, V., Kamrath, P., Hradil, P., Report of new hybrid solutions and testing methods, Deliverable D4.1 of PROGRESS project, Aachen, Germany, 2020.

[11] Kuhnhenne, M., Pyschny, D., Janczyk, K., Test report on connections, Deliverable D4.2 of PROGRESS project, Aachen, Germany, 2020.

[12] Kuhnhenne, M., Pyschny, D., Janczyk, K., Production and Testing of Prototypes, Deliverable D4.3 of PROGRESS project, Aachen, Germany, 2020.

[13] Ungureanu, V., Buzatu, R., Muntean, D., Neagu, C., Kuhnhenne, M., Pyschny, D., Janczyk, K., Evaluation of hybrid systems performance, Deliverable D4.4 of PROGRESS project, Timisoara, Romania, 2020.

[14] Ungureanu, V., Greca, D., Hradil, P., Vares, S., Sansom, M., Pyschny, D., Report on the methodology to declare environmental benefits of reused elements, Deliverable D5.1 of PROGRESS project, Timisoara, Romania, 2019.

[15] Vares, S., Hradil, P., Sansom, M., Ungureanu, V., Kamrath, P., Economic assessment of reusing steel-based elements, Deliverable D5.2 of PROGRESS project, Espoo, Finland, 2019.

[16] Sansom, M., Hradil, P., Kamrath, P., Circular economy business models, Deliverbale D5.3 of PROGRESS project, Ascot, UK, 2020.

[17] Girão-Coelho, A., Ungureanu, V., Hradil, P., Kesti, J., European Recommendations for Reuse of Reclaimed Steel Products in Single-Storey Buildings, Deliverables D6.1 and D6.2 of PROGRESS project, Ascot, UK, 2020.

[18] Kamrath, P., Report on deconstruction of a single storey hall for reuse. Deliverable D7.1a of PROGRESS project, Dortmund, Germany, 2020.

[19] Rantala, J., Kilpi, L., Andersson, T., Kivi, S., Nyholm, A., Arffman, P., Hradil, P., Kesti, J., Kuhnhenne, M., Pyschny, D., Janczyk, K., Ungureanu, V., Kamrath, P., Report on testing of materials and products, Deliverable D7.1b of PROGRESS project, Espoo, Finland, 2020.

[20] Ungureanu V, Buzatu R, Muntean D, Hradil P, Vares S, *Case studies for the implementation of reclaimed elements*, Deliverable D7.2 of PROGRESS project, Timisoara, Romania, 2020

[21] Savolainen, J., Kesti, J., Pajala, O.-P., Improved design solutions for better reusability, Helsinki, Finland, 2020.

[22] Dehan, V., Hradil, P., Webpage, Deliverable D8.1 of PROGRESS project, Brussels, Belgium, 2017.

[23] Dehan, V., Grogna, F., Hradil, P., Workshop materials, Deliverable D8.2 of PROGRESS project, Brussels, Belgium, 2020.

[24] Sansom, M., Prototype information sharing portal, Deliverable D8.3 of PROGRESS project, Ascot, UK, 2020.

[25] Hradil, P., Fülöp. L., Vares, S., Wahlström, M., Sansom, M., Kesti, J., Lautso, P., Kuhnhenne, M., Pyschny, D., Dubina, D., Ungureanu, V., Dehan, V., Kamrath, P., Comprehensive overview of the project, Deliverable (confidential) D9.1 of PROGRESS project, Espoo, Finland, 2017.

[26] Hradil, P. (ed.) PROGRESS Periodic Technical Report No. 1, Part B, Espoo, Finland, 2018.

[27] Hradil, P. (ed.) PROGRESS Periodic Technical Report No. 2, Part B, Espoo, Finland, 2020.

[28] Hradil, P., Talja, A., Ungureanu, V., Koukkari, H., Fülöp, L., Reusability indicator for steel-framed buildings and application for an industrial hall, ce/papers, Ernst & Sohn, Vol. 1, Issue 2-3, p. 4512-4521, 2018

[29] Hradil, P., Fülöp, L., Ungureanu, V., Assessment of reusability of components from single-storey steel buildings, proceedings of IALCCE 2018, Ghent, Belgium, 2018.

[30] Kamrath, P., Calculating the climate impact of demolition, proceedings of IALCCE 2018, Ghent, Belgium, 2018.

[31] Vares, S., Hradil, P. Pulakka, S., Ungureanu, V., Sansom, M., Environmental- and life cycle cost impact of reused steel structures: a case study, proceedings of IALCCE 2018, Ghent, Belgium, 2018.

[32] Kuhnhenne, M., Pyschny, D., Deconstruction, recycling and reuse of metal building envelopes, proceedings of IALCCE 2018, Ghent, Belgium, 2018.

[33] Hradil, P., Fülöp, L., Ungureanu, V., Reusability of components from single-storey steel-framed buildings, Steel Construction, Design and Research, 12 (2), 2019.

[34] Vares S, Hradil P, Sansom M & Ungureanu V, Economic potential and environmental impacts of reused steel structures, Structure and Infrastructure Engineering, 2019, DOI: 10.1080/15732479.2019.1662064.

[35] Seppälä, J., Designing steel framed buildings for reuse: a case study, Master's thesis, University of Oulu, Finland, 2018.

[36] Pajala, O.-P., Reuse of buildings and their parts in single-storey steel buildings – economic view, Master's thesis, Aalto University, Espoo, Finland, 2019.

[37] DGNB certification system Criterion „Deconstruction and Disassembly", Version 2014 accessed onlie at: http://www.dgnb-system.de/en/system/certification_system/, 2020.

[38] BRE Design for Deconstruction assessment methodology accessed online at: https://www.breeam.com/, 2020.

[39] VDI 2243, Recycling-oriented product development, Association of German Engineers, Düsseldorf, Germany, 2002.

[40] Iron and Steel Industry Report, Deloitte, 2015, , accessed online at https://www2.deloitte.com/, 2020

[41] Review of the UK Steel Fabrication Market, KPMG, 2016.

[42] Panasiyk, D., Laratte, B., Remy, S., Steel Stock Analysis in Europe from 1945 to 2013, Procedia CIRP 48, 2016, pp. 348 – 35.

[43] Prefabricated steel structures for low-rise buildings in seismic areas (PRECASTEEL), database accessed online at http://www.unav.es/Precasteel/

[44] European Demolition Association, EDA – European Demolition Industry Report 2016, Rabuso (Ed.), Brussels, Belgium, 2016.

[45] Eurostat, Generation of waste by waste category, hazardousness and NACE Rev. 2 activity [env_wasgen], accessed online at http://ec.europa.eu/, 2020.

[46] Bureau of International Recycling, World Steel Recycling in Figures 2012-2016, accessed online at http://www.bundesverband-recycling.de/, 2020.

[47] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), Brussels, Belgium, 2008.

[48] Guidelines for the waste audits before demolition and renovation works of buildings, EU Construction and Demolition Waste Management, Brussels, Belgium, 2018.

[49] Resource Efficient Use of Mixed Wastes, Improving management of construction and demolition waste, Final report, Deloitte, 2017.

[50] CEN, EN 1090-2:2018 Execution of steel structures and aluminium structures, Part 2: Technical requirements for steel structures, European Committee for Standardization, Brussels, Belgium, 2018.

[51] CEN, EN 10034:1993 Structural steel I and H sections - Tolerances on shape and dimensions, European Committee for Standardization, Brussels, Belgium, 1993.

[52] CEN, EN 10219-1:2006 Cold formed welded structural hollow sections of non-alloy and fine grain steels, Part 1: Technical delivery requirements, European Committee for Standardization, Brussels, Belgium, 2006.

[53] CEN, EN 10219-2:2006 Cold formed welded structural hollow sections of non-alloy and fine grain structural steels, Part 2: Tolerances, dimensions and sectional properties, European Committee for Standardization, Brussels, Belgium, 2006.

[54] CEN, EN 10210:2006 Hot finished structural hollow sections of non-alloy and fine grain steels, Part 1: Technical delivery requirements, European Committee for Standardization, Brussels, Belgium, 2006.

[55] CEN, EN ISO 8501-1:2007 Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness, Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings, European Committee for Standardization, Brussels, Belgium, 2007.

[56] CEN, EN 1090-1:2009 Execution of steel structures and aluminium structures, Part 1: Requirements for conformity assessment of structural components, European Committee for Standardization, Brussels, Belgium.

[57] CEN, EN 10025-2:2019 Hot rolled products of structural steels, Part 2: Technical delivery conditions for non-alloy structural steels, European Committee for Standardization, Brussels, Belgium, 2019.

[58] CEN, EN 10346:2009 Continuously hot-dip coated steel flat products – Technical delivery conditions, European Committee for Standardization, Brussels, Belgium, 2009.

[59] CEN, EN 1090-4:2018 Execution of steel structures and aluminium structures - Part 4: Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications, European Committee for Standardization, Brussels, Belgium, 2018.

[60] CEN, EN 1990:2010 + A1:2005/AC:2010 Eurocode: Basis of structural design, European Committee for Standardization, Brussels, Belgium, 2010.

[61] CEN, EN 14509:2013 Self-supporting double skin metal faced insulating panels - Factory made products - Specifications, European Committee for Standardization, Brussels, Belgium, 2013.

[62] Brown, D.G., Cosgrove, T.C., P419 Brittle fracture: Stelection of steel sub-grade to SB EN 1993-1-10, Steel Construction Institute, Ascot, UK, 2017.

[63] Internationaler Verband für den Metallleichtbau, IFBS, accessed online at https://ifbs.eu/

[64] CEN, EN ISO 17637:2016 Non-destructive testing of welds, Visual testing of fusion-welded joints, European Committee for Standardization, Brussels, Belgium, 2016.

[65] CEN, EN 1090-4:2016 Execution of steel structures and aluminium structures - Part 4: Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications, European Committee for Standardization, Brussels, Belgium, 2016.

[66] Commission Delegated Regulation (EU) No 568/2014 of 18 February 2014 amending Annex V to Regulation (EU) No 305/2011 of the European Parliament and of the Council as regards the assessment and verification of constancy of performance of construction products, Brussels, Belgium, 2014.

[67] CEN, CWA 17316:2018 Smart-CE-Marking - Smart CE marking for the construction industry, CEN Workshop Agreement, European Committee for Standardization, Brussels, Belgium, 2018.

[68] Regulation (EU) No 305/2011 of the European Parliament and of the Council laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, Brussels, Belgium, 2011.

[69] CEN, EN ISO 19650-1:2019 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling- Part 1: Concepts and principles (ISO 19650-1:2018), European Committee for Standardization, Brussels, Belgium, 2019.

[70] CEN, EN ISO 19650-2:2019 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling - Part 2: Delivery phase of the assets (ISO 19650-2:2018), European Committee for Standardization, Brussels, Belgium, 2019.

[71] CEN, prEN 17412:2019 Building Information Modelling - Level of Information Need - Concepts and principles, European Committee for Standardization, Brussels, Belgium, 2019.

[72] CEN, EN ISO 23387:2020 Building information modelling (BIM) - Data templates for construction objects used in the life cycle of built assets - Concepts and principles (ISO 23387:2020), European Committee for Standardization, Brussels, Belgium, 2020.

[73] ISO 20887:2020 Sustainability in buildings and civil engineering works — Design for disassembly and adaptability - Principles, requirements and guidance, International Organization for Standardization, Geneva, Switzerland, 2020.

[74] CEN, EN 15978:2011, Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method, European Committee for Standardization, Brussels, Belgium, 2020.

[75] Ubakus software, accessed online at https://www.ubakus.de/u-wert-rechner/.

[76] Graphisoft Archicad 21 software, build number 3005, accessed online at https://www.graphisoft.com/downloads/

[77] OpenLCA software, aacessed onlien at http://www.openlca.org/.

[78] Ecoinvent database, accessed online at https://www.ecoinvent.org/database/ecoinvent-36/ecoinvent-36.html

[79] ISO 14044, Environmental management - Life cycle assessment - Requirements and guidelines, International Organization for Standardization, Geneva, Switzerland, 2006.

[80] CEN, EN 15804:2012+A1:2013/prA2:2018. Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products, European Committee for Standardization, Brussels, Belgium, 2018.

[81] COM(2014) 445, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on Resource efficiency opportunities in the building sector, Brussels, Belgium, 2014.

[82] COM(2015) 614, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the loop – An EU action plan for the Circular Economy, Brussels, Belgium, 2015.

[83] Product Environmental Footprint Category Rules (PEFCR) for “Metal Sheets for various applications”. Revision 0.9a, Thinkstep AG, 17/06/2016.

[84] ISO TC59/SC17: Sustainability in buildings and civil engineering works, International Organization for Standardization webpage accessed online at: https://www.iso.org/committee/322621.html

[85] World Resources Institute (WRI)/ World Business Council for Sustainable Development (WBCSD): The Greenhouse Gas Protocol (GHG Protocol) accessed online at: https://ghgprotocol.org/

[86] BSI, PAS 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services accessed online at: https://shop.bsigroup.com/upload/shop/download/pas/pas2050.pdf

[87] Wolf, M-A., Pant, R., Chomkhamsri, K., Sala, S., Pennington, D., ILCD: The International Reference Life Cycle Data System (ILCD) Handbook, JRC reference reports, Luxembourg, 2012.

[88] Ellen MacArthur Foundation, Circularity Indicators: An Approach to Measuring Circularity, Methodology, 2015.

[89] McDonough, W., Braungart, M. Cradle to Cradle: Remaking the Way We Make Things. New York: North Point Press, 2002.

[90] CEN, EN 16627:2015 Sustainability of construction works - Assessment of economic performance of buildings - Calculation methods, European Committee for Standardization, Brussels, Belgium, 2015.

[91] Ruukki Construction, personal communication, 2018.

[92] Cyrille F. Dunant, Michał P. Drewniok, Michael Sansom, Simon Corbey, Jonathan M. Cullen a, Julian M. Allwood. Options to make steel reuse profitable: An analysis of cost and risk distribution across the UK construction value chain. Journal of Cleaner Production 183, pp. 102-111, 2018.

[93] Interview with Ing. Arnošt Balcar published online at “montované haly” company webpage http://www.haly-sklady.cz/

[94] ArcelorMittal Europe – Long Products (2016), Environmental Product Declaration – Reinforcing steel in bars, accessed online at 12.8.2019

[95] Sibley S.F, Overview of flow studies for recycling metal commodities in the United States, chap. of U.S. Geological Survey Circular 1196, p. AA1–AA25, available only at http://pubs.usgs.gov/circ/circ1196-AA/.

[96] Geyer R., Jackson T., Clift R., Economic and environmental comparison between recycling and reuse of structural steel sections, 2002

[97] Material Economics: The Circular Economy, A powerful force for climate mitigation, Transformative innovation for prosperous and low-carbon industry, The Finnish Innovation Fund Sitra, 2018.

[98] ISO 15686-5:2017, Buildings and constructed assets — Service life planning, Part 5: Life-cycle costing, International Organization for Standardization, Geneva, Switzerland, 2017.

[99] Weigand, A. Zur energetischen Sanierung von Kassettenprofilfassaden mit einer neuen Außenschale aus Sandwichelementen, PhD. Thesis, TU Dortmund, Germany, 2020.

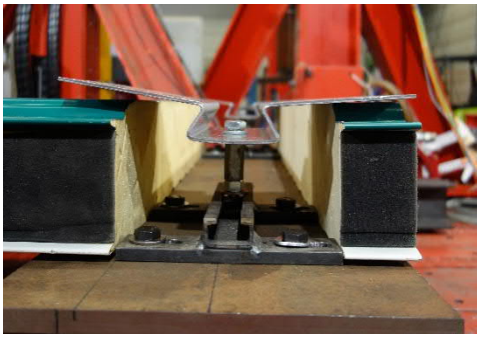
Annexes

The following section contains additional results from the experiments carried out in Work Package 4, three protocols developed in the Work Package 2 and a Technical Annex of the project proposal. The particular parts of this section are:

- WP4 Test results of envelope systems
- WP2 Protocols
    - Pre-deconstruction audit protocol for single-storey steel framed buildings
    - Deconstruction protocol for single-storey steel framed buildings
    - Quality verification protocol
- Technical Annex of PROGRESS project

Test results of envelope systems

(a) During Test



(b) After Test

Figure 100 Failure mode of Smart Flashing Connector

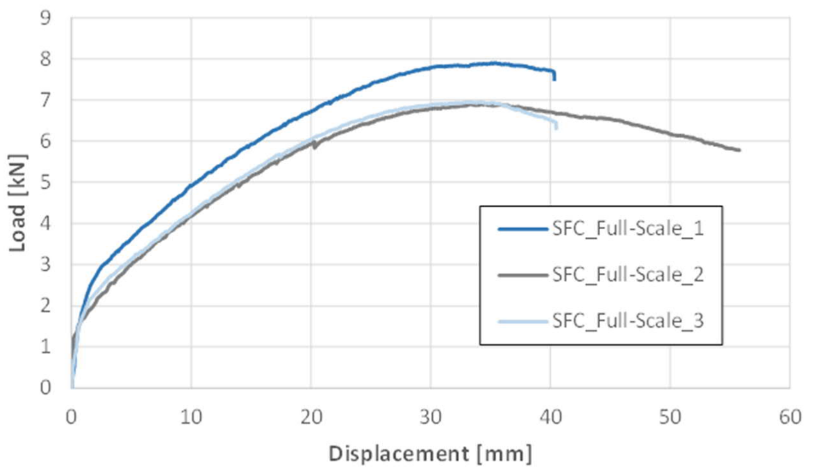


Figure 101 Load-Displacement-Diagram of clamped panel under tensile load

Table 41 Test results Smart Flashing Conncetor

Specimen	**Max. Load** [kN]	**Displacement** [mm]
SFC_1	7.88	36.19
SFC_2	6.75	39.18
SFC_3	6.94	34.04
Average	7.19	36.48

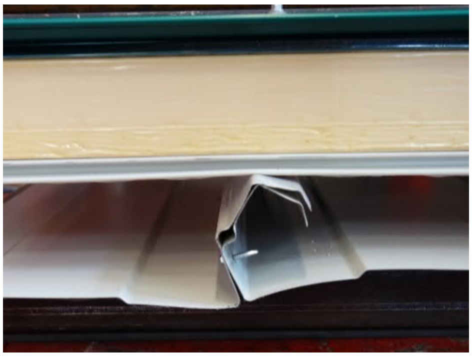


Figure 102 Failure mode of hybrid system at the end-support (left) and its detail (right)

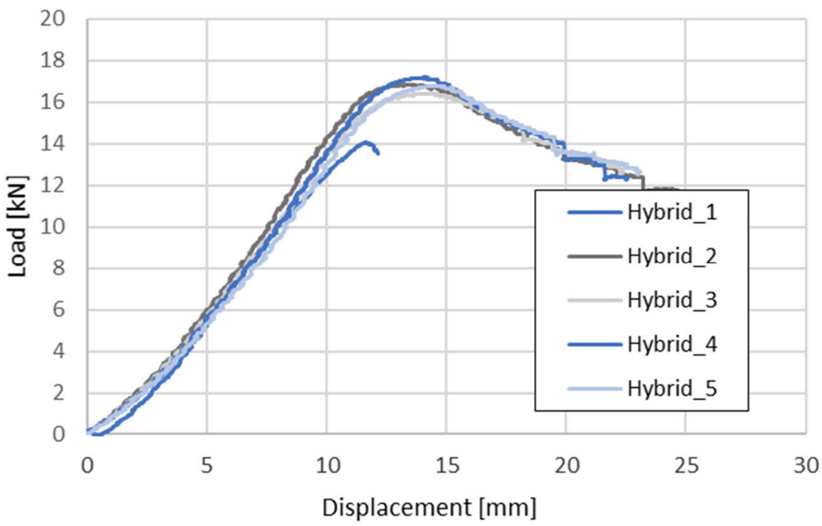


Figure 103 Load-Displacement-Diagram hybrid-system

Table 42 Test results hybrid system

Specimen	**Displacement** [mm]	**Max. Load** [kN]	**Reaction Force End-Support** [kN]	**Reaction Force on one web** [kN]
Hybrid_1	11.5	14.2	9.5	4.7
Hybrid_2	13.4	16.8	11.2	5.6
Hybrid_3	12.8	16.2	10.8	5.4
Hybrid_4	14.2	17.1	11.4	5.7
Hybrid_5	13.0	16.4	10.9	5.5
Average	12.98	16.14	10.76	5.38

(a) Failure Mode at the webs

(b) Detailed failure mode

Figure 104 Failure mode of hybrid system with FRP profiles V1

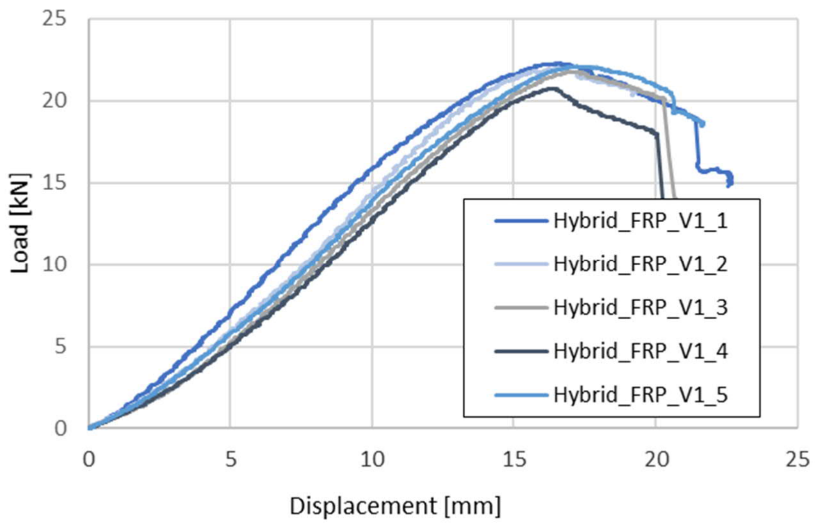
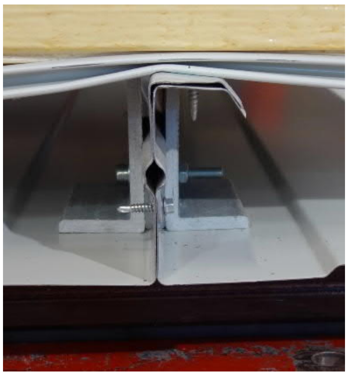


Figure 105 Load-Displacement-Diagram V1

Table 43 Test results hybrid system with FRP reinforcement V1

Specimen No.	**Displacement** [mm]	**Max. Load** [kN]	**Reaction Force End-Support** [kN]	**Reaction Force on one web** [kN]
Hybrid_FRP_V1_1	16.7	21.9	14.6	7.3
Hybrid_FRP_V1_2	16.5	21.2	14.1	7.1
Hybrid_FRP_V1_3	17.1	20.9	13.9	7.0
Hybrid_FRP_V1_4	16.9	20.2	13.5	6.7
Hybrid_FRP_V1_5	17.4	22.1	14.7	7.4
Average	16.92	21.26	14.2	7.1

(a) Shear failure in core of sandwich panel



(b) Liner tray web after test

Figure 106 Failure mode of hybrid system with FRP Profiles V2

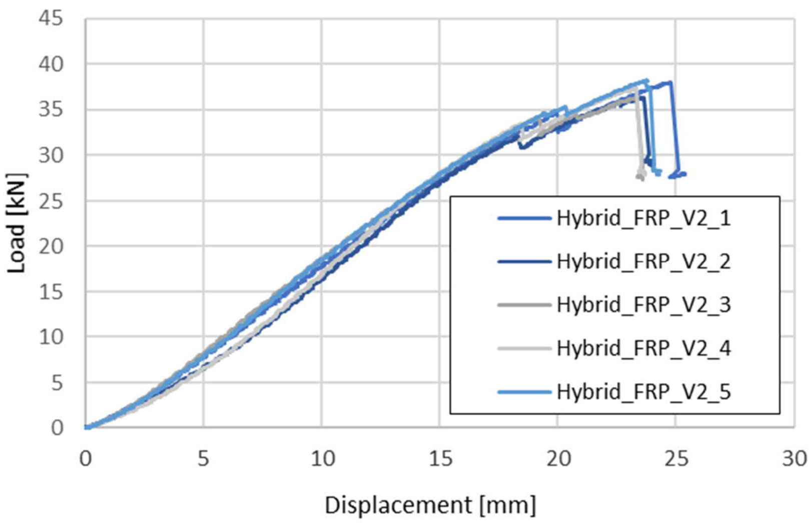


Figure 107 Load-Displacement-Diagram V2

Table 44 Test results Hybrid System with FRP reinforcement V2

Specimen	**Displacement** [mm]	**Max. Load** [kN]	τ_{max} [MPA]
Hybrid_FRP_V2_1	19.7	34.5	0.160
Hybrid_FRP_V2_2	20.9	35.1	0.163
Hybrid_FRP_V2_3	18.2	34.8	0.161
Hybrid_FRP_V2_4	17.8	33.2	0.154
Hybrid_FRP_V2_5	18.1	32.7	0.151
Average	34.06	34.1	0.158

2017-2020

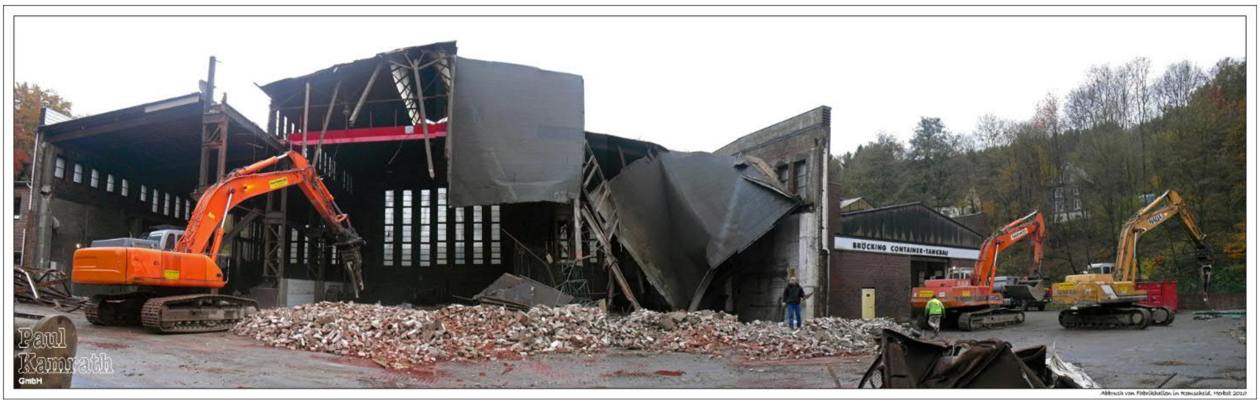
PROGRESS

PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Research Fund for Coal and Steel
Grant agreement No: 747847

Pre-deconstruction audit protocol for single-storey steel framed buildings

February 2020



Confidentiality: Public

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Contents

1. Introduction

Any demolition, renovation or deconstruction project needs to be well planned and managed. This brings about important cost benefits, as well as environmental and health benefits and carbon-savings. Such preparatory activities are particularly important for larger buildings.

Within the scope of the structural steelwork, the main goal of the audit is to identify steel components, structural systems that can be reused and to document the amounts of other materials and wastes. Three different reclaimed steel classes are identified in the audit, for which different testing and design requirements are proposed (see Figure 1.1). The three reclaimed steel classes are:

- **Class A** – Material documentation is available (e.g. original material certificate or declaration of conformity to the harmonized product standard);
- **Class B** – Material documentation is not available. A comprehensive assessment of material, member and section properties and characteristics are undertaken to produce new documentation;
- **Class C** – Material documentation is not available. Conservative assumptions can be assumed for the design.

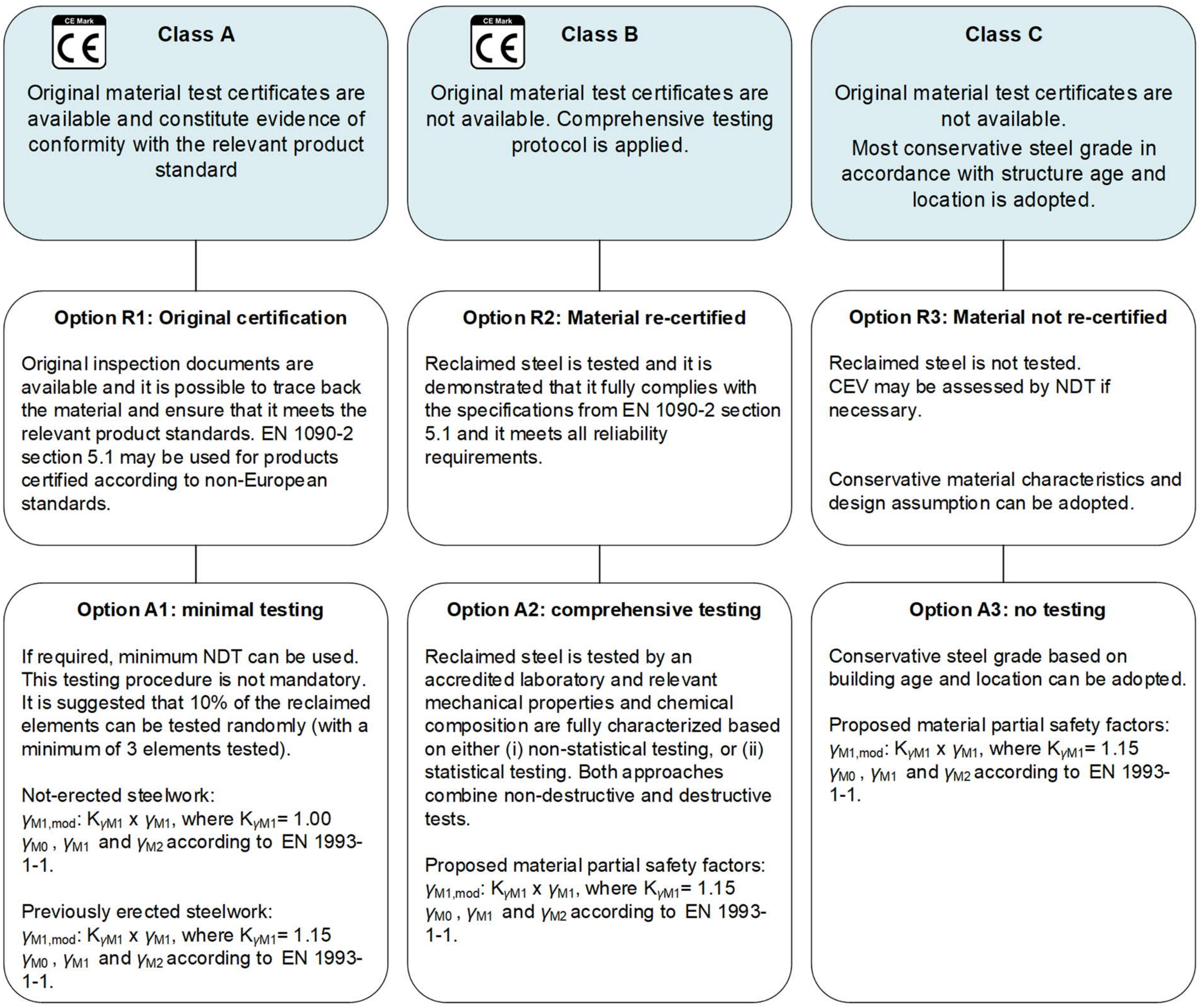

Figure 1.1. Summary of reclaimed steel classes

Examples of steelwork classified as **“Class A”** are steelwork reclaimed from a cancelled project (never erected) or components reclaimed from different sources, for which documentation is available. For the cases where documentation is available but the steelwork was already erected and disassembled, a conservative value of γ_{M1} is recommended in combination with an assessment of geometric tolerances (essentially bow imperfections). An optional testing procedure for Class A steel is proposed with the intent of confirm the traceability of the reclaimed steelwork (rather than to justify material characteristics).

It is envisaged that **“Class B”** steel will cover (currently) most of the practical applications of reclaimed steelwork. This class deals with reclaimed steelwork with no documentation for which a material re-certification is required. Recommendation from EN 1090-2 section 5.1 need to be followed to achieve such re-certification. “Class B” steel imply a comprehensive testing procedure where relevant material characteristics are justified and geometry tolerances are inspected against EN1090-2 requirements. The testing procedure comprehends a combination of non-destructive and destructive tests together with inspection of geometric tolerances. Conservative measures for the value of γ_{M1} are recommended, as some uncertainty in the member and section imperfections (other than bow) are recognized. Even with inspection, the procedures used to perform the assessment of geometric tolerances will certainly be less reliable in comparison with “new” steel.

“Class C” steel is only recommended for projects that represent a low risk for human safety, as higher uncertainty in material characteristics is recognized. “Class C” steel envisages that no testing is undertaken (where conservative material properties are assumed based steelwork location and age – historical data). If welding is necessary, CEV (carbon equivalent value) may be assessed by non-destructive tests. It is required that geometric tolerances according to EN1090-2 are assessed (usually during fabrication; straightening can be performed). Conservative measures for the value of γ_{M1} is recommended for this approach. CE marking is not envisaged using the Class C reclaimed steel approach. However, this may change in the future based on recent initiatives from the European Union to facilitate the circularity of construction products [1]. It is expected that the Construction Products Regulation (CPR) will be revised to facilitate the practice of reuse of steel (and other constructional products).

Pre-deconstruction audit needs to be undertaken so that relevant building documentation is collected and the feasibility of reusing existing steelwork is assessed. The following chapters provide guidance for two phases of the assessment:

- preliminary assessment (documentation research) and
- comprehensive assessment (field survey and condition evaluation).

2. Documentation research and inspection planning

Assessment of the reclaimed steelwork begins before the existing structure is deconstructed with the collection and thorough analysis of relevant data. This documentation research helps with the evaluation of the existing structural concept and adequacy of the existing steelwork for the possible future reuse. It makes sure that the following field survey will be appropriate and safe for the personnel. Locations, mechanisms and nature of possible structural damage and deterioration can be evaluated in order to prepare efficient field survey plan.

Building documentation is extremely valuable for the reuse of existing steelwork. However, it is necessary to ensure that the collected information is updated and refers to the as-build structure. The consistency of the collected documentation must be therefore assessed not only for building geometry and section sizes but also for details (i.e. joints). Construction documents of interest include design drawings, specifications, material test records, and quality assurance reports covering original construction and subsequent modifications to the structure. Available engineering reports, including any previous inspection, maintenance or records of possible modifications shall be also reviewed. Specifications (including possible original welding procedure specifications), shop drawings, erection drawings, and construction records shall be reviewed when available.

If the documentation indicates the possibility of hazards such as asbestos, radiation or volatile chemicals, the decontamination and removal of hazardous materials must be carried out before the field survey.

For the cases where documentation is available, but no compliance is found according to the on-site inspection the percentage of details and members/cross sections to be checked must be the ones suggested to the cases where no documentation is available. Cross-sections must be checked against available documentation. If building documentation is not available, the cross-sections should be compared against relevant catalogues according to be building age and location. Geometric tolerances should be expected.

Table 2.1 Plan for the field survey of each group of elements

Detailed construction documentation	Details to be checked during the field survey[1]	Members to be checked for cross section dimensions[1]	Building dimensions and structural solution
Available (limited on-site inspection recommended)	10% min 3 detail types, details selected randomly	10% min 3 different sections, members selected randomly	Minimum inspection for a regular single storey building (e.g. a typical frame): Span; Eaves height; Apex height; Frames spacing; Vertical and roof bracing arrangement; Eaves struts; Fly bracings; Etc.
Not available (comprehensive on-site inspection recommended)	25% min 5 detail types, details selected randomly	25% min 5 different sections, members selected randomly	

[1] Percentages to be applied to a group of elements with same geometric and load history (e.g. for a portal frame the three types of details to be checked: base connections, apex and eaves, three different section can be columns, rafters and vertical bracings), if the number of sections or details in the assessed steelwork is lower than the minimum required, all details or sections will be checked.

The documentation research shall be performed by a team with engineering, fabrication and erection expertise. This is a very important step, as it is intended to evaluate the feasibility of reclaiming and reusing the existing steelwork. It needs to take into account the expected reuse scenario. The main purpose of this step is to avoid efforts and costs of a careful inspection, deconstruction and documentation of an existing building which offers limited opportunities for steel reuse.

The construction date must be identified, as well as the likely materials to be found in the existing building when documentation is not available. With a similar process, the likely standards that were used for the structural analysis and design shall be identified. The limitation to steel produced after 1970 relates to the material properties assumed by modern design Standards. Steel from 1970 was considered as part of the Eurocode programme and the development of product and design Standards. It is therefore assumed that steel produced after 1970 meets the material properties assumed in product Standards such as EN 10025 and EN 10219.

Whenever the structural elements are not visually exposed, measures should be specified to expose a sufficient number of elements for the inspection (only a representative/limited number of elements need to be exposed).

Table 2.2. Preliminary assessment checklist

Preliminary assessment		
✓	All available documentation and expected reuse scenario are obtained from the facility owner;	
✓	All available documentation including reuse and recycling targets are obtained from the building authorities;	
✓	Age of the building and its parts is determined;	
✓	Possible hazards are identified for the field survey and their removal planned (e.g. decontamination or structural stabilization);	
✓	Field survey is adequately planned;	
	✓	Number and locations of important details and cross-sections is determined;
	✓	(optional) Number and locations of sample extraction points is determined;
	✓	Labelling method is recommended;
	✓	All necessary equipment is available.

3. Field survey

After completing the preliminary assessment by documentation research, a comprehensive assessment is undertaken in this step. The comprehensive assessment implies field survey and eventual preliminary testing to confirm the assumptions about the properties and condition of the reclaimed steelwork and its coating.

The possible defects in steel structures are according to [2]:

- accumulation of water, obstructed water run-off or possible accumulation of waste and dirt
- missing structural members or stabilising elements,
- missing rivets, bolts or welds in connections,
- missing stiffeners or poor structural design of stiffeners,
- obstructed access to individual areas of the structure or structural members,
- inadequately applied corrosion protection (e.g. an unapproved surface protection, improperly executed repairs),
- lack of or insufficient protection against accidental actions (e.g. impact, fire),
- imperfections in manufacture or installation (e.g. eccentricities, deflection in members, misalignment),
- unfavourable flow of forces (e.g. in stabilising elements).

Welds can display both external defects (e.g. welds with too little or too much weld material, offset edges, asymmetrical fillet welds) as well as internal defects (e.g. lack of penetration, lack of fusion, cracks, inclusions, pores). External defects of welds are generally identified through visual checks, while internal defects are generally identified using specific test methods. The scope of testing and test methods to be used depend on the level to which the weld is loaded and on the consequences in the event of failure.

The following types of deterioration, among others, can occur in steel structures according to [2]:

- material loss due to corrosion or wear,
- swellings between steel plates or structural members,
- cracking, in particular at locations with geometrical discontinuities (stress concentrations), in connections and in fasteners,
- cracking as a result of imposed repeated displacements,
- unforeseen deformations in connections, loose nuts, slip in pre-tensioned connections,
- broken fasteners,
- permanent deformations in structural members (instability, plastification, etc.), especially following impact, earthquake or fire,
- unfavourable changes in the mechanical properties of the steel as a result of fire,
- cracking as a result of impact or earthquakes, even without permanent deformations,
- deterioration of the coating system (corrosion protection, fire protection).

All structural steel reclaimed for reuse has to be visually inspected and sent for testing and re-certification after deconstruction if no appropriate documentation and traceability are available. Important step for the planned testing programme is the grouping of fundamentally identical members into groups, whereby one (or more) members are assumed to be representative of the entire group, thus moderating the requirements and costs of the future testing.

Without traceability of each component, the value of the reclaimed material will be compromised. It is therefore important for material stockists to maintain full traceability of the reclaimed steelwork, including the grouping and labelling of members. A permanent unique physical label is recommended for each member. Then the location of the member shall be marked in the drawings and photo documentation. Each label shall be unique (e.g. number, barcode, QR code or RFID tag) so the original location of each of the components will be known.

Table 3.1. Field survey checklist

Field survey	
✓	Visual inspection and photo documentation is performed;
✓	Overall building dimensions and main spans is measured;
✓	Details are checked according to the inspection plan;
✓	Cross-sections are checked according to the inspection plan;
✓	(optional) Samples are extracted for laboratory testing;
✓	Structural members intended for reuse are labelled and their location documented.

4. Condition evaluation

Based on the information collected from the documentation research, visual inspection and preliminary testing, the decision about reusability of components and structural systems is made in this step. If any structural element is classified as non-reusable, it will become waste. Such element may be repaired, refurbished or repurposed (prepared for reuse with End-of-Waste processing), or sent for recycling. The amount of material in the steelwork that is not directly feasible for reuse shall be summarized in the waste inventory.

In the case of weather resistant steel (with increased corrosion resistance), the material loss is evaluated in the most severely affected areas.

Deterioration of the coating should be always evaluated.

Although, the cracked material is generally unsuitable for reuse, the cracks may be detected and their cause and mechanism evaluated. Possible mechanisms may be attributed to

- fatigue,
- corrosion fatigue,
- hydrogen embrittlement,
- stress corrosion cracking or
- high local stress (notch effect).

The size of a crack in a structural member or in a connection should be recorded at least by measuring the length of the crack on the surface. It is recommended to take urgent safety measures in the case of cracks due to corrosion fatigue or stress corrosion cracking to secure stability and integrity of the structure during the deconstruction or refurbishment process.

Apart from the physical condition of the steelwork, the audit may contain evaluation of additional indicators related to the materials and components such as their residual value, remaining service life or carbon footprint.

All experimental and numerical methods need to be properly listed. It is recommended that the auditor keeps the raw data and models until the final inspection after demolition is concluded.

Table 4.1. Admissibility of reclaimed steelwork and condition evaluation checklist

Condition evaluation checklist		
✓	Selected structural systems or components can be reused;	
	✓	Steelwork is not older than 1970 (in order to use Eurocode rules);
	✓	Material is not classified as hazardous or can be decontaminated;
	✓	No built-up members unless welds are tested;
	✓	No spliced members (the individual lengths of a member with a bolted or welded splice can be disassembled/cut and reclaimed; otherwise welds need to be tested);
	✓	No significant section loss due to corrosion (loss exceeding 5% of the element thickness is considered significant);
	✓	No signs of fire exposure;
	✓	No evidence of plasticity observed in the steel surface or coating;
	✓	No other defects or signs of deterioration;
	✓	Members meet the geometric tolerances of EN 1090-2 (straightening can be performed if tolerances are not met).
✓	The suitability of other non-reusable materials and components for high-level recovery and recycling is evaluated;	
✓	(optional) Additional indicators required by the facility owner (e.g. cost, residual value, remaining service life or carbon footprint) are evaluated.	

5. Recommendations

The recommendations for the materials and waste management are prepared in this step. For the reusable structural steelwork the recommendation follow the classification “A”, “B” or “C” depending on the knowledge of its material properties (see Table 5.1).

Table 5.1. Resume of reuse protocol for steelwork erected after 1970

Property / procedure	Reclaimed steelwork class		
	Class A	**Class B**	**Class C**
Test programme	Minimal (optional[1])	Comprehensive	No testing
Adequacy and reliability assessment	Yes	Yes	No
Percentage of non-destructive tests (NDT)	10% (randomly) with a minimum of 3 tests per group	100%	-
Minimum number of destructive tests (DT)	-	1 for CC1 & CC2 3 for CC3	-
Geometric tolerances	Assessed[2]	Assessed	Assessed
CE marking	Yes	Yes	No
Global analysis	Elastic	Elastic	Elastic
Section analysis	Elastic/plastic	Elastic/plastic	Elastic/plastic
$k_{\gamma M0}$	1.00	1.00	1.00
$k_{\gamma M1}$	1.15[3]	1.15	1.15
$k_{\gamma M2}$	1.00	1.00	1.00
CC1 structures	Yes	Yes	Yes
CC2 & CC3 structures	Yes	Yes	Not recommended

[1] Material testing in Class A can be required by the local building authorities.
[2] For the cases where the steelwork was never erected, visual inspection is sufficient.
[3] For the cases where the steelwork was never erected the value of $K_{\gamma M1}$=1 can be used.

The main difference between the classified steel products is in their recommended material testing. For Class A reclaimed steel, testing is not mandatory (unless required by the building authority) as material documentation and reliable tracing system exists. Testing is mandatory for class B reclaimed steel. Class B may be seen as the standard case of an existing building with no material documentation for which CE marking is required. Class C reclaimed steel can rely on conservative assumptions for the material properties but a more thorough inspection of the structure (or individual elements) is still required to evaluate de admissibility of the reclaimed steel.

After the pre-deconstruction audit, some of the existing members may be classified as not suitable for reuse, which should be sent for recycling.

Recommendations on minimal testing or reusable components

Minimal testing is intended for the cases where material documentation is available (Class A steel) or to perform a preliminary assessment of existing steelwork.

Minimal testing is optional because if a unique label identifies every member of a documented group of elements, a testing procedure is unnecessary. However, for the cases where a unique label for each element within a group is not available, but only documentation of the group of elements is available, the minimal testing procedure may be implemented. Only non-destructive tests are recommended.

It should be noticed that this procedure is intended to "new" steelwork never erected and for which documentation is available.

Table 5.2. *Recommendations for minimal testing*

Characteristic to be determined	Type of testing	Percentage of elements to be tested
Tensile and yield strength	Non-destructive	10% - with a minimum of 3 tests per group.
Chemical composition (CEV)	Non-destructive	

Recommendations on comprehensive testing of reusable components

The recommendations for comprehensive testing procedure (testing protocol) require 100% non-destructive testing of the reclaimed structural members in combination with non-statistical or statistical destructive testing.

The non-destructive testing of all reclaimed members establishes that a group of members can be represented by destructive test results from one or more representative members from the group.

Non-statistical testing requires just one destructive test, taken from a member in each group, to confirm the results obtained from the non-destructive tests. Non-statistical testing is recommended for Consequence class 1 or 2 structures. Non-statistical testing is equivalent to the requirements for 'new' steel specified in the product Standard.

Statistical testing requires more destructive testing to assess material characteristics in accordance with EN 1990. Statistical testing is recommended for reclaimed steel to be used in Consequence class 3 buildings, or when the provenance or quality of the original source material is considered to be unreliable. Statistical testing exceeds the requirements for 'new' steel specified in the product Standard.

Table 5.3 relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition to Consequence class.

Table 5.3.*Number of members to be tested for yield and tensile strength and CEV*

Consequence class	Non-destructive testing (NDT)	Destructive testing (DT)	Acceptance approach
CC1	All members	min 1	Non-statistical (maximum value of CEV)
CC2		min 1	Non-statistical (maximum value of CEV)
CC3		min 3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)

Other recommendations

The audit shall be completed with recommendations on how to perform on-site material management and interventions. The issues to be considered may include the following:

- recommendations on decontamination and safe removal of hazardous coatings,
- recommendations on repair and rehabilitation of components and assemblies,
- recommendations regarding possible health and safety precautions to take during the deconstruction,
- identification of potential material diversion (e.g. if the component will not be reused at the end)
- identification of economically or environmentally beneficial on-site sorting activities that may include the description of the installation requirements for storage, handling, separation and for any other operation to manage the different material streams.
- recommendations on the management of waste materials according to one or more of the operations described in *Table 5.4* and *Table 5.5*.

Table 5.4.*Waste recovery and disposal operations relevant for the structural steel according to [3]*

Code	Description	Operations relevant for the structural steel
R4	Recycling/reclamation of metals and metal compounds	Preparing for reuse of discarded steel components, recycling of steel scrap
R12	Exchange of waste for submission to recovery	Dismantling, conditioning, sorting, shredding or separating prior to other recovery
D1	Deposit into or on to land	Landfill of inert waste
D5	Specially engineered landfill	Placement of the hazardous waste into lined discrete cells which are capped and isolated from one another and the environment, etc.

Table 5.5. *Waste recovery and disposal operations relevant for the other materials according to [3]*

Code	**Description**	**Examples of building materials**
R1	Use principally as a fuel or other means to generate energy	Wood and wood-based materials, cardboard, textiles, and other incinerable materials
R3	Recycling/reclamation of organic substances which are not used as solvents	Wood and wood-based materials, and other organic materials
R5	Recycling/reclamation of other inorganic materials	Concrete and masonry, mineral insulation, and other inorganic materials
D1	Deposit into or on to land	Any inert material excluding organic materials
D5	Specially engineered landfill	Hazardous materials
D8	Biological treatment not specified elsewhere in this list resulting in final compounds or mixtures which are disposed	Wood and wood-based materials, and other organic materials or materials that can be biologically treated
D9	Physico-chemical treatment not specified elsewhere in this list resulting in final compounds or mixtures which are disposed	Any material
D10	Incineration on land	Wood and wood-based materials, cardboard, textiles, and other inicinerable materials that can be burned on land
D12	Permanent storage (e.g. emplacement of containers in a mine, etc.)	Any material
D13	Blending or mixing prior to submission to any of the disposal operations	Any material
D14	Repackaging prior to submission to any of disposal operations	Any material

If the steelwork partially reused in-situ (without deconstruction) or requires serviceability during the deconstruction (e.g. the floors are used by the deconstruction crew), it needs to be checked and provisionally repaired if needed. The following rehabilitation actions to secure serviceability of steel structures and their connections can be recommended according to SIA 296-3 [2]:

- Loosened structural bolts may be retightened, but high-strength pretensioned structural bolts have to be replaced with equivalent new pretensioned bolts.
- Cracks shall never be repaired by welding. It is recommended to replace whole components with cracks.
- On-site welding sequence shall be defined to limit the heating of steel under 120ºC in the vicinity of the weld. Welding repairs of dynamically loaded structural elements (such as crane structures) is prohibited.

- Renewal of the corrosion protection should be recommended when (a) the degree of protection weathering and rusting is pronounced, (b) the existing protection is insufficient or (c) the base coating is no longer bonded.
- In case of overcoating, compatibility and bonding between new and existing corrosion protection shall be ensured. For this purpose, the properties of the existing protection layer are to be examined and both the method as well as the products used for the rehabilitation shall be chosen carefully.
- When carrying out rehabilitation or renewal of the corrosion protection, the joints that cannot be blasted shall be cleaned appropriately and sealed with a suitable sealing compound.

Additional recommendations can be provided for the off-site material management including the list of possible salvage markets and storage areas. In the case of waste recovery and disposal, the codes listed in *Table 5.4* and *Table 5.5* shall be used.

Table 5.6. Checklist for the materials and waste management recommendations

Materials and waste management recommendations		
✓	Recommended testing procedure for reusable steelwork and components;	
	✓	Testing programme (comprehensive, minimal or no testing);
	✓	Limitations for the re-design and future use;
✓	Recommended on-site management and interventions;	
✓	(optional) Recommended off-site management;	

6. Reporting

All collected data are be presented in the pre-deconstruction audit report, where any concern/issue found shall be documented. Based on the date of construction, the expected (or preliminary tested) steel properties as well as the possible/likely design codes shall be clearly identified. The report shall define any urgent safety measures required for the existing building.

If building documentation and/or material certificates are not available, it is necessary to produce that documentation. Class C doesn't require testing, but documentation referring to the assumed properties is still required.

The following template is recommended (Example report is in Annex A):

A General information

A1 Description of the building A1.1 Building description …………………………………………………………………………….. A1.2 Address, site number ……………………………………………………………………… A1.3 Year of steelwork fabrication ……………………………………………………………….. A1.4 Floor area ……………………………………………………………………………………... A1.5 Main dimensions ……………………………………………………………………………... A1.6 Envelope ……………………………………………………………………………............... A1.7 Crane (description, type, tonnage)………………………………………………..............	
A1.8 Steelwork is already deconstructed	yes / no
A2 Purpose of the deconstruction (if A1.8 is yes) ……	
A3 Description of the future use of deconstructed components (if known) ……	
A4 Building owner (name, address, e-mail, phone) ……	
A5 Information about the auditor (name, address, e-mail, phone, certification(s)) ……	
A6 Information about the demolition/deconstruction company (if known) ……	
A7 Building documentation and drawings	
A7.1 Design documentation	yes / no
A7.2 Fabrication documentation	yes / no
A7.3 Documentation of use and inspection reports	yes / no
A8 Certification	
A8.1 Mill certificates of delivered steel	yes / no
A8.2 CE marking of delivered steel products or steelwork	yes / no
A8.3 Other certification: ………………………………………………………………………………..	

B Description of the audit and recommendations

- B1 Description of the available documentation
- B2 Description of the on-site visits (dates, persons, equipment)
- B3 Description of the labelling system of reusable components
- B4 Description of the on-site measurements (equipment, results)
- B5 Description of sampling (methods, sample sizes, locations, numbers)
- B6 Evaluation tools and methods for off-site testing and condition evaluation
- B7 Results of the evaluation
- B8 Recommended reuse scenario(s) with optional evaluation of reusability (if not in A3).
- B9 Recommended treatment of materials and components

C Inventory of reusable components

C1 General information

C1.1 Component[1]	C1.2 Dimensions[2]	C1.3 Quantity[3]	C1.4 Location[4]	C1.5 Year of fabrication[5]	C1.6 Will be reused[6]	C1.7 Reuse description[7]
					yes / no	
					yes / no	
					yes / no	

[1] Description or the component (or group of components) type and label number according to attached drawing or model
[2] Main dimensions (cross-section, thickness, length or surface area)
[3] Number of components or their total length or surface area
[4] Location within the building
[5] If different than in the general description in A1.3
[6] Only if the owner declares his intention to reuse the components in A3
[7] Reference to scenario(s) described in A3

C2 Material information

C2.1 Component[1]	C2.2 Steel manufacturer[8]	C2.3 Component manufacturer[8]	C2.4 Certified steel grade[9]	C2.5 Recommended steel grade[10]	C2.6 Recommended material testing[11]

[8] If known
[9] The acceptable certificates listed in A8 are described in PROGRESS methodology [4]
[10] Minimum steel grade (e.g. S235) according to PROGRESS methodology [4]
[11] Testing protocol according to PROGRESS methodology [4]

C3 Recommended treatment

C3.1 Component[1]	C3.2 Observed damage[12]	C3.3 Recommended repairs[12]	C3.4 Existing coating[13]	C3.5 Recommended surface treatment[13]

[12] Damage assessment according to PROGRESS methodology [5]
[13] Description of the coating, its quality and recommended treatment for reuse (e.g. cleaning, shot-blasting, overpainting)

D Inventory of waste and hazardous substances

D1 Hazardous and dangerous substances[14]

D1.1 Substance	D1.2 Present	D1.3 Quantity/concentration[16]	D1.4 Location[17]	D1.5 Recommended treatment[18]
[15]	yes / no			
[15]	yes / no			
Other:[15] …………………………………..				

[14] Including substances in reusable components listed in C
[15] Compulsory substance are pre-filled according to local legislation or guidance, if the owner/auditor has the knowledge about any other hazardous substances, he is obliged to report it as well
[16] According to the limits in the local legislation or guidance
[17] Description of the materials/components containing this substance and their location in the building
[18] According to local legislation or guidance

D2 Inventory of waste[19]

D2.1 Material[20]	D2.2 Code[20]	D2.3 Hazardous[21]	D2.3 Quantity[22]	D2.4 Location[23]	D2.5 Condition[24]	D2.6 Recommended treatment[25]
		yes / no				
		yes / no				
		yes / no				

[19] Including materials in reusable components not intended for immediate reuse (declared in C1.6 as “no”)
[20] Name and code according to European List of Wastes [6]
[21] If contains substances listed in D1
[22] Material quantity in tonnes
[23] Location within the building
[24] Level of deterioration or other relevant condition
[25] Treatment code according to the Waste Framework Directive [3]

References

[1] European Commission, *Guidelines for the waste audits before demolition and renovation works of buildings*, May 2018, accessed online at http://ec.europa.eu/.

[2] Swiss Society of Engineers and Architects, Swiss Norm SIA 269/3:2001 Existing structures – Steel structures, Zurich, Switzerland

[3] Waste Framework Directive; Directive 2008/98/Ec of The European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.

[4] Ungureanu, V., Girão Coelho, A.M., *Report on the suitability of materials and components to be used in a new design situation*, Deliverable D2.2 of PROGRESS project, Timisoara, Romania, May 2020.

[5] Vares, S., Hradil, P., Sansom, M., Ungureanu, V., Kamrath, P., Economic assessment of reusing steel-based elements, Deliverable D5.2 of PROGRESS project, Espoo, Finland, to be submitted in February 2019.

[6] European Commission, *Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C(2000) 1147)*, 2000/532/EC, Brussels, Belgium.

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PROGRESS

PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

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Deconstruction protocol for single-storey steel framed buildings

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Deliverable: D 2.1b Deconstruction protocol for single-storey steel framed buildings

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Executive summary

The report presents a deconstruction protocol for single-storey steel buildings (SSB) to ensure safety in deconstruction and integrity of the deconstructed elements.

The components of SSB addressed by this protocol include:

- primary structural elements;
- secondary structural elements;
- cladding systems.

The protocol will focus on the following structural solutions, considered as the most frequently used in practice in EU Member States.

Main structure:

- single-storey steel framed buildings made of hot-rolled steel profiles;
- single-storey steel framed buildings with members made of welded steel plates and variable cross-section;
- single-storey steel framed buildings with hot-rolled steel profile columns and steel truss girders.

From the point of view of secondary structure, the protocol will focus on systems built using light gauge, cold-formed steel profiles used both for purlins and for side rails.

The cladding systems:

- cladding systems using sandwich panels with various thermal insulation layers (PUR foam, PIR foam, mineral wool layer);
- cladding systems using built-up systems (internal + external layer of trapezoidal sheet containing in between the secondary structure and thermal insulation layers);
- system made with deep corrugation trapezoidal steel sheet for roofing and liner trays for wall cladding.

The protocol will cover the following aspects:

1. Preparation of deconstruction documentation
2. Site preparation
3. Deconstruction sequencing and labelling of steel components
4. Storage and transport
5. Health and safety.

Contents

1. Introduction

It is estimated that 80% of the primary and secondary steelwork in existing single-storey steel buildings (SSB) in the EU could be reused instead of the usual practice of recycling. Many existing structural steel components are inherently reusable due the nature of SSB design and construction. Current estimates suggest that only around 5% of structural steel frames are reused. Consequently, more actions are necessary to remove barriers that inhibit the supply, specification, and stocking of building elements for reuse. The steel construction industry should be at the forefront of reuse and the circular economy of steel sections, components, and structures.

According to EN 15978, during the end of life (EOL) stage of a building, all outputs from dismantling, deconstruction or demolition processes are first considered to be waste. The Waste Framework Directive, however, defines waste as objects or substances that the owner intends to discard. The idea is to consider the “wastes” in the EOL stage as resources such as closed-loop or circular material economies, and sustainable materials management by reinforcing the notion of a “resource-based paradigm” rather than “waste-based” one. The components for reuse are considered as potential resources for future use.

This protocol is designed as a guide to deconstruct single-storey steel-framed buildings (SSB) so that the entire structure or parts of it or the reclaimed elements can be reused in future applications.

Single-storey steel-framed buildings include the following basic components:

- primary structure;
- secondary structure;
- cladding systems.

1.1 Aim of the Protocol

The aim of this protocol is to encourage the safe reclamation of structural steel elements from existing single-storey steel framed buildings in the EU so that the reclaimed elements can be reused in subsequent construction applications.

Generally, it is assumed that the deconstruction of the steel frame is the same process as its erection with additional effort to maintain the integrity of the disconnected components. The aim of this Protocol is to create a unitary system for the deconstruction of single-storey steel framed buildings.

1.2 Description of the basic components of SSB

As far as the primary structure is concerned, the single storey steel buildings (SSB) of possible interest include (description not exhaustive):

(1.1) single-storey steel framed buildings made of hot-rolled steel profiles (haunches may be present);

(1.2) single-storey steel framed buildings with built-up elements made of hot-rolled steel profiles;

(1.3) single-storey steel framed buildings with members (columns + rafters) made of welded steel plates (i.e. variable cross-section or tapered elements);

(1.4) single-storey steel framed buildings with hot-rolled steel profile columns (plus possible crane girder made of a single hot-rolled profile) and steel truss girders;

(1.5) single-storey steel framed buildings with built-up columns made of hot-rolled profiles and/or steel plates (plus possible built-up crane girder) and steel truss girders;

(1.6) single-storey steel framed buildings with lattice structure columns and hot-rolled profile rafters or truss girders;

(1.7) single-storey steel framed buildings with both columns and rafters made of cold-formed steel profiles (usually built-up sections);

(1.8) single-storey steel framed buildings with columns made of built-up cold-formed steel profiles and cold-formed profiles lattice girders.

Buildings having a partial two-storey zone (frequently an office zone which occupies a minor part of the building) can also be included in the above categories.

From the point of view of the secondary structure functioning as a support for the cladding, SSB buildings include purlins and side rails (girts). As the market reality clearly shows, different situations are possible in case of these elements, requiring different deconstruction solutions i.e.:

a) Purlins:

(2.1) Purlins made of hot-rolled steel profiles (classic solution) with various static schemes (simply supported, continuous beam, Gerber beam etc.);

(2.2) Purlins with a built-up cross-section made of welded steel plates (classic solution) with various static schemes (simply supported or continuous);

(2.3) Purlins made of castellated beams, fabricated using hot-rolled steel profiles, in case of larger spans (i.e. 9.0-12.0 m) and usually simply supported;

(2.4) Purlins made with lattice steel structure in case of larger spans (i.e. 9.0-12.0 m) and usually simply supported;

(2.5) Purlins made of thin-walled cold-formed profiles with various cross –sections and various static schemes where the possible effect of beam continuity is usually obtained by profiles overlapping;

(2.6) No purlins at all in case of roofing made of deep corrugation trapezoidal steel sheet.

b) Side rails (girts):

(3.1) Side rails made of hot-rolled steel profiles (classic solution) with various static schemes (simply supported or continuous);

(3.2) Side rails made of thin-walled cold-formed steel profile with various static schemes (simply supported or continuous);

(3.3) In case of larger spans between primary structure columns (i.e. 9.0-12.0 m) secondary mid-span columns supporting the side rails may be provided both in case of hot-rolled or cold-formed side rails;

(3.4) No side rails at all in case of the lateral cladding built using cold-formed steel liner trays or horizontally installed sandwich panels.

As far as the cladding system (roofing or walls) is concerned, a certain number of practical situations also exist which require different deconstruction approaches, i.e.:

a) Roofing system:

(4.1) Simple corrugated (sinusoidal) steel sheet or trapezoidal steel sheet with no thermal insulation provided, usually working as a continuous beam supported by the secondary structure;

(4.2) Simple corrugated (sinusoidal) external steel sheet or trapezoidal steel sheet with the mineral wool thermal insulation plus vapour barrier attached underneath, usually working as a continuous beam supported by the secondary structure (no internal steel sheet provided in this case);

(4.3) Built-up roofing made of an inner trapezoidal steel sheet installed on the purlin bottom flange (from the inner side) plus an external trapezoidal steel sheet installed on the purlin upper flange (from the outer side). Both layers work as continuous beams supported by the purlin system, thus a kind of cellular roofing system is achieved with the thermal insulation and vapour barriers contained inside the cells, between the purlins;

(4.4) Roofing made of sandwich panels built with internal plus external steel or aluminium sheet and thermal insulation (various foams or mineral wool) injected between them. The panels are installed using adequate fasteners on the upper flange of the purlins and work as continuous beams;

(4.5) Roofing made of deep corrugation steel sheet supported directly by the main frame; no purlins necessary in this case; all insulation layers installed from the outer side on the supporting internal sheeting; various static systems used for the sheeting (i.e. simply supported beam, continuous beam, Gerber beam, etc.).

b) Cladding walls system:

(5.1) Simple corrugated (sinusoidal) steel sheet or trapezoidal steel sheet with no thermal insulation provided, usually working as a continuous beam supported by the secondary structure;

(5.2) Built-up cladding made of an inner trapezoidal steel sheet installed on side rail inner flange (from the inner side) plus an external trapezoidal steel sheet installed on the side rail outer flange (from the outer side). Both layers work statically as continuous beams supported by the side rail system, thus a kind of cellular cladding system is achieved with the thermal insulation and vapour barriers contained inside the cells, between the purlins;

(5.3) Cladding made of sandwich panels built of internal plus external steel or aluminium sheet and thermal insulation (various foams or mineral wool) injected between them; the panels are installed vertically using adequate fasteners on the outer flange of the side rails (girts) and work as continuous beams;

(5.4) Cladding made of sandwich panels built of internal plus external steel or aluminium sheet and thermal insulation (various foams or mineral wool) injected between them; the panels are horizontally laid and installed using adequate fasteners directly on the outer flange of the primary columns; no side rails (girts) necessary; in such cases secondary columns are sometimes necessary for longer distances (6.0-12.0 m) between primary frames to create adequate wind load resistance;

(5.5) Cladding made of thin-walled steel sheet and liner trays installed horizontally, directly on the columns using adequate fasteners; no side rails (girts) necessary; outer layer of sinusoidal or trapezoidal steel sheeting laid on the outer flanges of the liner trays creating a cellular steel cladding with the insulation layers installed inside the cells; sometimes secondary mid-span columns are necessary for longer distances (i.e. 6.0-12.0 m) between primary frames to create adequate wind load resistance.

1.3 Scope of the Protocol

The scope of this protocol covers steel reclaimed from any geographical location as material characteristics are established by test. When using reclaimed steel, the design is based on the material properties (either tested or based on conservative assumptions) maintaining the relationship between design assumptions and material resistance with an adequate level of reliability.

The components of SSB addressed by this protocol include:

- primary structure;
- secondary structure;
- cladding systems.

From the large variety of constructional systems described in section 1.2, this **protocol will focus on the following structural solutions,** considered as the most frequently used in practice.

Main structure:

- **(1.1)** single-storey steel framed buildings made of hot-rolled steel profiles;
- **(1.3)** single-storey steel framed buildings with members made of welded steel plates and variable cross-section;
- **(1.4)** single-storey steel framed buildings with hot-rolled steel profile columns and steel truss girders.

From the point of view of **secondary structure**, the protocol will focus on systems built using light gauge, cold-formed steel profiles used both for **purlins (2.5)** and for **side rails (3.2)**. These are also considered as the most frequently used systems in practice.

The chosen **cladding systems** considered more frequent and thus of interest for the deconstruction protocol are:

- cladding systems using sandwich panels with various insulations layers (PUR foam, PIR foam, mineral wool layer) – **(4.4)** and **(5.3)**;
- cladding systems using built-up systems (internal + external layer of trapezoidal sheet containing in between the secondary structure and insulation layers) – **(4.3)** and **(5.2)**;
- system made with deep corrugation trapezoidal steel sheet for roofing **(4.5)** and liner trays for wall cladding **(5.5)**.

The protocol will cover the following aspects: (1) preparation of deconstruction documentation, (2) site preparation, (3) deconstruction sequencing and labelling of steel components, (4) storage and transport and (5) health and safety.

1.4 Terms and definitions

Deconstruction: the process dismantling a building in such a manner that its component parts can be re-used.

Reclamation and reclaimed: material is set aside from the waste stream for future reuse with minimal processing.

Re-use: means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.

Recycling and recycled: the manufacture of a new product using reclaimed materials, scrap, or waste as feedstock.

1.5 Target audience

This Protocol will help all those seeking to reuse structural steel reclaimed from single-storey buildings. The key target audience however is the demolition contractor.

1.6 Cost and environmental benefits of deconstruction and reuse

The use of reclaimed structural steel is an effective strategy to reduce the environmental impact of a building by eliminating the environmental impact of producing new steel. Steel (as a material) theoretically has an infinite life cycle, through multiple recycling loops, whereas building assessments are generally limited in scope, to the predicted design life of the building. Structural steel (as a product) also has the potential to be reused over several building life cycles.

Calculation of the environmental benefits of reuse should reflect the fact that the functional unit, i.e. the building structure, is (a) completely reused and its lifecycle is extended, or (b) its components are reused or designed for the future reuse.

In terms of using reclaimed materials, it is important that the cost of using new products and materials, as well as their transportation and disposal costs are offset against the cost of the reclaimed materials and any additional labour cost for installing these.

Current economic barriers regarding the reuse of reclaimed steel components/structures are: the additional time involved for deconstruction and the difficulty of costing this against re-used materials which will be used on a different project, the damage caused by poorly designed assemblies and connectors as well as the limited flexibility of reclaimed elements. Reuse is not subsidised in the same way that manufacture is in terms of energy, infrastructure, transportation, and economies of scale, all of which have hidden environmental costs.

The ideal use of reclaimed products is either on the same site, or a new one, but to avoid excessive transport costs.

1.7 Structure of the protocol and how to use it

This protocol focuses on deconstruction process only, anticipating that the primary use of reclaimed steelwork will be reuse of the complete (or partial) structure, re-erected in a different location. However, the reuse as plain members, i.e. with existing connections removed, used within a new structure is also possible.

The overall structure of the protocol is presented in Figure 1 and comprises:

1. Preparation of deconstruction documentation (see Section 2). Demolition Contractor have to plan the deconstruction sequencing based on existing or new drawings/sketches, focusing on the stability of the structural components and parts, identification of the components, including steel marking labels preparations, storage and transport and health and safety on site;
2. Site preparation (see Section 3). Is in the responsibility of Demolition Contractor to check if the site is suitable for deconstruction to proceed safely.
3. Deconstruction sequencing and labelling of steel components (see Section 4);
   - Non-structural elements and equipment (see Section 4.1);
   - Cladding and roofing system (see Section 4.2);
   - Secondary structure (see Section 4.3);
   - Primary structure (see Section 4.4);
4. Transport and storage and of the reclaimed components (see Section 5);
   - Cladding and roofing system;
   - Secondary structure;
   - Primary structure;
5. Health and safety on site (see Section 6).

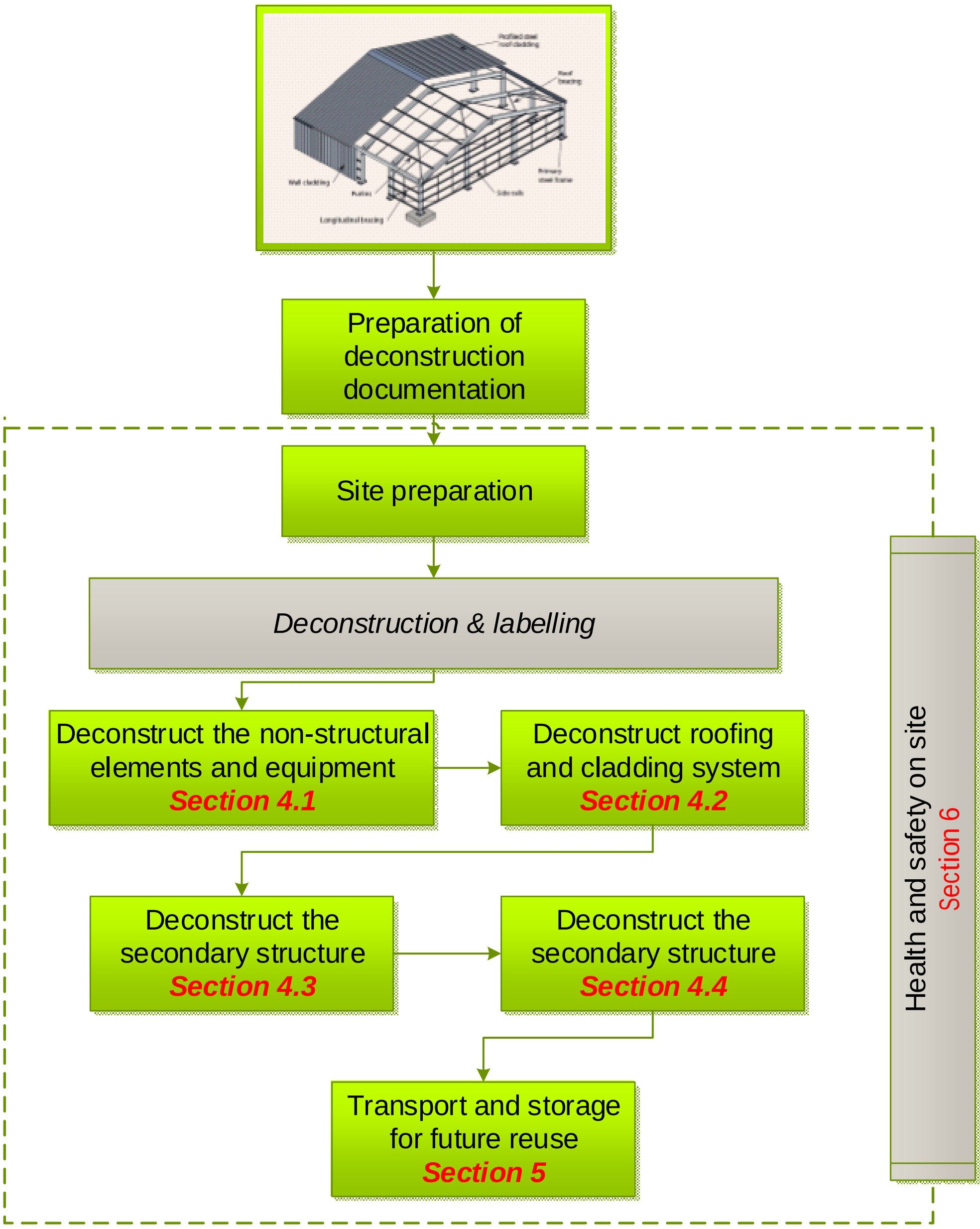


Figure 1. Overall structure of the protocol

Subsequent sections and appendices provide more detail.

2. Preparation of deconstruction documentation

Demolition contractors have to plan the deconstruction sequencing based on existing or new drawings/sketches and the complexity of the structure, focusing on the:

1. stability of the deconstructed structural components and remaining parts
2. identification of the components
3. steel marking labels preparations
4. transport and storage recommendations, and
5. health and safety on site.

Demolition Contractor should also consider details such as:

- site limitations;
- local street access;
- transport requirements;
- overhead obstructions.

Depending on the complexity of the SSB, the Demolition contractor can hire a Designer for staged deconstruction, analysing the following aspects:

- Special care should be taken during the deconstruction to guard against progressive collapse of the structure. Progressive collapse means a continuous sequence of failures initiated by the local failure of one part of the structure;
- Stability of long slender members. Large spans can exist with slender rafters or trusses and such members require restraints to stabilise them against collapse by buckling during the deconstruction;
- In case of structures with valley beams it is quite common for alternate columns to be omitted on valley lines to span over two bays. If the portal rafter or relatively slender trusses are connected to the mid-span of the valley beam, the beams may lack the torsional rigidity needed to secure the end moment connection required by the rafter/truss. Temporary supports are needed to provide stability in deconstruction;
- Even if the deconstruction sequences relay on permanent bracing, it is not uncommon that other temporary bracing to be required.

Drawings or sketches are needed to be used as marking plan. The marking plan shows where each member is located on the site. The marking plan includes:

- location of each element;
- configuration of braces and any temporary bracing/supports;
- clear markings to identify each member.

Bar codes, QR codes or Radio frequency identification (RFI) provide for an efficient and reliable method of component tracking. This technology can be used as a digital passport for each reclaimed member. It is possible to store the relevant information in a simple QR code, bar code or RFID. Steel marking labels should be with tear-resistant film substrate with super-strong adhesive and excellent outdoor durability.

The Demolition contractor is responsible for producing transport and storage recommendations (see Section 5) and recommendations for health and safety on site (see Section 6).

3. Site preparation

Safe deconstruction of structural steelwork depends on proper and timely planning. All personnel should be aware that deconstruction of any structural steel is potentially hazardous, and that planning must control any risk from these hazards.

Is in the responsibility of the Demolition Contractor to check whether the site is suitable for deconstruction to proceed safely. Any risks arising from poor site conditions should be removed, avoided, or reduced.

Before work even begins on site, thought needs to be given to the sequence or order in which work will be done and to any especially hazardous operations or processes.

The Demolition Contractor should identify the items to be considered in defining the site conditions suitable for safe deconstruction, e.g.:

- access to the site and within the site for people and equipment, including loading materials. Routes should be free from obstruction and from exposure to hazards such as falling materials, materials-handling equipment, and vehicles. Suitable warning notices should be posted. Routes to and from welfare facilities need equal consideration. Edge protection will be required at the edge of floor openings and stairs, and wherever there is a drop of 2 m or more;
- worker and visitor parking that does not conflict with other vehicles;
- a traffic management plan is developed and implemented (which includes safe access / egress points);
- the ground surface or supporting structure is suitable for plant (such as elevating work platforms, mobile scaffolds and cranes) to operate safely. The most common construction plants used for steel deconstruction activities are mobile telescopic cranes, all-terrain telehandlers, crawler cranes, cherry pickers and boom-type elevating work platforms (scissor lifts);
- deconstruction activity must be safely demarcated, and workers should not be in conflict with machinery;
- provides clear advice on how to achieve stability for each stage of the structure’s deconstruction - temporary bracing, lifting points, loads and conditions likely to be experienced during the lifting;
- joint positions (as they affect the deconstruction sequences) and accessibility of connections;
- limitations on dimensions or weights of components that can be manipulated onto the site;
- preferred type and number of cranes to deconstruct members of particular size and shape, and for vertical and horizontal bracing requirements;
- details of overhead cables or site obstructions;
- special environmental and climatic conditions on and around the site. Weather conditions are continually monitored, particularly potentially hazardous situations like high or strong

winds and electrical storms, and that a contingency plan has been developed for severe weather;

- fixings for working platforms, handrails etc.;
- particulars of adjacent structures affecting or affected by the works;
- measures to avoid accidental vehicle impact;
- to provide a processing location depending upon where and what activities are taking place, and to provide areas to capture all bolts, nuts, washers and related fastening products, as well as of offcuts - convenient to both waste disposal and the removal of processed materials from the site;
- plan for all employee needs such as drinking water, water for cleaning up, a shaded area and toilet facilities.

The Demolition Contractor is responsible for the removal from the structural steel of dust, dirt or other foreign matter that may accumulate during the deconstruction process as the result of job-site conditions or exposure of the elements.

4. Deconstruction sequencing

The deconstruction process of a single storey steel building (SSB) can be divided into the following steps:

1. Non-structural elements/equipment;
2. Cladding and roofing system;
3. Secondary structure;
4. Primary structure.

Depending on the practical situation encountered, this order may be changed as described below.

In the next sections, recommendations for the deconstruction of each building layer are provided.

4.1 Non-structural elements/equipment

Non-structural elements such as HVAC units, solar panels, cranes, lighting, ceilings and other integrated systems must be removed before proceeding with the deconstruction of the building.

4.2 Cladding and roofing system

4.2.1 Flashing elements and gutters

Flashing elements will be usually located near building edges (see Figure 2). Careful deconstruction of these elements is required to avoid damaging the cladding system. Gutters will also need to be removed.

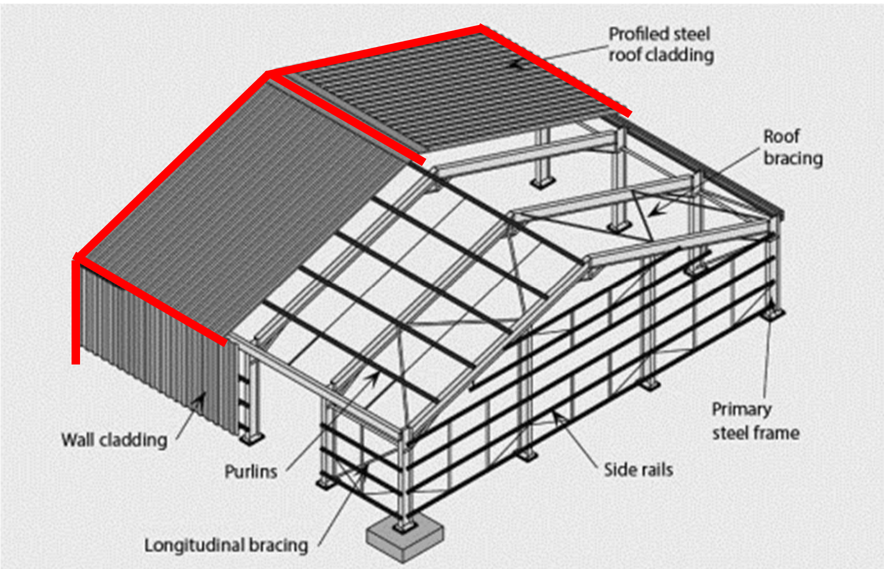


Figure 2. Usual flashing areas on SSB cladding

Plant and equipment: scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required.
2. Removal of fixings: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the cladding (see Figure 3 for common types of fixings).

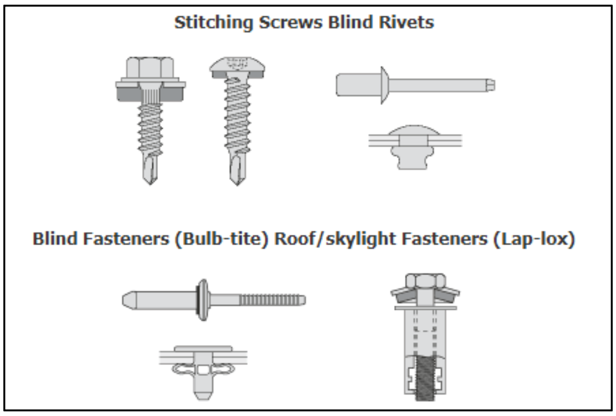


Figure 3. Usual flashing fixings with self-drilling / self-tapping screws

3. Removal of fixings for the gutters. Fixings shall be removed from one gutter coupon at a time (i.e. usually 2-3 m length).
4. Gutter coupons shall be left down manually by the operatives (as they are very light) using ropes.
5. Removal of fixings for the flashing coupons. Fixings shall be removed from one flashing coupon at a time (i.e. usually 2-3 m length).
6. Flashing coupons on the lateral claddings shall be left down manually by the operatives (as they are very light) using ropes.
7. Temporary storage at height for the ridge flashing coupons: Coupons should be stacked in groups of 3-5 pieces, tied together on the roof and left down manually using ropes.
8. Due to possible tightness problems, the reclaim and further use of these elements is not recommended.

4.2.2 Deconstruction of roof sandwich panels

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required.

2. Removal of fixings: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the panel (see Figure 4 showing typical fixing types used). Fixings shall be removed from one panel at a time.

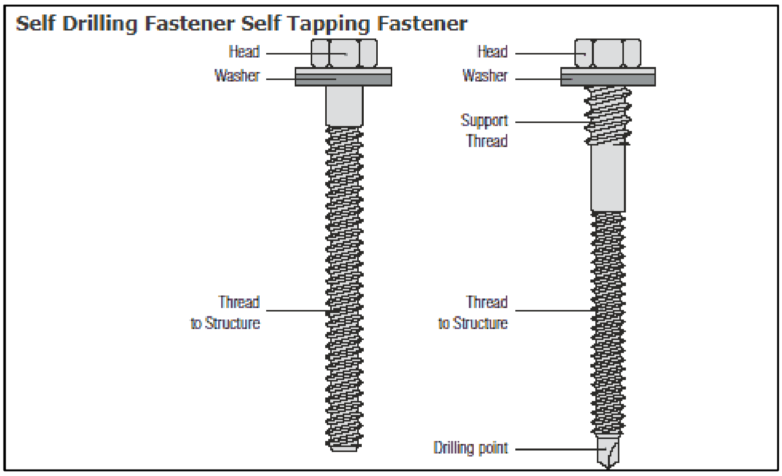


Figure 4. Typical fasteners used for sandwich panels

3. Temporary storage at height: Panels to be stacked in groups of 3 pieces perpendicular to rafters. Temporary fixing against wind of panels stack on the roof as recommended by the manufacturer.

4. Attachment to crane: Depending on the panel length (usually between a minimum few meters = half the building span and maximum 14.0 m = transport limit length) a single or double cradle and sling arrangement shall be used for lowering panels to the ground. In practice usual panel lengths would be of 6.0-8.0 m.

Lowering can be done by sling the package by using a rocker arm and min. 200 mm-wide nylon belts (see Figure 5). Insert min. 200 mm-wide wooden boards between the package and the belts. The wooden boards will have to be approximately 2 cm longer than the package width.

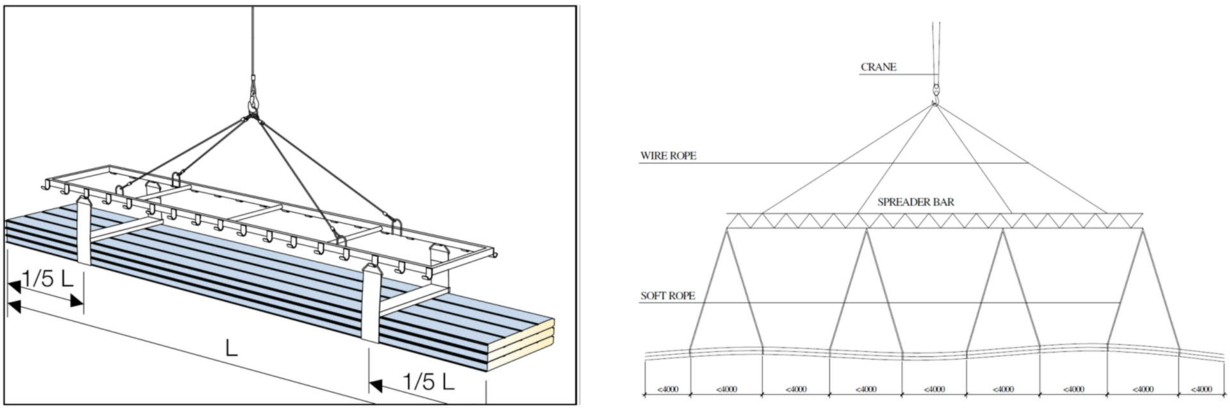


Figure 5. Single and double cradle and sling arrangements

A double cradle and sling arrangement are also presented in Figure 5.

An alternative is lowering the panels horizontally. The panels are handled using special lifting devices which can be used like a suitably sized device with clamps, which in turn is held by a lifting device (see Figure 6).

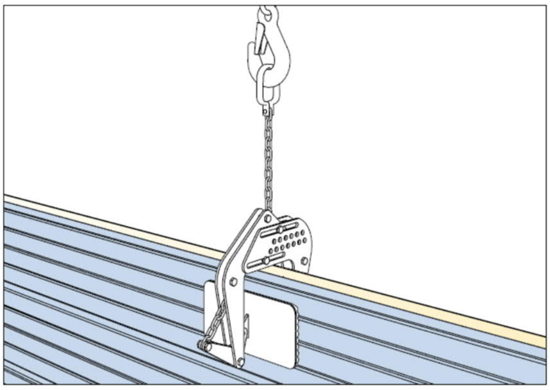


Figure 6. Special clamping devices to handle the panel horizontally when lowering

5. Storage on ground: Panels should be stacked horizontally on timber bearers placed on the ground. Stacking height will depend on the type and thickness of the panel. As a rule of thumb, the maximum stacked height should not exceed 1200 mm.
6. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Guidance on size and weight of panels for manual handling: Depending on panel type (i.e. nature of the insulation, thickness, and length) the panel coupon may allow for manual handling by two operatives or require mechanical handling. The maximum allowed load for manual handling as per national Health & Safety (usually around 50 kg for two operatives).

The panel packages may not be stored on top of each other. It is recommended to not store more than three packages one on top of another, and place spacers or boards between them (see Figure 7). The package should be placed on a flat and rigid surface, and position 50 mm-thick and 200 mm- wide polystyrene spacers or wooden boards at max. 1 m intervals. Panels will have to be stored slightly sloping in order to help possible condensation flow and to prevent backwater.

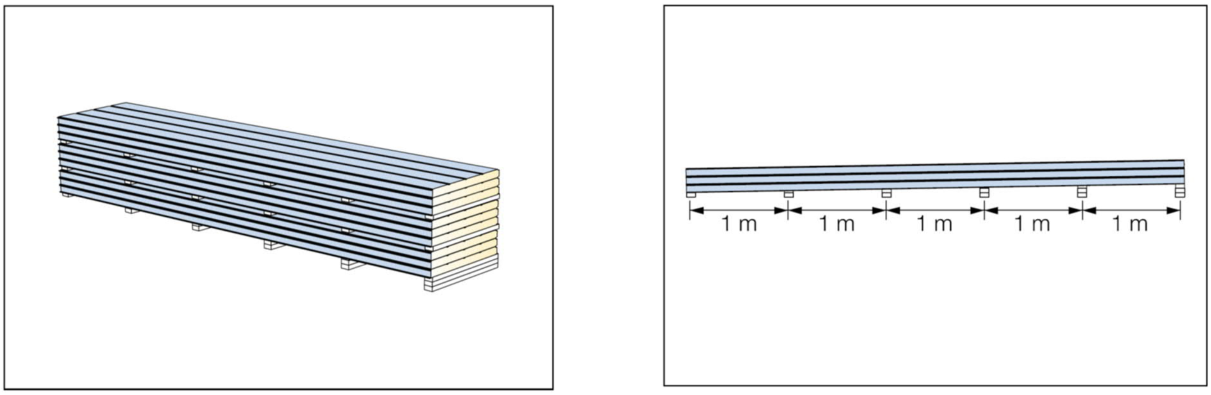


Figure 7. Storing of the deconstructed panels

When stored outdoors, the panel packages must be protected from rain, sun, and dirt. When stored for long periods, the packages must be stored indoors. If the panel packages are stored in exceptionally humid conditions, ventilation and sufficient air circulation should be ensured. This allows evaporation of humidity that may condense inside the packages. If this is impossible to protect the packages with rainproof membranes, make sure that the goods are appropriately aerated.

4.2.3 Deconstruction of wall sandwich panels installed vertically or horizontally

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:
1. Stability during deconstruction: None generally required.
2. Removal of fixings: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the panel (see Figure 4 showing typical fixing types used). Fixings shall be removed from one panel at a time.
3. Manual handling by 2-3 operatives of the wall panels is allowed (see *Figure 8*) as per national Health & Safety provisions (usually up to 50 kg weight).

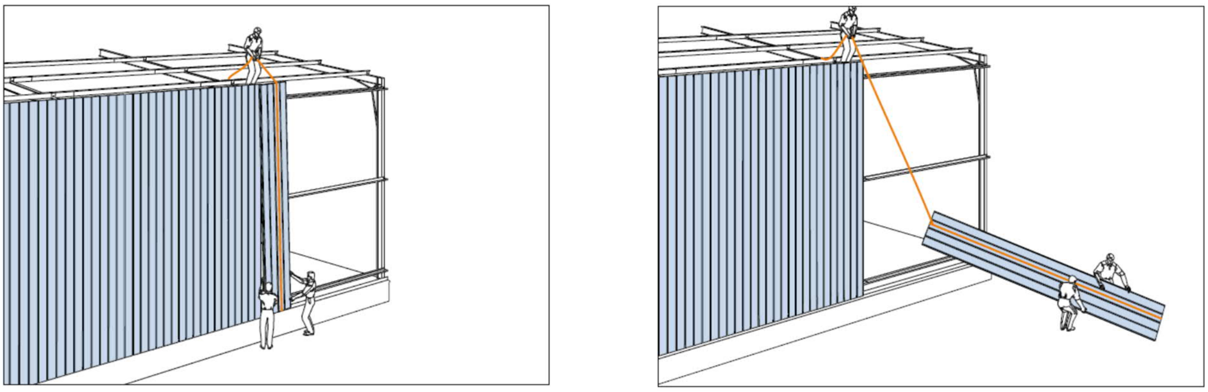


Figure 8. Manual handling of the panels during deconstruction

4. Attachment to a crane for heavy wall panels (i.e. more than 50 kg weight): For lowering panels installed vertically, an easy support-solution to handle the panels by crane is to use a U-profile fixed on the end of the panel can be used (see Figure 9).
5. Lowering wall panels installed horizontally between primary structure columns occurs identically to previous description. If handling manually by 2 operatives is not possible (panel too heavy) a crane handling is used attaching the panel with clamping devices (see Figure 6).
6. Storage on ground: Identic with the previous roof panels (paragraph 4.2.2).
7. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

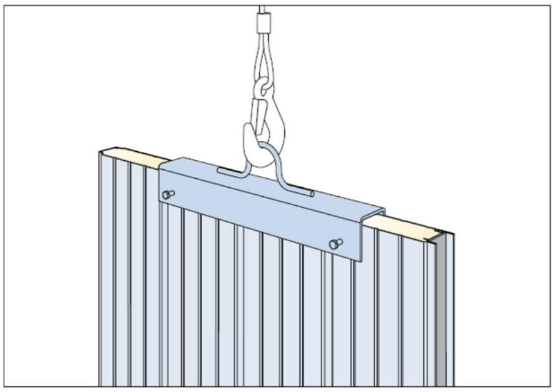
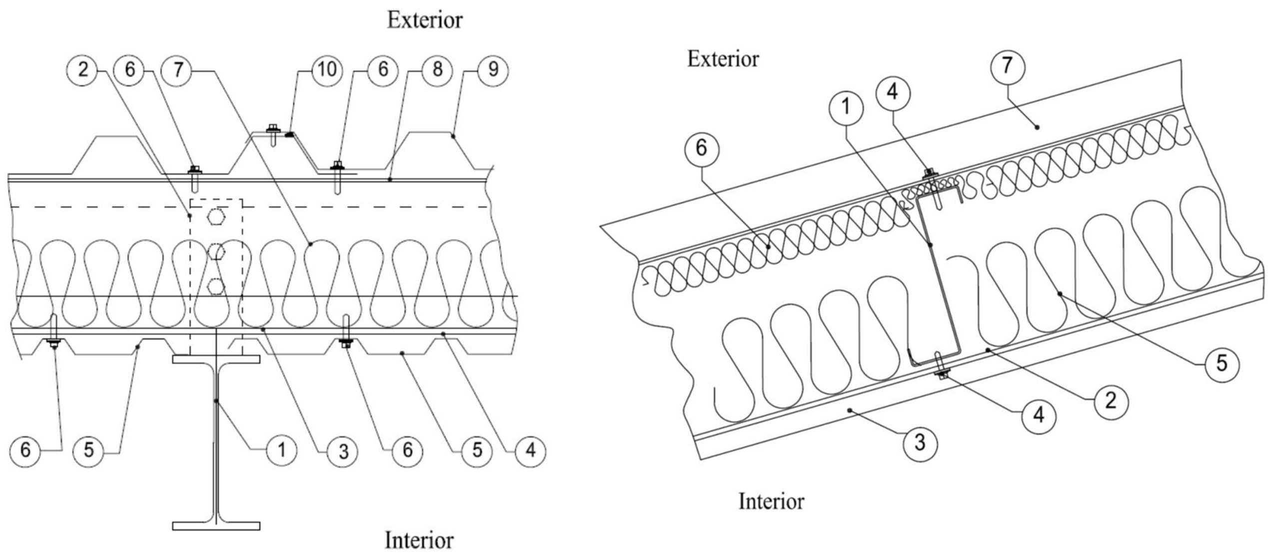


Figure 9. Device for attaching the wall panel to a crane

4.2.4 Deconstruction of trapezoidal sheet built-up claddings

The built-up roof cladding using two layers (inner / outer) of trapezoidal sheet hiding the purlin system in between is described in Figure 10.



a) Longitudinal cross-section b) Transversal cross-section

Figure 10. Longitudinal and transversal cross-section for built-up roof cladding

The relevant items on the transversal cross-section b) are:

(1) thin-walled cold-formed Z-purlin located between outer and inner sheeting;

(2) vapour barrier;

(3) inner trapezoidal sheet installed transversally to the purlin;

(4) self-drilling self-taping fastener;

(5) thermal insulation of mineral wool;

(6) upper layer of cashier mineral wool;

(7) outer trapezoidal sheeting installed transversally to the purlin (carrying climatic loads).

The longitudinal cross-section a) presents the same items as before plus the rafter (1) which supports the purlins working as continuous beams.

An alternative to the above built-up roof system is compose by a steel liner tray that is fastened to the purlins, followed by a spacing system (plastic ferrule and spacer or rail and bracket spacer), insulation, and outer sheet, as shown in Figure 11 and Figure 12.

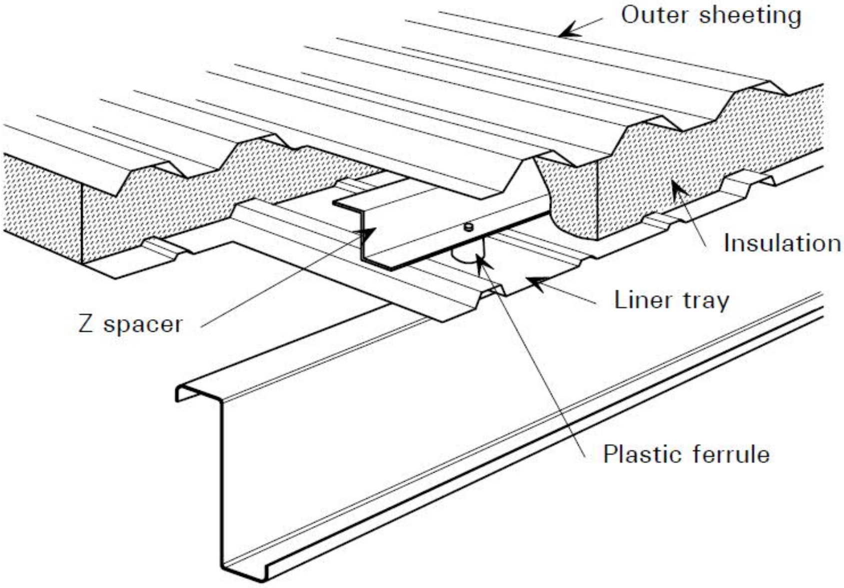


Figure 11. Built-up system using plastic ferule and Z spacers

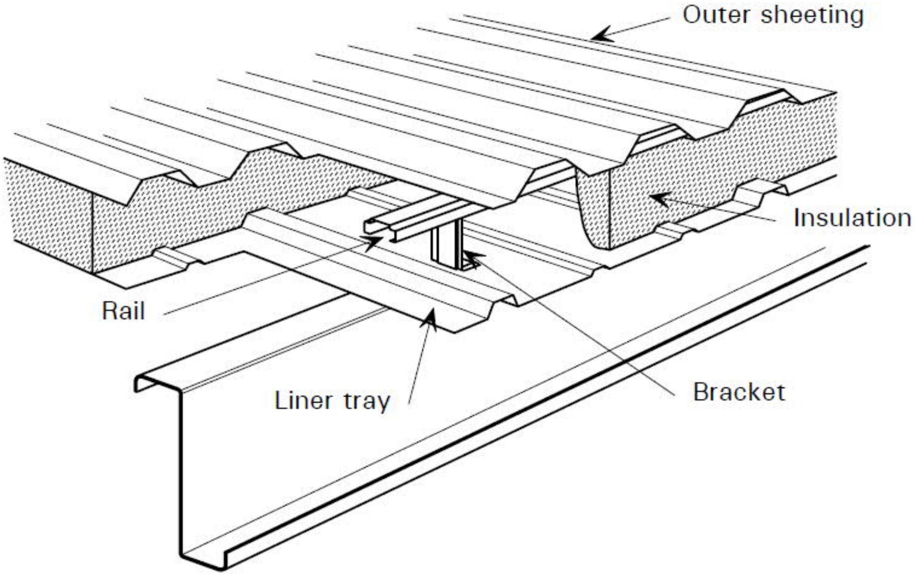


Figure 12. Built-up system using rail-and-bracket spacers

The built-up wall cladding using two layers (inner / outer) of trapezoidal sheet hiding the side rails (girts) system in between is described in Figure 13.

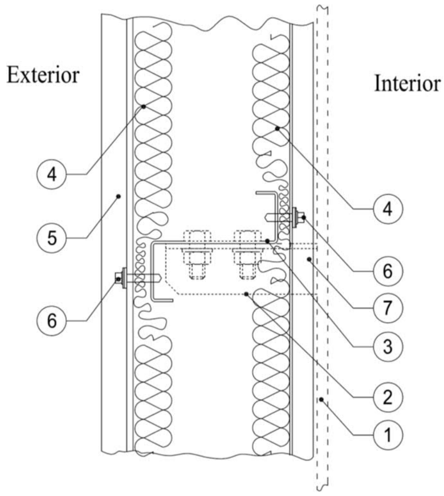


Figure 13. Transverse cross-section of built-up wall cladding (detail)

The relevant items on the transversal cross-section are:

1. primary steel structure (column);
1. cantilever welded on the primary structure to provide side-rail support;
2. side rail (thin-walled cold-formed Z profile with overlapping working as continuous beam);
3. thermal insulation of mineral wool;
4. outer thin walled trapezoidal sheet;
5. self-drilling self-taping fastener;
6. inner thin walled trapezoidal sheet.

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required.
2. Removal of fixings for the outer sheet panels: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the panel (see Figure 3 showing typical fixing types used). Outer panel fixings shall be removed from one sheet panel at a time. The operation shall be repeated until the whole outer layer of the subsequent surface is removed.
3. Temporary storage at height: Sheet panels to be stacked in view of handling and crane lowering (in case of the outer sheeting of the roof) in groups of 3-6 sheet panels parallel to the rafters. Manual handling and lowering piece by piece in case of outer wall sheeting.
4. Attachment to crane: Depending on the length a single or double cradle and sling arrangement shall be used for lowering panels to the ground.

5. Removal of cladding thermal insulation (manual) made of mineral wool in form of re-made rolls. Manual handling of each roll and manual lowering using ropes.
6. Removal of the vapour barrier, folding and packing. Manual handling and lowering.
7. Removal of fixings for the inner sheet panels: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the panel (see Figure 3 showing typical fixing types used). Inner panels fixings shall be removed from one sheet panel at a time. As this operation takes place from the inner side of the cladding the access of operative will be achieved via scissor lift. For the roof inner sheeting panels two scissor lifts would be necessary in order to support the panel against falling down after finishing fixings removal.
8. In roof areas and wall areas where the handling of the inner panels after removal of fixings is prevented by the presence of X bracings, the loose panel sheets shall be left to rest on the bracings. After removal of the purlins /side rails (acting from the outer side) these parts of the inner sheeting may be handled also from the outer side of the building. This allows for keeping intact the bracing system with stabilizing role for the primary structure.
9. Storage on ground: Sheeting panels should be stacked horizontally on timber bearers placed on the ground. Panels should be stacked no more than x panels high.
10. Identifying, grouping and labelling the products: Panels should be grouped as appropriate (separate groups for outer, respectively inner trapezoidal sheet which have different cross section geometry) and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Guidance on size and weight of panels for manual handling: The sheet layers either exterior or interior, in case of this particular system usually result of a convenient weight (usually under 50 kg) which allows for manual handling by two operatives. However, care should be taken in case of windy conditions.

Advice about stacking, storing, lifting, etc., can be taken from construction guidance and manufacturers information.

2.2.5 Deconstruction of roof cladding made of deep corrugation trapezoidal sheet

A quite frequent roof cladding uses deep corrugation trapezoidal sheet supported directly by the primary structure (frame rafter or truss). No purlins are used in this case as the sheeting has the role to carry dead load plus climatic loads. The steel sheeting is connected to the primary steel structure via fasteners of the type presented in Figure 3.

The outer insulating layers, supported by the inner sheeting (see Figure 14), are: hydro-insulating PVC or bituminous membrane, thermal insulation and vapour barrier in direct contact with the sheeting.

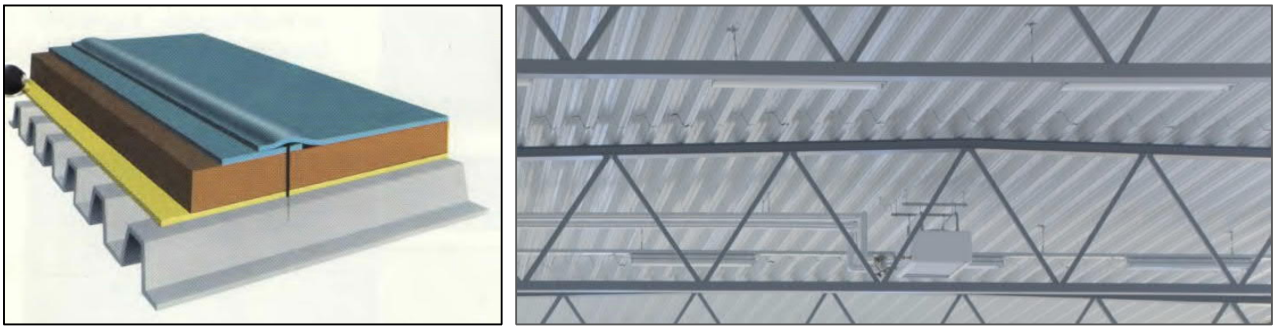


Figure 14. Roof cladding made of deep corrugation trapezoidal sheet supported by primary structure

The package of insulating layers of the cladding is connected to the steel trapezoidal sheet via fasteners of a special type. An example of such fasteners is *presented in Figure 15.*

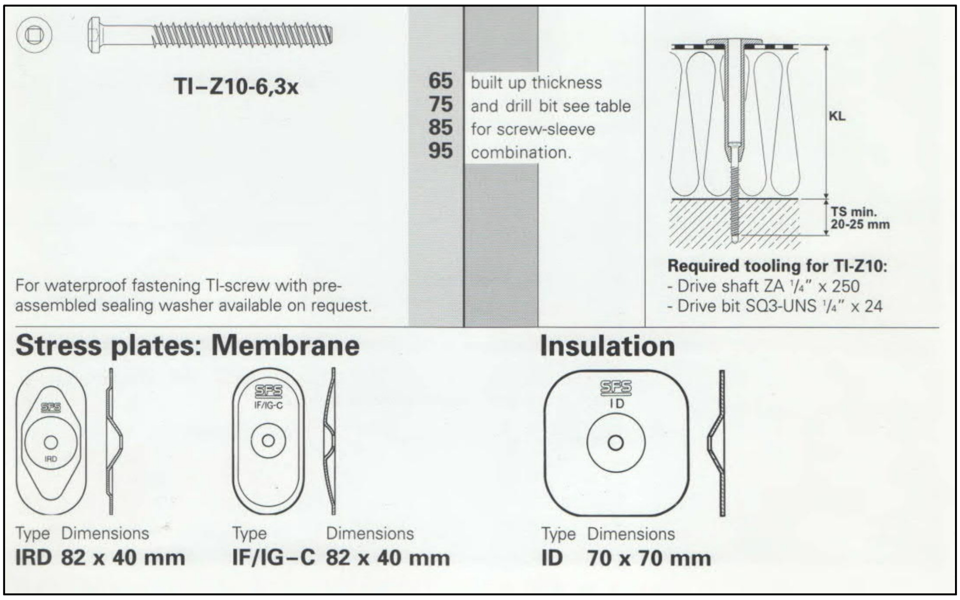


Figure 15. Typical fastener to connect the cladding insulation layers

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required
2. Removal of insulating layers fixings. Fixings should be manually removed by operatives on cherry pickers working on roof zones and thus leaving the rest of the roof secure to wind suction.

3. Removal of the insulating layers from the working zone established on the cladding (where fixings have been removed) starting with the outer PVC membrane (cut and rolled) continuing with the rectangular pieces of rigid mineral wool (usual thermal insulation in such systems) and ending with the vapour barrier (cut and rolled). Manual handling by 2 operatives should be possible for the removed components and manual lowering also.
4. Removal of the deep corrugation trapezoidal sheet fixings: Fixings (to the primary structure and saw fixings) should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the sheeting. Fixings shall be removed from one panel at a time.
5. Temporary storage at height: Panels to be stacked on the roof in groups of 3-5 overlapping sheet panels perpendicular to rafters.
6. Attachment to crane: Depending on the sheet panel length, a single or double cradle and sling arrangement shall be used for lowering sheet panels to the ground. Lowering can be done by sling the package by using a rocker arm and min. 200 mm-wide nylon belts (figure 4). Insert min. 200 mm-wide wooden boards between the package and the belts. The wooden boards will have to be approximately 2 cm longer than the package width.
7. Storage on ground: Panels should be stacked horizontally on timber bearers placed on the ground. Panels should be stacked no more than x panels high.
8. Identifying, grouping and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Guidance on size and weight of panels for manual handling: In practice usual panel lengths would be of 6.0-8.0 m allowing for manual handling.

Advice about stacking, storing, lifting, etc, can be taken from construction guidance and manufacturers information.

4.2.6 Deconstruction of the cold-formed liner-tray wall cladding system

Liner trays are thin-walled cold-formed steel profiles (see Figure 16) used to build SSB wall cladding without providing a secondary structure.

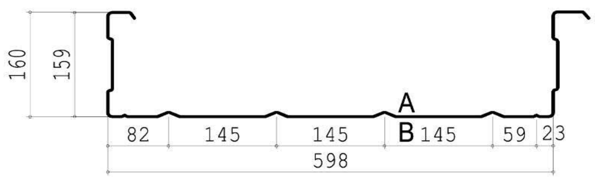


Figure 16. Example of liner tray thin-walled cold-formed profile

The system uses light gauge, cold-formed steel sections of large channel-type with two narrow flanges, two webs and one wide flange (see Figure 16 and Figure 17), frequently used in practice, to resist perpendicular uniformly distributed wind loading as well as to create a diaphragm effect which acts against horizontal wind/earthquake loading at the level of industrial building cladding. Such systems are normally built using a required number of horizontally laid, inter-connected, adjacent liner trays plus an external skin of sinusoidal or trapezoidal sheeting installed perpendicularly to their direction (with vertical corrugations). This results in a stiff metal cellular system (SSB cladding wall) having its inner space filled with thermal insulating material.

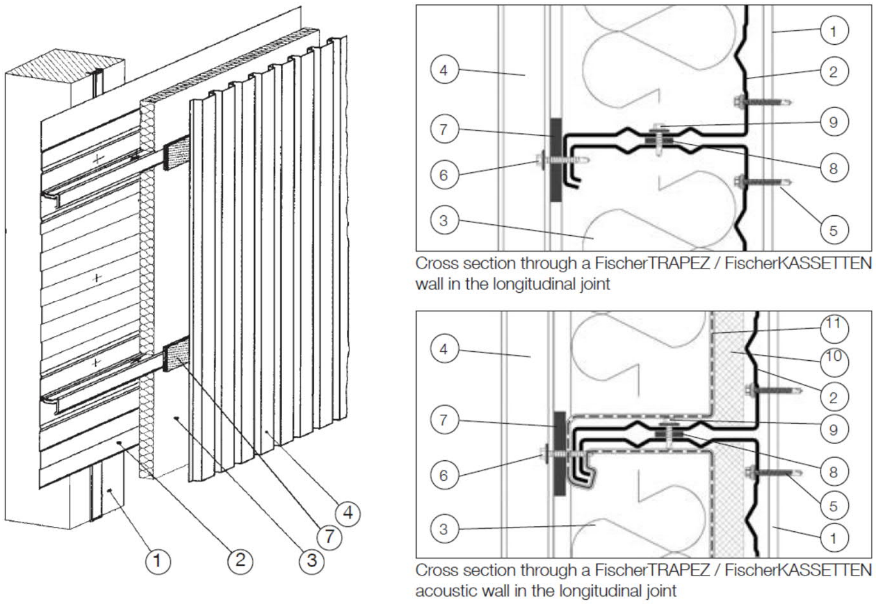


Figure 17. Wall cladding using liner trays profiles

Self-drilling self-trading fasteners or cartridge fired bolts pins serve to fix the wide flange of the horizontal profiles on the SSB columns (see Figure 17). The outer skin (usually made of trapezoidal steel sheet vertically installed across the narrow flanges) is fixed to the narrow flanges of the liner trays using self-drilling fasteners of the type described in Figure 3.

Plant and equipment: Mobile crane, 2 scissor lifts, cherry picker, power tools.

Man-power requirements: 2 men working at height, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required
2. Removal of outer skin fixings: Fixings should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the panel – refer to Figure 5 showing typical fixing types used. Fixings shall be removed from one sheeting panel at a time.
3. The loose outer sheet of the cladding is manually handled and lowered by the operatives on the scissor forklifts and on the ground around. Clamping devices of the type described in Figure 5 and ropes may be used during this operation.
4. The deconstruction process continues with the removal of the thermal insulation layers, installed inside the liner trays i.e. mineral wool layer (in form of wool roll or semi-rigid panels) and vapour barrier.

5. Storage of trapezoidal sheet panels on the ground: Trapezoidal sheet panels should be stacked horizontally, overlapping, on timber bearers placed on the ground. Panels should be stacked in overlapping piles and handled by crane (see Figure 5).
6. Removal of liner trays fixings: Fixings of the liner tray thin-walled profile to the primary column and saw fixings between adjacent liner trays should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the liner tray panel (see Figure 17). Fixings shall be removed from one liner-tray panel at a time.
7. The loose liner tray panel of the cladding is manually handled and lowered by the operatives on two scissor forklifts located at its opposite ends. Clamping devices of the type described in Figure 5 and ropes may be used during this operation. Manual handling is possible further on at ground level.
8. Storage on ground: The deconstructed liner trays should be stored on the ground in layers. Liner tray panels of the first layer should be stacked horizontally, one near each other, on timber bearers placed on the ground. The next layer should be laid on perpendicular direction to the first to provide stack stability and so on. Panels should be stacked in no more than 10-12 layers panels (i.e. 1-1.20 m high) to provide access for manual handling.
9. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Guidance on size and weight of panels for manual handling: usual liner tray panels have 4.0-6.0 m length and weight under 50 kg which allows manual handling by two operatives.

Advice about stacking, storing, lifting, etc., can be taken from construction guidance and manufacturers information.

4.3 Deconstruction of the secondary structure

Of the various constructional solutions of secondary structures (described in Section 1), the protocol focuses on light gauge, cold-formed purlins and side rails which are commonly used in SSB buildings.

In the case of purlins, the loading they should resist is that due to gravity (downward – self weight, snow, wind pressure) and uplift (wind suction) loading. Anti-sag ties at mid-span or third points may also be used to restrain the purlins, and these have the added benefit of reducing misalignment of the purlin during fixing the cladding. The purlins are all designed and installed according to several static schemes described in Figure 18.

Side rail design and detailing are very similar to that of purlins, and often the section used are the same. In the case of side rails, the major loading to be resisted is that due to wind (pressure and suction) on the side of the building. The self-weight deflection of the side rails due to bending about the week axis in counteracted by the provision of anti-sag bars and tension wires at mid-span or third points.

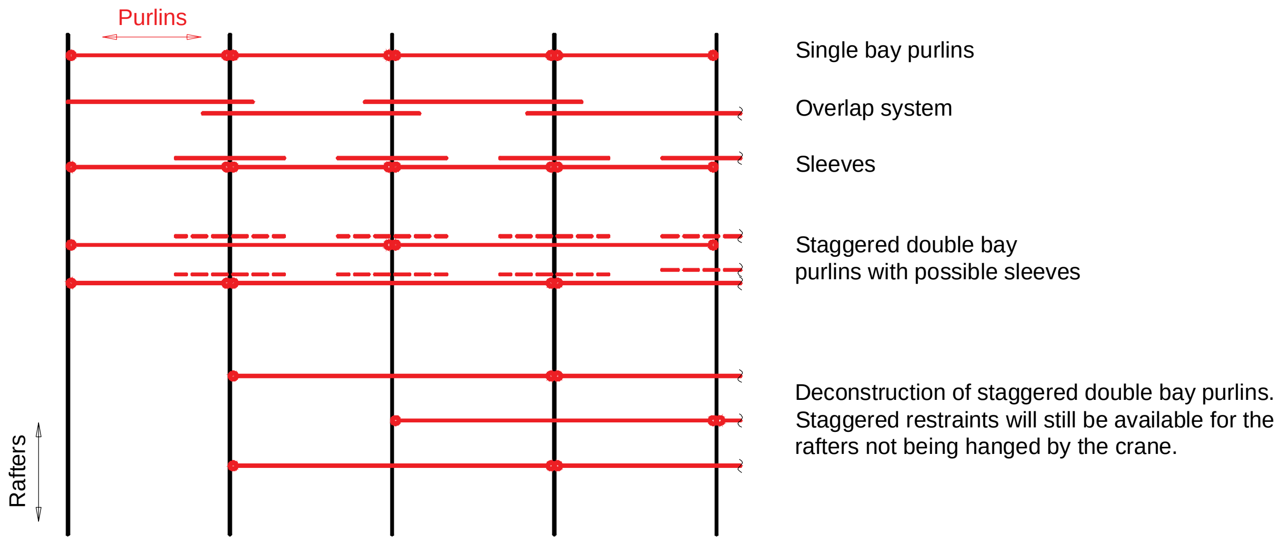


Figure 18. Static schemes used for purlins

4.3.1 Deconstruction of the cold-formed purlin system

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 2 men working at ground level.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required if independent bracing system present. In case of longitudinal bracing struts absent and participation of some purlins to primary structure bracing, these should be deconstructed in further steps (see general flowcharts in Sections 2.5, 2.6, 2.7).
2. Removal of fixings: Fixings (usually metric bolts) should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the cold formed profiles Fixings shall be removed from one purlin at a time beginning with sleeves if present.
3. Manual handling at height and lowering of the resulting profiles: Due to the loose profile length and reduced weight the manual handling is possible at height and lowering using ropes, piece by piece. The lowered profiles may be handled manually by two operatives at ground level.
4. Storage on ground: Profiles resulting from the deconstructed purlins / side rails should be packaged together by overlapping and stacked horizontally on timber bearers placed on the ground.
5. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Advice about stacking, storing, lifting, etc., can be taken from construction guidance and manufacturers information.

4.3.2 Deconstruction of the side rail system

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 2 men working at ground level.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required if independent bracing system present. In case of longitudinal bracing struts absent and participation of some side rails to primary structure bracing, these should be deconstructed in further steps (see further flowchart).
2. Removal of fixings: Fixings (usually metric bolts) should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the cold formed profiles Fixings shall be removed from one purlin / side-rail at a time beginning with sleeves if present.
3. Manual handling at height and lowering of the resulting profiles: Due to the loose profile length and reduced weight the manual handling is possible at height and lowering using ropes, piece by piece. The lowered profiles may be handled manually by two operatives at ground level.
4. Storage on ground: Profiles resulting from the deconstructed purlins / side rails should be packaged together by overlapping and stacked horizontally on timber bearers placed on the ground.
5. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Advice about stacking, storing, lifting, etc., can be taken from construction guidance and manufacturers information.

4.3.3 Discussion regarding the deconstruction order of the cladding

While removing façade cladding, it is prudent to make allowance for an opening in the cladding on opposite side of the façade being deconstructed. This measure will avoid unpredicted internal pressures on the structure (see Figure 19). The main concern of this recommendation is to avoid a scenario similar to a design case where a dominant façade needs to be considered for the wind action (for roof or façade wind action).

If no vertical/longitudinal bracing system is present, this means that the building stability is relying on the out of plane stiffness of the secondary system made up by side rails and cladding system. Therefore, removing cladding entirely is not recommended.

If by some reason cladding need to be entirely removed on an initial step, it is recommended that a temporary longitudinal vertical bracing system is installed, such as the ones proposed in Figure 22. Relying only on the purlins to provide the horizontal stability of the building is not recommended. There are reports of collapses during erection while relying on this behaviour.

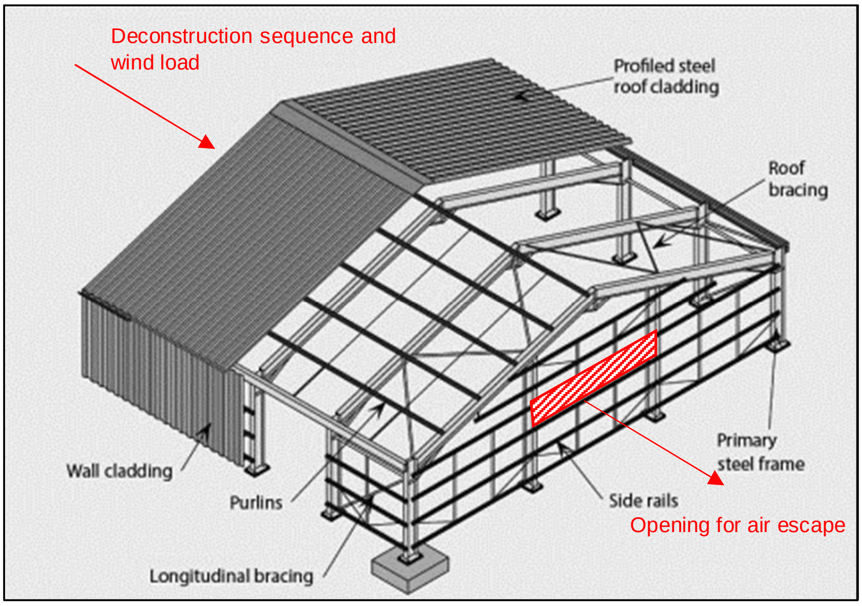


Figure 19. Partial deconstruction phase for cladding: opening for air escape

4.4 Deconstruction of the primary structure

4.4.1 Deconstruction of the bracing system

A usual single-storey building will normally rely on an independent bracing system for the global and members out of plane stability of the primary structure. This usually includes roof bracing and wall bracing systems built of X or V bracing working together with eaves or intermediate struts and separately from the secondary structure (see Figure 20 and Figure 21). In such a case the secondary system (purlins + side rails) has the only role of carrying climatic loads transmitted by the cladding and practically no role in providing the structural stability. These elements work in bending only.

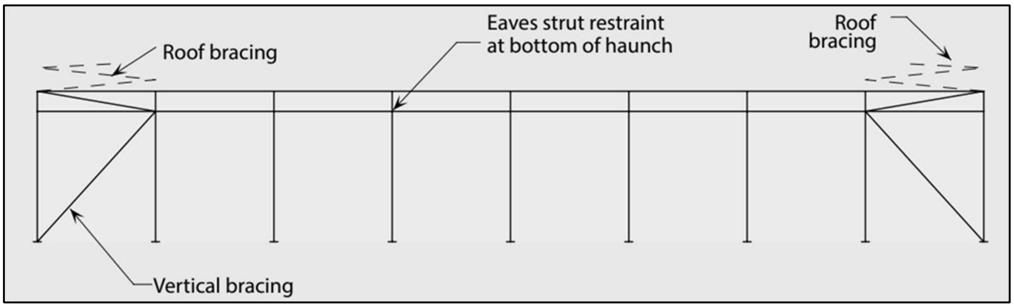


Figure 20. Vertical SSB bracings and eaves struts

This is a logic solution especially in case of secondary structure of thin-walled cold-formed profiles which are strongly affected by additional compression effects if obliged to work al longitudinal struts also. The deconstruction procedure for these secondary elements may operate independently of the primary structure and its bracing system.

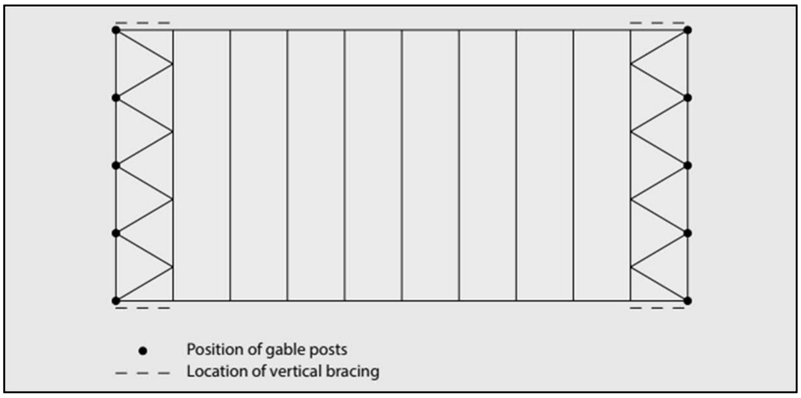


Figure 21. Conventional roof bracing

If the bracing system partially relies on purlins / side rails (all necessary bracings provided but no eaves or intermediate struts are provided and their role is taken by some purlins or side rails) then only a partial deconstruction of the purlin / side rail system is possible in the first phase, leaving the bracing zones untouched to stabilize primary structure in the process. The remaining secondary elements will be deconstructed in steps, together with the primary structure.

If no separate bracing system is provided (primary structure designed exclusively on the basis of diaphragm effect acting at the level of roof or walls) then the deconstruction order needs to change and proceed step by step (cladding of a single bay deconstructed followed by subsequent transverse frame deconstructed, then cladding of the next bay deconstructed followed by the next transverse frame and so on). Some temporary bracing systems may also need to be installed in such cases (see Figure 22).

Figure 22. Example of temporary bracing system

Suggestion for the system:

- Two tension only “X” bracings;
- One strut element.

It is suggested to have a temporary bracing element every 35 m (with a minimum of one system per longitudinal façade). It is recommended that the vertical temporary bracings are the last building elements (together with adjacent columns and eaves struts) to be deconstructed.

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 2 men working at ground level, 1 crane driver.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: None generally required if the bracing zones are left last in the primary structure deconstruction order.
2. Removal of fixings: The bracing elements are usually connected with bolts to the primary structure. These fixings should be manually removed by operatives on cherry pickers after de-tensioning the X arms- if existing- (operating on their tensioning devices). Fixings shall be removed from one bracing panel at a time. The complete removal of connecting bolts shall be correlated with the crane attachment of the member described below.
3. Attachment to crane: The bracing member (usually a linear element of relatively low weight, i.e. 50-100 kg) shall be attached to the crane (using a flexible belt attached to the hook) at one end by the operatives on cherry picker or scissor lift. The attaching operation should be performed before the complete removal of the connecting bolts
4. Storage on ground: Bracing members handled by the crane should be received by the two operatives working at ground level and stacked horizontally on timber bearers placed on the ground.
5. Identifying, grouping and labelling the products: Bracing members should be grouped by types as appropriate (separate piles on the ground) and each element clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

4.4.2 Deconstruction of the hot-rolled or tapered rafter system

The SSB portal frame is built of rafters and columns. Deconstructing rafters is one of the most delicate operations of the process, as the resulting elements shall be reclaimed and represent an important part of the reclaiming product. Common rafters are usually built of hot rolled profiles or of welded steel plates (so-called “built-up” sections).

For smaller frames (i.e. having a span less than 20 m) it may be more practical to handle an entire portal frame and perform the disassembling procedures of individual elements on the ground.

On the other hand, for long spans (i.e. more than 20 m) or multi-bay frames, the deconstruction of individual rafters or pairs of rafters in the same portal is recommended, due to the flexibility of the frame or simply to limit the handling and lifting equipment required (hook distance allowed by slings and spreader, or crane capacity).

Pairs of rafters can be kept connected by the apex connection, as long as the handling/lifting equipment allows for that option. For long spans, say more than 20 m, due to the flexibility of the rafters, it may be necessary to disassemble each individual rafter, as handling the pair may be impractical. The use of two cranes to perform the rafter pair deconstruction may be required (see Figure 23).

Figure 23. Rafter hung by two cranes to provide stability during deconstruction

Plant and equipment: Mobile crane(s), cherry picker, power tools.

Man-power requirements: 2 men working at height, 2 men working at ground level, 1-2 crane drivers.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: Especially built-up rafters made of welded steel plates tend be quite slender. This will be even more critical in countries where plastic global analysis is usually implemented where even rafters built of hot rolled welded profiles tend to be slender. For these cases, the independent bracing system or even the secondary steelwork plays an important role to restrain out of plane flexural buckling and lateral torsional buckling of the rafters. It is therefore necessary in some cases to make sure that before the removal of secondary steelwork, the rafter is hanged by a lifting equipment.
2. Removal of fixings: Fixings (usually metric bolts) should be manually removed by operatives on cherry pickers. Fixings are removed using tubular wrench key power tools taking care not to damage the rafter profile. Fixings shall be removed from one rafter at a time. Reclaiming of the unscrewed bolts is not in view as not being allowed by modern codes.
3. Attachment to crane: The attachment to crane (cranes) of rafter pairs or of individual rafters is illustrated in Figure 24. An assessment of the rafter weight is normally necessary when

choosing the crane capacity. This is possible either if the project of the deconstructed building still exists or by a rough evaluation based on site geometric measurements (cross-section and length).

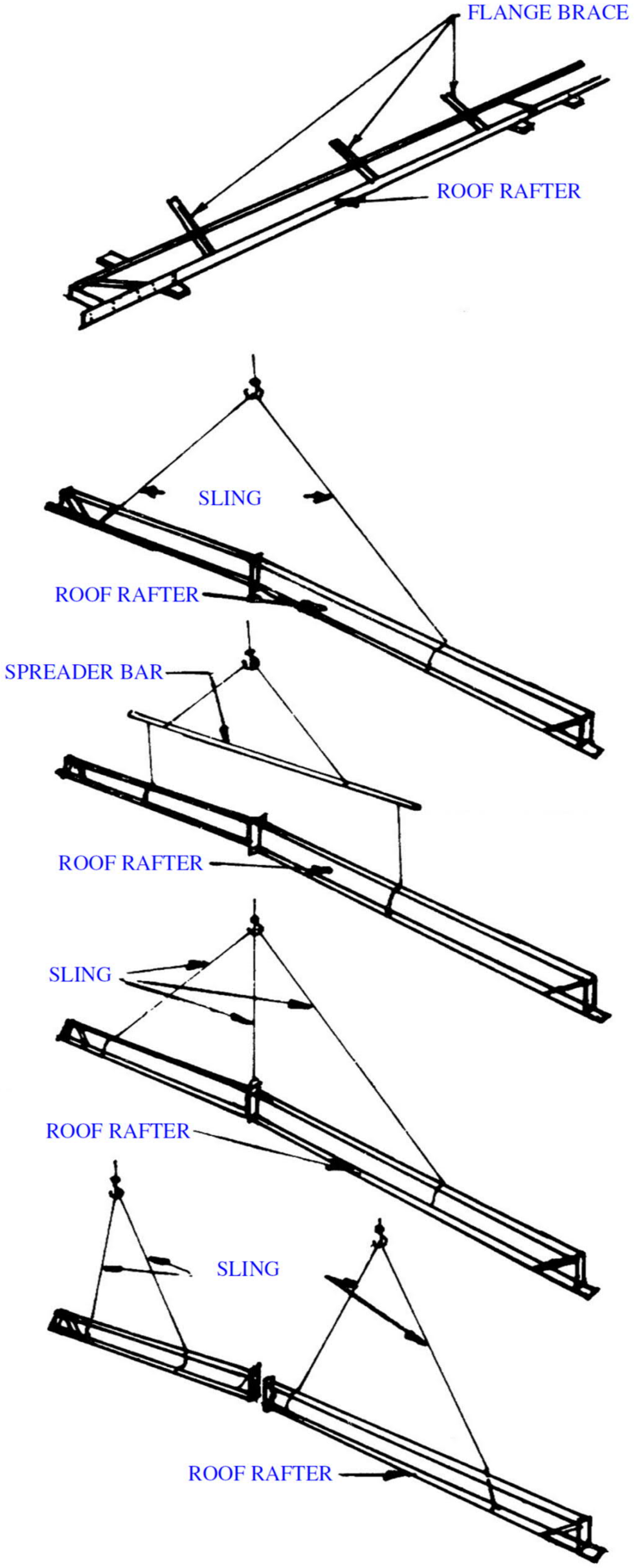


Figure 24. Attachment to crane for pairs of rafters or of individual rafters

4. Storage on ground: Profiles resulting from the deconstructed rafters should be stacked horizontally on timber bearers placed on the ground.
5. Identifying, grouping, and labelling the products: Panels should be grouped as appropriate and each panel clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

Additional notes:
Advice about stacking, storing, lifting etc. can be taken from construction guidance and manufacturers information. Steelwork that is to be stacked and stored should be laid on suitable timber packers, not directly onto the ground. It should be stacked in a manner and position that will avoid any risk of stack collapse or component distortion. To minimise re-handling of the material, stacks should be in an area which will provide convenient proximity to the point of loading into the vehicles to be sent to stockyard. Special care is taken in loading the components in the vehicles. They should be loaded in such a way (e.g. using timbers) so the slings may be place easily for unloading in the stockyard, ensuring the stability of the vehicle.

4.4.3 Deconstruction of the truss girder system

Truss girder solutions are used in many SSB of various spans however, they are particularly efficient, in terms of weight, for longer spans, i.e. greater than 20 m. This is a "classic" solution for the primary structure taking different forms as illustrated in Figure 25 and Figure 26.

Figure 25. Primary structure using a truss-girder and roof purlins (crane girder also present)

Plant and equipment: Mobile 1-2 cranes, cherry pickers (2-3), power tools.

Man-power requirements: 2-3 men working at height, 2 men working at ground level.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

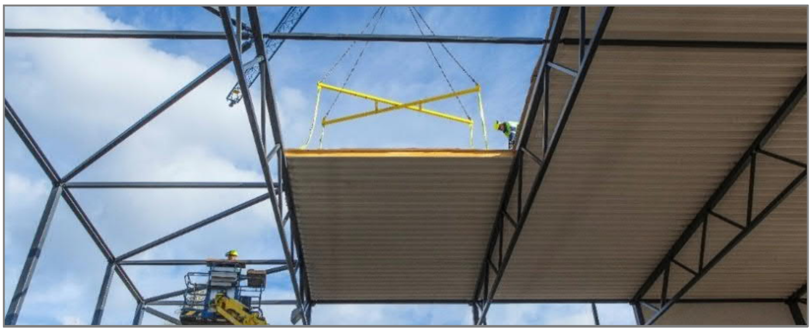


Figure 26. Primary structure using truss-girders and directly supported roofing (no purlins)

Deconstruction process:

1. Stability during deconstruction: None generally required if independent bracing system present. In case of longitudinal bracing struts absent and participation of some side rails to primary structure bracing, these should be deconstructed in further steps (see general flowcharts in Section 4.5
2. Removal of support fixings: Support fixings (usually bolts) should be manually removed by operatives on cherry pickers. Fixings are removed using power tools taking care not to damage the girder profiles Fixings shall be removed from one truss-girder at a time.
3. Attachment to crane: The attachment to the crane (or cranes) of truss girders in case of deconstruction, depends on the span and weight of the truss. For spans longer than the transportation limiting length, i.e. 14.5 m, the truss structure would normally be composed of two or more sub-parts defined in the project and assembled on site either by bolts or by welding. It is not recommended to disassemble the truss girder in these sub-parts when supported by the crane or cranes: preferably the entire truss-girder should be disconnected from its supports, lowered to the ground using 1-2 cranes and the sub-parts disassembled there to obtain transportable components. An assessment of the truss-girder weight is normally necessary when choosing the crane capacity or deciding to use two cranes for handling and lowering this part of the primary structure. This is possible either if the original structural information of the deconstructed building is available or by estimation based on site geometric measurements (cross-sections and length).
4. Storage on ground: The complete truss-girder shall be lowered onto the ground, laid down in a horizontal plane on timber bearers and further deconstructed in this position: the bolted or welded connection between transportable parts is then identified and removed to obtain the original transportable sub-parts.
5. Identifying, grouping and labelling the products: The similar sub-parts coming from different deconstructed truss-girders shall be stored together in the same location after labelling with a logical identifier identifying the product, group and if appropriate, location within the building.

4.4.4 Deconstruction of the columns

The deconstruction of the columns is the last deconstruction operation.

For smaller frames, having spans of 10 to 15 m and a frame weight (known from existing documentation or estimated) allowing handling with the available crane, it may be more practical to handle the entire frame (usually having a possible weight of 5-10 tones) and perform the disassembling procedures of individual elements on the ground.

While deconstructing frames / columns, it is necessary to assess the behaviour of the column base connections. Column base connections are, in general, nominally pinned, or fixed, which means that they usually have at least a nominal stiffness that can keep the column erect. Perfectly pinned base connections are quite rare and only used under architectural requirements.

Plant and equipment: Mobile crane, scissor lift, cherry picker, power tools.

Man-power requirements: 2 men working at height, 2 men working at ground level.

H&S risk: Working at height, strong winds.

H&S measures: Harness.

Deconstruction process:

1. Stability during deconstruction: It is important that bracing systems (linking the columns) and their adjoining elements are kept as the last elements to be deconstructed (see Figure 27). It is also important to ensure that the deconstruction sequence does not generate isolated structural zones without longitudinal bracings. If, during the deconstruction procedure, the primary structure is split in separate zones, every resulting zone must have a vertical/longitudinal bracing system either existing or temporary.

Figure 27. Individual columns prepared for deconstruction and handling

2. Removal of fixings: Fixings (usually anchor bolts) should be manually removed by operatives working at ground level. Fixings are removed using power tools taking care not to damage column base. Fixings shall be removed from one column at a time. To allow for

the deconstruction of entire 2D frames or individual columns, it may be necessary to expose the columns base connections by careful local demolition process of the ground floor slab. This is an operation that can be performed in parallel with the deconstruction of cladding and steelwork. However, in the case of fixed column bases, cast into the ground floor slab, this demolition operation might be difficult and with a high risk of damaging the column or the anchor bolts threads. Thus, loosening the anchor bolts nuts after concrete removal or even lifting the column still connected to the foundation by the mortar grout under its base might be difficult or even impossible. In such situations it is preferable to cut the column as close to its base as the cutting tools allow and lift / handle it afterwards. The column part remaining in the concrete will then be recycled (and not reclaimed for reuse) after the ground floor slab is broken out. Nominally pinned columns, i.e. with a base fixing using 2-4 bolts closely grouped near the column axis, usually have more accessible bases: either with visible base connection or with a smaller concrete cover allowing for easier removal.

3. Attachment to crane: Attachment to the crane of entire (smaller) frames shall proceed as illustrated in Figure 24 (using sling systems or sling systems with spreader). The individual columns usually weigh a few tonnes and therefore are generally easily lifted by the crane. They will be separately lifted and moved to the storage area.
4. Storage on ground: The complete frames shall be lowered on the ground, laid down in horizontal position on timber bearers and further deconstructed in this position if required: the bolted or welded connection between transportable parts is then identified on the structure and removed to obtain the original transportable sub-parts. The individually deconstructed columns will be stacked horizontally on timber bearers placed on the ground.
5. Identifying, grouping, and labelling the products: The columns should be grouped as appropriate and each column clearly marked or labelled with a logical identifier identifying the product, group and if appropriate, location within the building.

4.5 Deconstruction flowcharts

This section presents the recommended sequences of operations to be followed in the deconstruction process for three different combinations of main structure – secondary structure – roof and wall cladding as follows:

1. Deconstruction flowchart for a portal frame SSB made of hot-rolled steel profiles with secondary structure and sandwich panel cladding (see Figure 28);
2. Deconstruction flowchart for a SSB made of hot-rolled profiles for columns, truss girders and built-up cold-formed steel cladding (see Figure 29);
3. Deconstruction flowchart for a SSB made of fabricated sections (tapered structural elements), deep corrugation trapezoidal steel sheet for roof cladding and liner tray wall cladding (see Figure 30).

Annexes A and B present detailed examples of the deconstruction sequence for an SSB made of hot-rolled steel profiles (Annex A) and for a SSB made of hot-rolled profiles for the columns and truss girders (Annex B). Both examples have sandwich panel claddings systems.

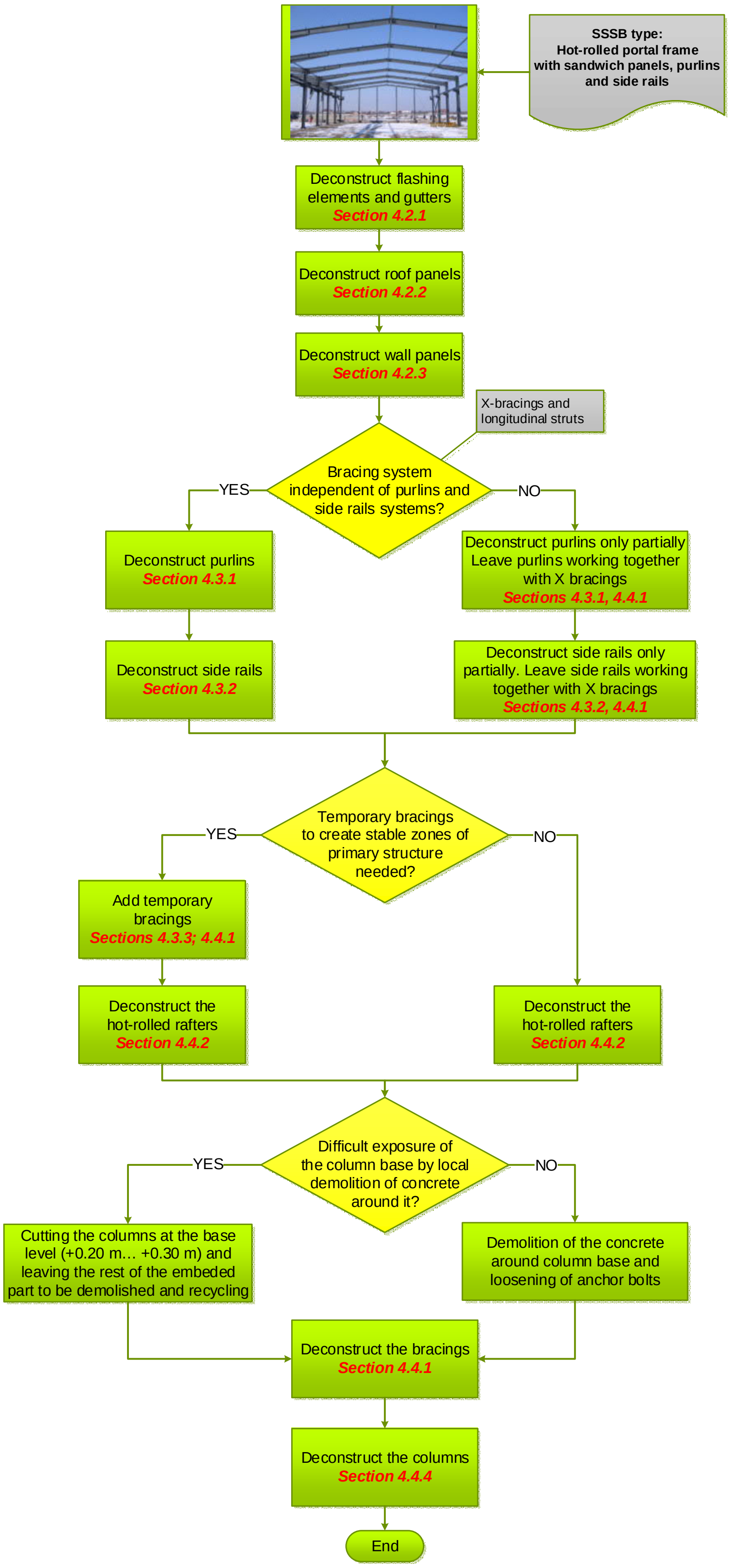


Figure 28. Deconstruction flowchart for a portal frame SSB made of hot-rolled steel profiles with secondary structure and sandwich panel cladding

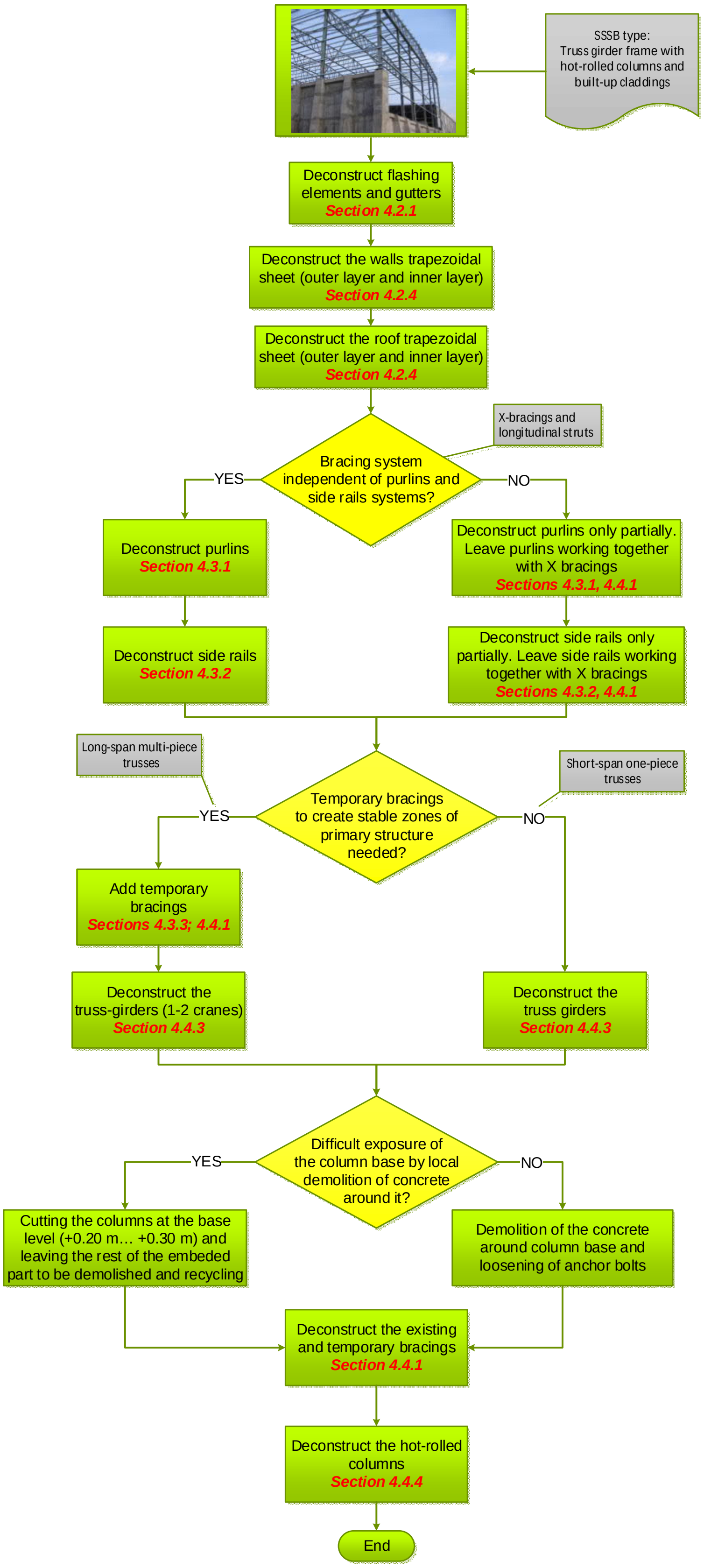


Figure 29. Deconstruction flowchart for a SSB made of hot-rolled profiles for columns, truss girders and built-up cold-formed steel cladding

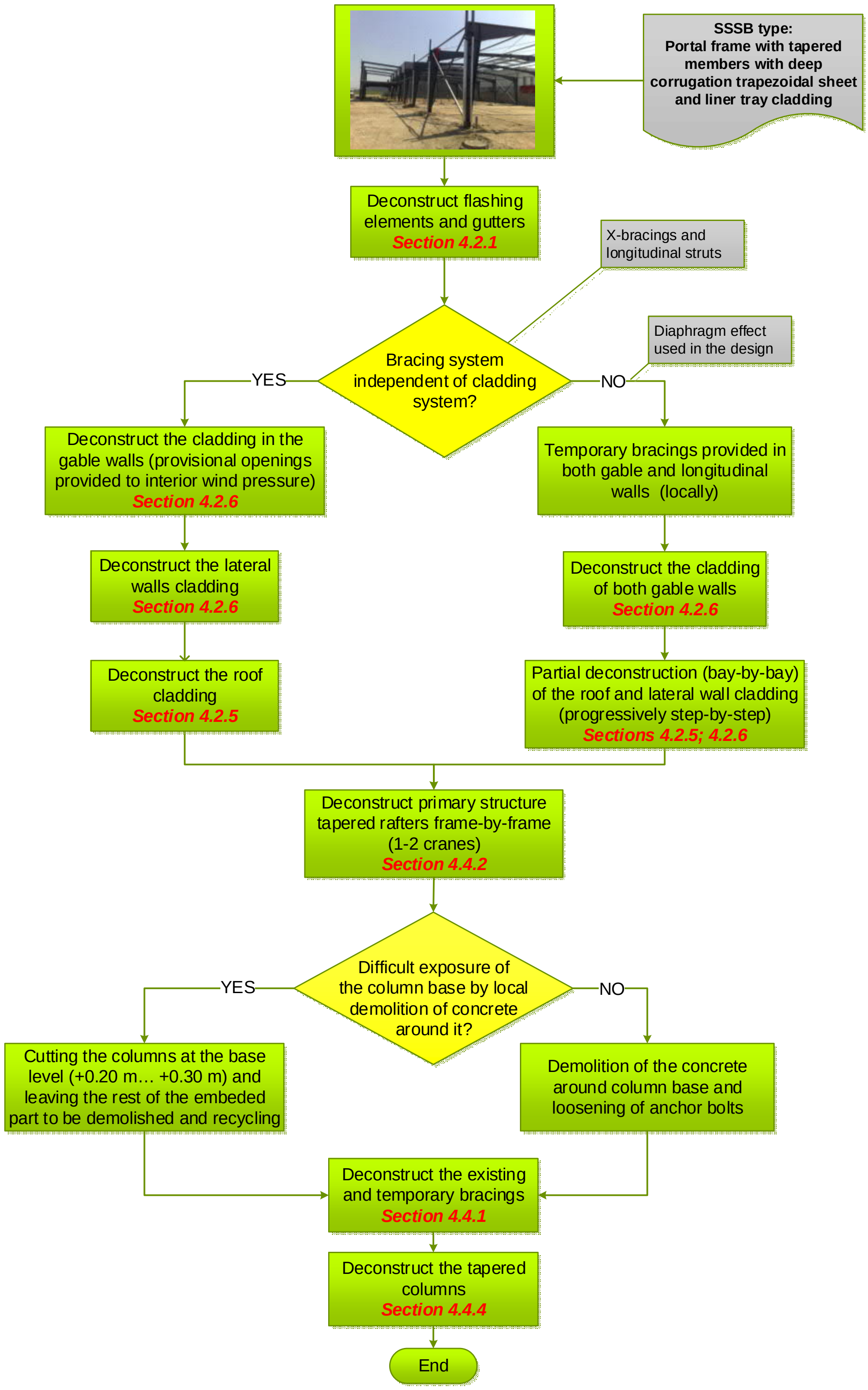


Figure 30. Deconstruction flowchart for a SSB made of fabricated sections (tapered structural elements), deep corrugation trapezoidal steel sheet for roof cladding and liner tray wall cladding

5. Storage and transport of reclaimed elements

After identification of the type and quantity of materials to be generated, the Deconstruction contractor needs to identify the disposal methods available. The Contractor also needs to determine the distance from the jobsite, material classification/ separation rules, and the tipping fees for the alternatives waste streams. The Demolish contractor will look at a number of disposal / reclaiming destinations, rather than the traditional single destination.

5.1 Storage and transport of sandwich panels for roof and walls

Wall panels are generally dismantled first. It is preferred for dismantling to start with the wall panels to allow for any interior disassembly work to continue and to maintain the roof diaphragm action in the partially constructed building.

Handling and machining the panels

Dismantling the roof sandwich panels usually starts at one of the end walls.

Stepping on the panel ribs is strongly discouraged, as is walking on partially attached or unattached panels. The safe way to walk on a fully fastened roof is to step on walk boards laid in the panels' flat areas and spanning between the purlins.

To prevent slippage, the walk boards should be secured to the roofing. If stepping on the panels is unavoidable, one should attempt to walk directly above the purlins where possible and to stay away from the middle of the flat panel part.

The panels must be handled to prevent damage and be protected against moisture or impact damage. Cutting or any other machining operation, during the dismantling process, must be carried out using adequate tools to ensure safety and to achieve a fault-free result. The panel surfaces must be protected against machining waste. Hot-cutting is strictly forbidden, as it would damage the coated surface of the panel.

Storing the panel package in a stockyard

The panel packages may be stored on top of each other as described in the deconstruction sequencing. It is recommended not to store more than three packages one on top of another, and place spacers or boards between them. The package should be placed on a flat and firm surface, using 50 mm-thick and 200 mm-wide polystyrene spacers or wooden boards at a maximum spacing of 1 m (see Figure 7). Panels should be stored at a slight incline to allow any moisture/water accumulating on the panels to drain from the panels.

When stored outdoors, the panel packages must be protected from rain, sun and dirt. When stored for a longer period, the packages must be stored indoors. If the panel packages are stored in exceptionally humid conditions, ventilation and sufficient air circulation should be ensured. This allows evaporation of humidity that may condense inside the packages. If it is impossible to protect the packages with waterproof membranes, make sure that the panels are appropriately ventilated.

Before packaging, any stains on the panels should be removed by washing with plain water or a mild detergent solution. If the surface of the panel has been slightly damaged, it can be repaired by touch-up painting, or the whole panel can be replaced if the damage is severe. The panel must always be replaced if there is a hole in the sheet metal face or the integrity and strength of the panel has been compromised.

5.2 Storage and transport of secondary steel structure

The secondary steel structure is connected to the primary loadbearing structure and its function is to transfer permanent load, dynamic load, and climatic loads.

The individual components are used as supports for roof cladding and wall cladding, to create openings for windows, doors, skylights, and possibly other enclosures of openings in the cladding.

Handling the purlins and rails

Side rails and purlins may be unbolted directly from the main frame steel structure or can be detached to it via the bolted bearing clips. Side rails and purlins necessary for bracing are installed along with the main frame. It is recommended to start by dismantling the secondary structure that does not play the role of bracing, followed by the remaining secondary elements.

It is usually quicker and more cost-effective to lower purlins from the roof in bundles rather than one by one. The bundles are placed on the top of the structure to facilitate the individual purlins to be moved by hand from their position.

Care should be taken to prevent damage to the secondary elements. Even small dents and deflections may impair the load bearing capacity of the purlin significantly. Scratches to the zinc coating of the components should be avoided. The materials shall be sufficiently protected against moisture and damage at all stages of their deconstruction and handling.

Roof purlins do not usually require temporary bracing during dismantling, but this should be verified when longer spans or higher slopes are concerned.

It is important to verify that the materials and accessories from dismantling comply with standards or are delivered with certified product declarations. It is recommended that during dismantling, attention is paid to the following factors:

- location of structural elements;
- straightness of structures;
- angles between members;
- joints between components;
- main dimensions;
- handling and storage of materials, accessories, and parts.

Transport and storage

Purlins should be packaged in bundles so that they are easy to handle. Purlins are packed together, and small components (as connecting bolts) are packed in separate packages. The content is clearly marked on each package to ensure they will be easily identified in the stockyard.

On the site, before packaging, the materials should be carefully checked to ensure the correct quantity and condition of the products. Damaged products are not allowed without approval.

Purlins shall be stored in a dry place protected against rain and snow, on a level base. The dry storing conditions will prevent white rust forming on the galvanised surface. Products shall be supported at regular intervals to prevent deformation. It is recommended that products are supported on a slight incline (1:20), to ensure that possible water leaking onto the purlins will naturally drain away. The packages should be raised above ground to allow ventilation of the bottom side of the packages. Materials should not be piled on top each other, as this may damage the sections. If purlins get wet, they must be separated and dried to eliminate the possibility of white rust. If required, sufficient support shall be provided for the packages to prevent them from tipping or falling over.

5.3 Storage and transport of the main structural steel elements

The structural frames and other parts of the building can be dismantled in various ways which will depend on the following key factors:

- The type of structures such as: small clear span, large clear span, type of single storey steel building, height of the building etc.;
- The availability of plant and equipment such as cranes, winch, manually lift etc.;
- The site conditions;
- The experience level of the deconstruction company;
- The sequence/method of deconstruction shall be planned so that it can be carried out in a safe, economical and efficient manner.

Deconstruction of the primary structure shall begin with the unbraced bays followed by the braced ones, the braced bays providing support for the other members during dismantling process. Whichever method is preferred, they should incorporate proper bracing, which may be more substantial than the permanent bracing of the building. Inadequately braced metal buildings have been known to collapse during erection. Physical marking of critical props and/or bracing including identifying whether they are temporary or permanent, and physical protection of the same if they are in a location where there is risk of impact/damage.

Lifting methodology including crane selection, major plant set-up areas, expected loads including size, weight and geometry, lifting point locations with associated certification and any specialised rigging equipment required.

Protection and storage of the main structural elements

With the purpose of protecting elements and preventing damage during storage, the following measures are recommended:

- Choose a firm and dry area for storage;
- The materials or component or member shall be stored separately, above ground on timber spacers; They shall not be stacked directly on top of each other but must be separated by 50mm thick timber, and shall not be stacked in contact with other steel member but must be separated by a minimum 250 mm gap;

- Particular care shall be taken to stiffen free ends at 200 mm distance from ends, to prevent permanent distortion;
- The sections should be placed at a minimum 5% slope to avoid water ponding on the surface;
- The materials shall be kept free from dirt, grease, and other foreign materials and shall be protected from road splash;
- Never step on the materials;
- All small plates and articles generally shall be suitably packed and identified;
- Bolts, nuts, washers, screws are not reused and should be sent to recycling;
- The ends should be not covered to permit air circulation. Do not wrap under or restrict air movement.

5.4 Roles during the transportation stage

Workers can be exposed to the risk of injury when loading, transporting, and unloading steel from transport vehicles. Delivery of steel to the storage sites requires co-operation between the demolition contractor, transporter, and stockholder, so that the steel is delivered in a timely and efficient manner, and that it does not overload the delivery area.

The transporter should have planned the routes and obtained all necessary permits and authorisation - for oversized or wide loads, restricted routes etc.

The transporter should be familiar with the traffic management plan that includes, where necessary, traffic controllers and road closure which permits to allow unimpeded access to the site.

The stockholder should also provide a safe and adequate unloading and lay-down area on the site and ensure that the transporter has detailed instructions on how to enter the site.

5.4.1 Managing risk during transportation

Common hazards:

- Steel falling from slung loads while unloading;
- Steel falling because the vehicle load is unstable or becomes unstable during unloading;
- Vehicle becoming unstable;
- Vehicle collapsing into a hole (if the site isn’t adequately prepared);
- Lack of set-up space;
- Lack of traffic management plan;
- Access/egress: steep grade and short pitch;
- Vehicle collision;
- Worker falling from vehicle during loading and unloading.

Risk controls:

Before loading vehicle

The *demolish contractor* should check that:

- the sequence of loading is agreed;
- each member is clearly marked (together with its mass where it is over 1.5 tonnes) before loading.

The *transporter* should check that:

- trucks have restraining spikes in place;
- steel is supported and secured, so that there is no uncontrolled movement of the steel until it is ready to lift;
- sufficient hardwood bearers, or equivalent, have been provided for loading.

When loading the vehicle

The *transporter* should check that:

- the vehicle and load is stable and load will remain stable during unloading.

When vehicle's arrival at stockholder site

The *transporter* should check that:

- securing chains or straps are not removed until restraining spikes in place;
- the steel has not shifted into a dangerous position;
- the vehicle is positioned as directed by the erector and stabilised before the steel restraints are released;
- if the unloading sequence can lead to the instability of loads, the steel is individually restrained, and the loading configuration checked so that unloading does not result in the load or the vehicle becoming unstable;
- the vehicle is not moved without the steel being properly secured.

The *stockholder* should check that:

- the sequence of unloading is agreed;
- a crane of the required type and capacity is at the site;
- the area for unloading is firm and level and checked for load capacity and where applicable or necessary, ground computations;
- there is an adequate set-up area;
- there is a traffic management plan;
- the grade and pitch of access/egress is suitable and safe for the vehicles and their loads.

6. Contractual framework

Before commencing work the Demolition Contractor shall report to the Employer's appointed representative. The Demolition Contractor and his sub-contractors in carrying out the Contract shall conform with all applicable legislative provisions and by-laws in particular (but without limitation) building and constructional laws and regulations including the Health and Safety and the construction regulations made there-under and with any local and Site Regulations of the Employer particularly (but without limitation) those relating to health, safety and hygiene. The Contract also incorporates security of payment, planning and environmental regulations.

Before beginning work on the site the Demolition Contractor shall sign a Certificate provided by the Employer certifying that the Demolition Contractor has been made aware of the Employer's local and Site Regulations and that the Demolition Contractor will abide by them and will procure his sub-contractors' employees and all other persons having access to the Site by his authority to abide by the same. The Contract shall be governed and construed in accordance with the laws chosen by the parties.

A very important contractual aspect is the assessment of demolition waste streams and to facilitate and maximize recovery of materials and components from deconstruction for beneficial reuse and recycling, without compromising the safety measures and practices. The Demolition Contractor should make an overview about what will be collected and to where the waste materials have been transported (for re-use, for pre-treatment (sorting), for recycling, for incineration, landfilling, …). This information should be (1) checked with what was foreseen in the inventory, and (2) provided to the authorities.

6.1 Deconstruction contract requirements

The Demolition Contractor must determine how their waste management requirements will be represented in the contract documents and incorporated into the project. Several provisions are relevant to the project's overall waste reduction performance:

- Describe the waste reduction goals and rely on the Demolition Contractor 's own initiative to achieve them.
- Require to the Demolition Contractor to submit a Demolish Waste Management Plan.
- Require the Demolition Contractor to document their actual waste diversion performance throughout the project. The Waste Management Plan should also include progress reporting procedures to record actual diversion and cost corresponding to each diversion and cost estimate.
- As the accepted Plan is a part of the contract document, it should be incorporated into the Demolition Contractor's Quality Control processes.
- Allow the Demolition Contractor to accrue the economic benefits. These include cost avoidance through reduced debris tipping expenses, revenues from salvaged and recycled materials, and cost avoidance by using materials taken from the jobsite back into the project.

6.2 Jobsite Waste Reduction

The waste diversion potential in a deconstruction scenario is considerable. The building's construction type and project schedule are the two primary factors in determining what and how salvage, reuse, and/or recycling can be accomplished. Consider the following:

- Develop the project schedule to accommodate salvage, reuse, or recycling. The quality and quantity of materials salvaged is a direct function to the time available for salvage.
- Prior to demolition, salvage as much useable material and components as the schedule will allow, i.e. windows and doors, electrical fixtures, plumbing fixtures, mechanical equipment… anything that can be detached and removed… can be usually salvaged and reused.
- Structural steel and metals are almost universally recycled. This should be standard practice with any demolition contractor.
- If none of the alternative salvage, reuse, or recycling options are possible, mixed demolition debris can be hauled to a debris recycling facility.

7. Deconstruction-phase health and safety

Measures that need to be taken to control the risks to health and safety in a particular project are described below. The general principles of prevention are set out in summary:

(a) avoid risks where possible;

(b) evaluate those risks that cannot be avoided; and

(c) put in place proportionate measures that control them at source.

7.1 General duties

The Demolition contractor, the Transporter and the stockholder appointed to work on a project must have the skills, knowledge, experience and the organisational capability, necessary to fulfil the role that they are appointed to undertake, in a manner that secures the health and safety of any person affected by the project.

Everyone involved in a project has a duty to report instances where they or others are working in a way that puts them or anyone else in danger. Any instances must be reported to the person in control of the work. The person in control should encourage workers to stop work and report dangerous conditions when they see them.

7.2 Good order and site security

Each part of a deconstruction site must be kept in good order and those parts in which deconstruction work is being carried out must be kept in a reasonable state of cleanliness.

Where necessary in the interests of health and safety, a deconstruction site must comply with either or both of the following:

a. have its perimeter identified by suitable signs and be arranged so that its extent is readily identifiable; or
b. be fenced off.

7.3 Stability of structures

All practicable steps must be taken, where necessary, to prevent danger to any person, to ensure that any part of the existing structure does not collapse if, due to the carrying out of deconstruction work, it may become unstable; or is in a temporary state of weakness or instability.

Any temporary support or temporary structure must be of such design and installed and maintained so as to withstand any foreseeable loads which may be imposed on it and only be used for the purposes for which it was designed and installed and is maintained.

A structural component must not be so loaded as to render it unsafe to any person.

7.4 Dismantling

The dismantling of a structure must be planned and carried out in such a manner as to prevent danger or, where it is not practicable to prevent it, to reduce danger to as low a level as is reasonably practicable. The arrangements for carrying out dismantling must be recorded in writing before the dismantling work begins.

7.5 Emergency procedures

Where necessary in the interests of the health or safety of a person on a deconstruction site, suitable and sufficient arrangements for dealing with any foreseeable emergency must be made and, where necessary, implemented, and those arrangements must include procedures for any necessary evacuation of the site or any part of it.

7.6 Emergency routes and exits

Where necessary in the interests of the health or safety of a person on a construction site, a sufficient number of suitable emergency routes and exits must be provided to enable any person to reach a place of safety quickly in the event of danger. An emergency route or exit must lead as directly as possible to an identified safe area and must be kept clear and free from obstruction. Each emergency route or exit must be indicated by suitable signs.

7.7 Fire detection and firefighting

Where necessary in the interests of the health or safety of a person on a construction site, suitable and sufficient fire-fighting equipment and fire detection and alarm systems must be provided and located in suitable places.

Fire-fighting equipment or fire detection and alarm systems must be examined and tested at suitable intervals and properly maintained.

Each person at work on a construction site must be instructed in the correct use of fire-fighting equipment which it may be necessary for the person to use.

Fire-fighting equipment must be indicated by suitable signs.

7.8 Temperature and weather protection

Where necessary to ensure the health or safety of persons at work on a construction site that is outdoors, the deconstruction site must be arranged to provide protection from adverse weather, having regard to the purpose for which the site is used and any protective clothing or work equipment provided for the use of any person at work there.

7.9 Lighting

Each site and approach must be provided with suitable and sufficient lighting, which must be by natural light.

7.10 Health and Safety

The items below help to identify hazards and control risks and it explains how to plan, organise, control, monitor and review health and safety throughout the life of a project.

7.10.1 Accidents

The construction industry accident rate is considerably higher than the average in all other sectors. The most frequent causes of accidental death and injury are:

- *Falls:* People fall because access to and from the workplace is not adequate, or the workplace itself is not safe.
- *Mobile plant:* Construction plant can be heavy. It often operates on ground, which is muddy and uneven, and where driver visibility is poor. People walking on site are injured or killed by moving vehicles, especially reversing ones. Others, particularly drivers and operators, are killed or injured by overturning vehicles and plant.
- *Falling material and collapses:* People are struck by material falling from loads being lifted and material that rolls or is kicked off work platforms; others are struck or buried by falling materials when excavations, buildings or structures collapse.
- *Electrical accidents:* People suffer electric shock and burns when they use unsafe equipment and when they contact overhead power lines and buried cables.
- *Trips:* Trips are the most common cause of reported injuries on construction sites. Most of these can be easily avoided by effective management of access routes such as corridors, stairwells and footpaths.

7.10.2 Health considerations

The construction industry has a poor health record. The workers are likely to suffer ill health as a result of their work after exposure to both harsh working conditions and hazardous substances. Ill health can result from:

- *Asbestos:* Exposure to asbestos can cause serious respiratory diseases such as asbestosis and cancer.
- *Manual handling:* Lifting heavy and awkward loads causes back and other injuries. Some injuries can result from a single lift, but more commonly, long-term injury develops as a result of repeated minor injury due to repetitive lifting.
- *Noise and vibration:* High levels of noise can cause hearing loss and repeated use of vibrating tools can cause hand-arm vibration syndrome (damage to nerves and blood vessels – most commonly in the hands and fingers).
- *Chemicals:* Exposure to materials such as cement and solvents can cause skin problems such as dermatitis.

7.10.3 Protective equipment

This section gives advice about general personal protective equipment, which may be required to protect against injury. The following protective equipment should be considered:

- On almost all sites there is a risk of injury from falling materials. Minimise these risks by providing suitable barriers and toe boards at the edge of work platforms to prevent materials from falling. Deal with the remaining risks by providing suitable head protection. Hard hats are required where anybody might be struck by falling materials or where people might hit their heads.

- Footwear to protect materials being dropped on workers' feet or nails, or other sharp objects, penetrating the sole.
- In deconstruction the employees regularly work outdoors, and they cannot be sheltered from the weather, wind and waterproof clothing will be needed. There should be facilities for storing clothing not worn on site and protective clothing as well as for drying wet clothing.
- Many accidents happen when people in hazardous positions cannot be seen. It is important to plan work to avoid placing people in these positions. Where this is not possible, provide high-visibility clothing.
- Suitable gloves should be used to protect against cuts and splinters when handling materials.

7.10.4 Working at height

Falls are the largest cause of accidental death in the construction industry; accounting for around 50% of all fatalities. There is no distinction between low and high falls. This means that for any work at height, precautions are required to prevent or minimise the risk of injury from a fall.

Those in control of the work must:

- avoid work at height where they can;
- use work equipment to prevent falls where work at height cannot be avoided;
- where the risk of a fall cannot be eliminated, use work equipment to minimise the distance and consequences of a fall should one occur;
- always consider measures that protect all those at risk, i.e. collective protection measures (scaffolds, nets, soft landing systems) before measures that only protect the individual, i.e. personal protection measures (a harness);
- ensure work is carried out only when weather conditions do not harm the health and safety of the workers.

The deconstruction process of structural steel is "high risk work", involving the operation of a variety of plant and the use of certain skills. Those workers operating cranes and other particular plant must have the appropriate licence before anyone can perform high risk work.

References

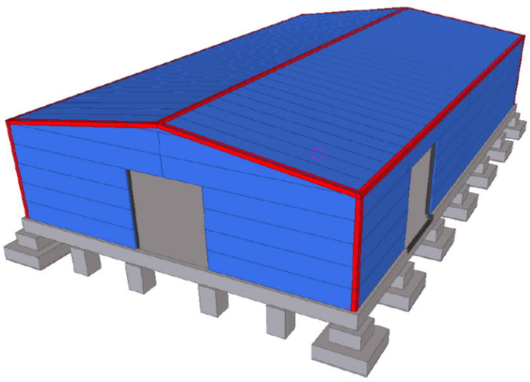
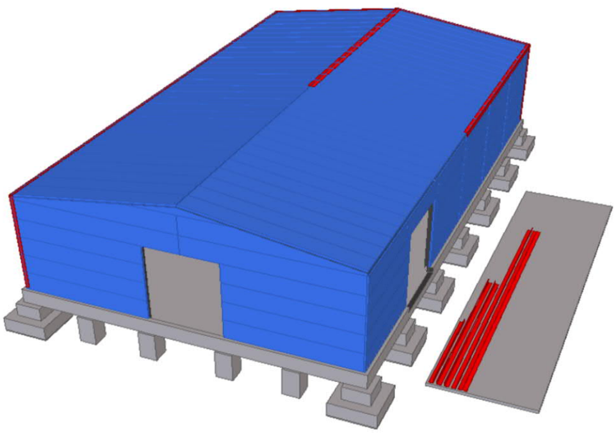
[1] Health and Safety Executive (UK), Managing health and safety in construction, 2015.

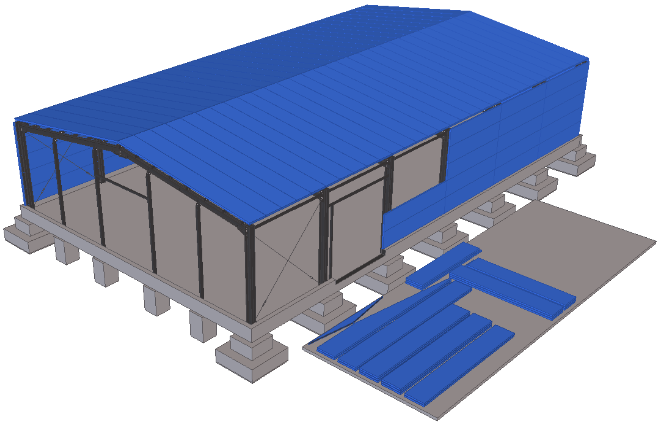
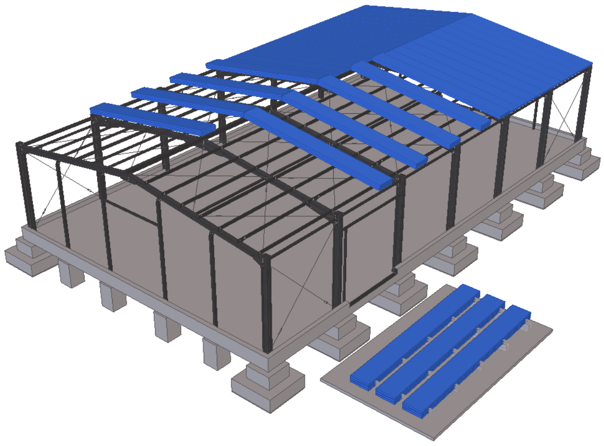
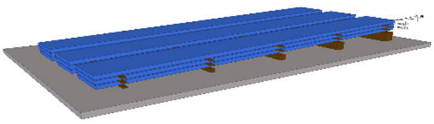
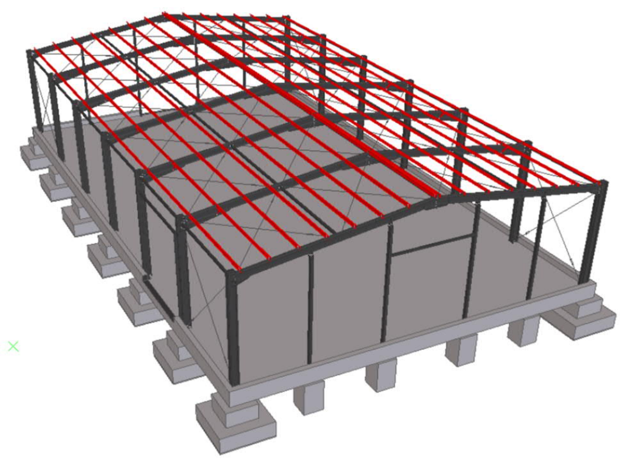
[2] HSG150 (Third edition, published 2006), Health and Safety Executive, Health and safety in construction, ISBN 978 0 7176 6182 2, 2006, www.hse.gov.uk/construction.

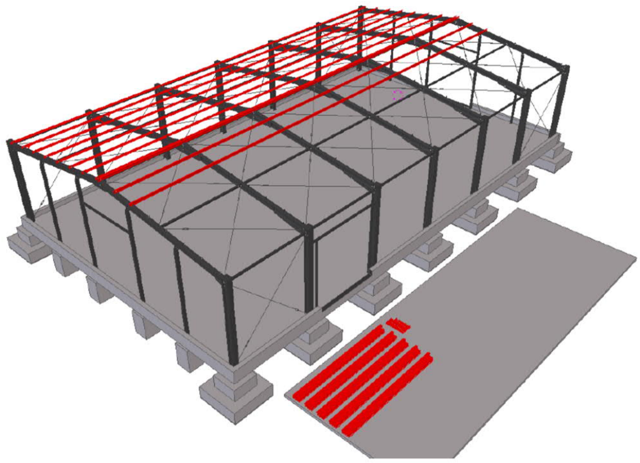
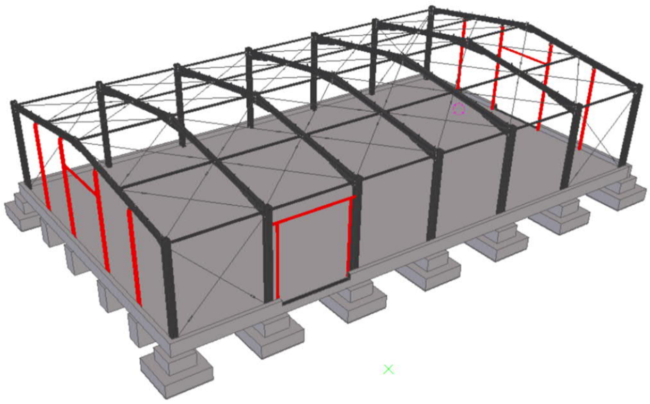
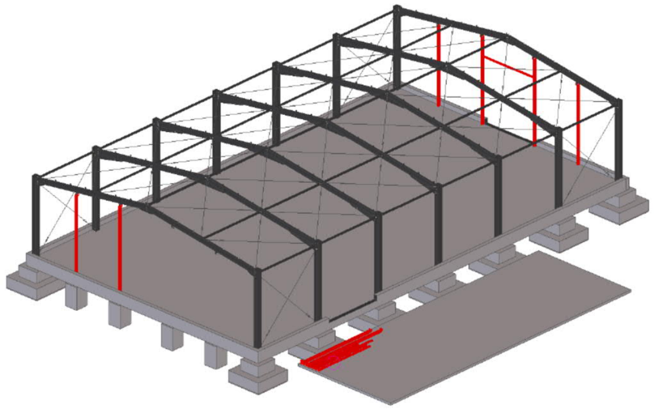
[3] Health and safety advice for steel erectors, CITB-Construction skills, Northern Ireland, www.citbcsni.org.uk.

[4] Worksafe Victoria, Industry standard, Safe erection of structural steel for buildings, Edition No. 1, May 2009.

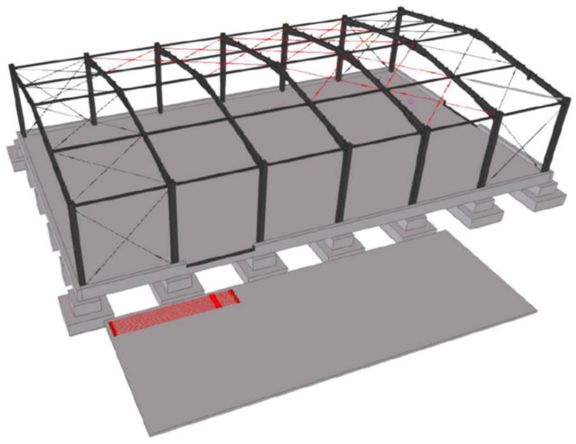
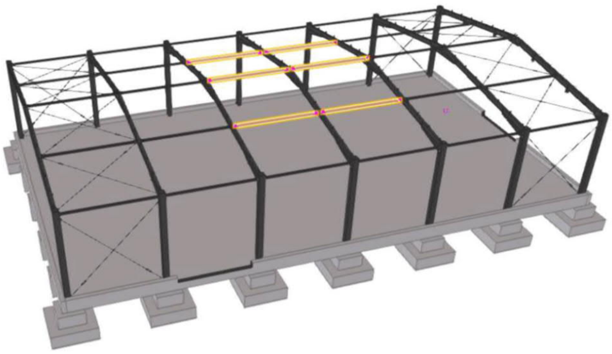
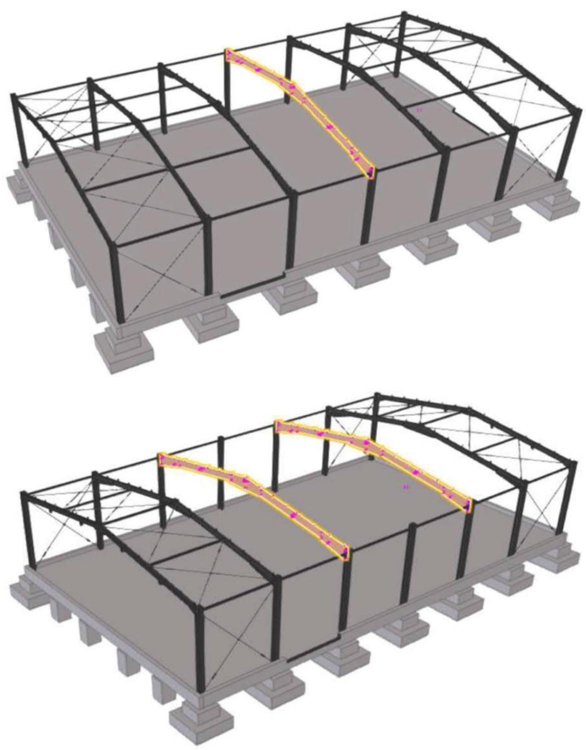
Annex A: Detailed example of the deconstruction of a portal frame SSB made of hot-rolled steel profiles with secondary structure and sandwich panel cladding

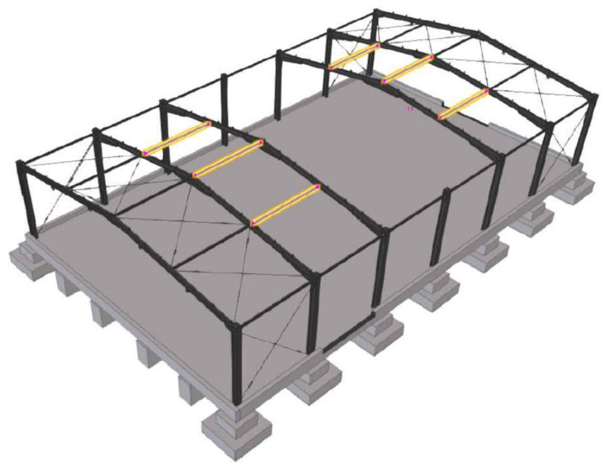
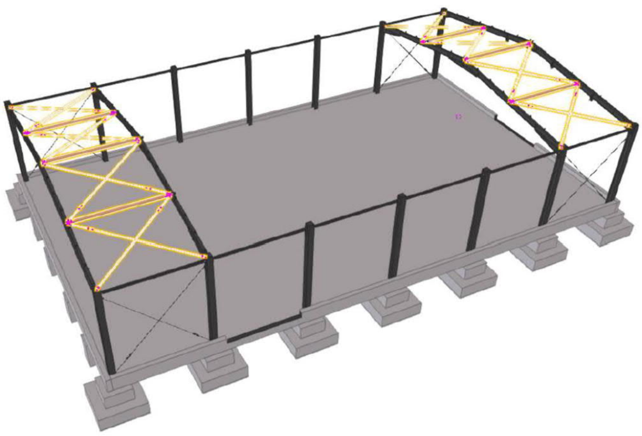
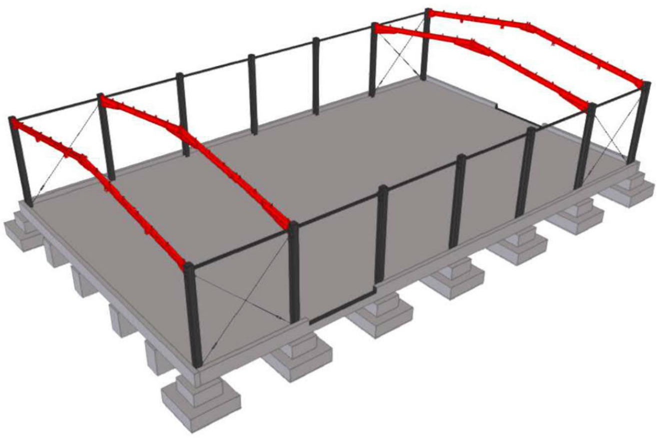
Hot-rolled steel structure	Comments
	This example gives a step-by-step guidance on how to deconstruct a portal frame SSB following the recommendations given in this protocol. The bracing system is independent of the secondary structure and sandwich panel cladding.
Deconstruction of sandwich panels for roof and walls	
Deconstruct flashing elements & gutters	
	First, all flashing elements and gutters should be removed.
	The flashings scheme is described in upper row. Reclaiming of such materials quite unlikely by aesthetic and tightness reasons (i.e. existing holes in the flashings after deconstructions).

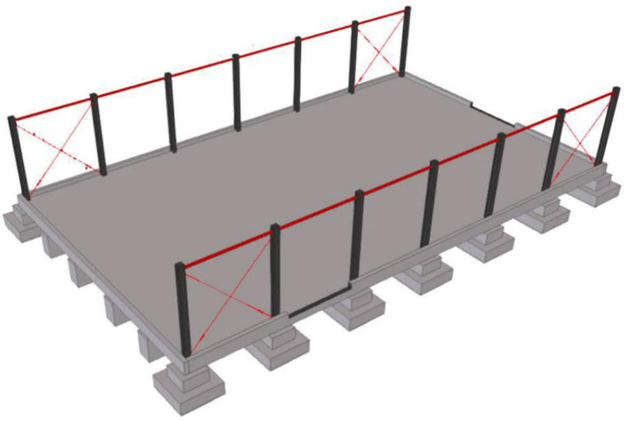
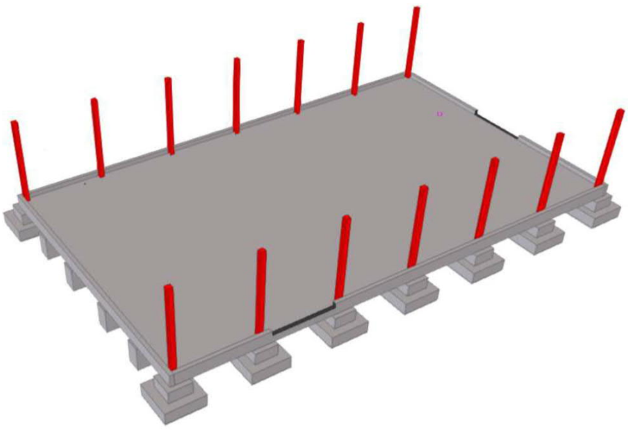
Deconstruct wall cladding	
	Wall cladding has to be deconstructed first on the purpose to have access to the structure. Special tools like clamps with special clamping shoes can be used for lowering of sandwich panels. Sandwich panels may be deposited near the structure in a first step and then removed to the final storing place.
Deconstruct roofing system	
 	Roofing system will start after the deconstruction of the wall cladding. Dismantling the roof sandwich panels usually starts at one of the end walls. Special tools like clamps with special clamping shoes can be used for the lowering of sandwich panels.
Deconstruction of secondary steel structure	
Deconstruct purlin system	
	Purlin system can be deconstructed. Reclaim possible (total or partial).

<table>
<tr><td></td><td>Purlins may be deposited near the structure, till their evacuation from the site.
Reclaim possible (total or partial).</td></tr>
<tr><td colspan="2">Deconstruct the windows, doors and gates structure and the gable posts</td></tr>
<tr><td>
</td><td>Deconstruction the windows, doors, gates structure.

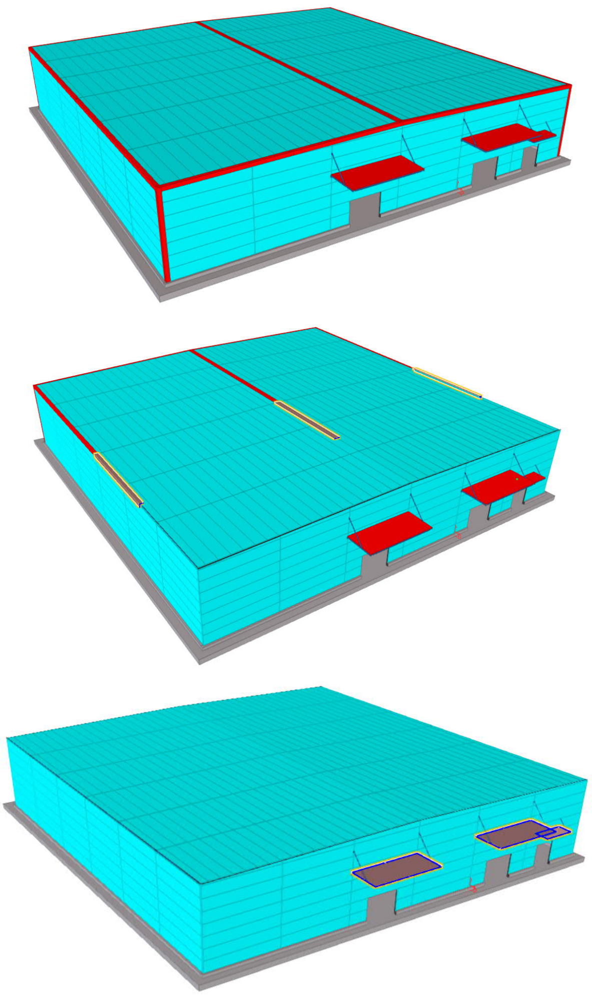
Deconstruction of gable posts (if the gable frame is identical to the current portal frame allowing for future extension of the SSB).
In case of gable frames made of slender elements rafter / columns (designed using actual 50% loading) the deconstruction order is identical to portal frames: i.e. rafter first and intermediate columns last.</td></tr>
</table>

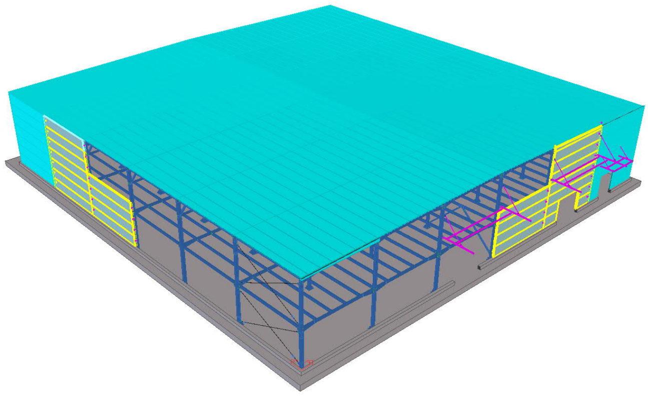
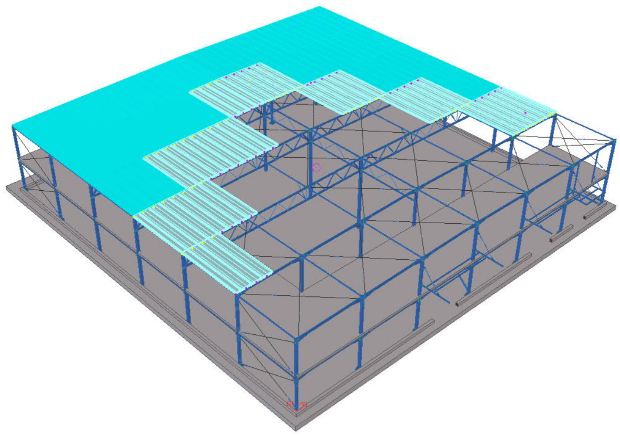
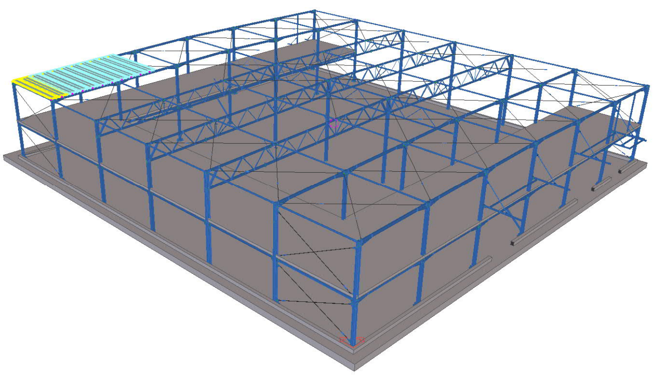
Deconstruction of the main steel structure	
Deconstruct roof bracings system	
	Deconstruction of the main steel structure is starting with roof bracing system. Intermediate zones of these bracings are dismantled leaving parts of the building stabilized by the existing bracings (see missing roof X bracings in the figure left).
Deconstruct central longitudinal members	
	Deconstruction of longitudinal struts from the central part of the structure (see yellow members in figure).
Deconstruct transversal members	
	Deconstruction of transversal members (rafters) from the central part of the structure.

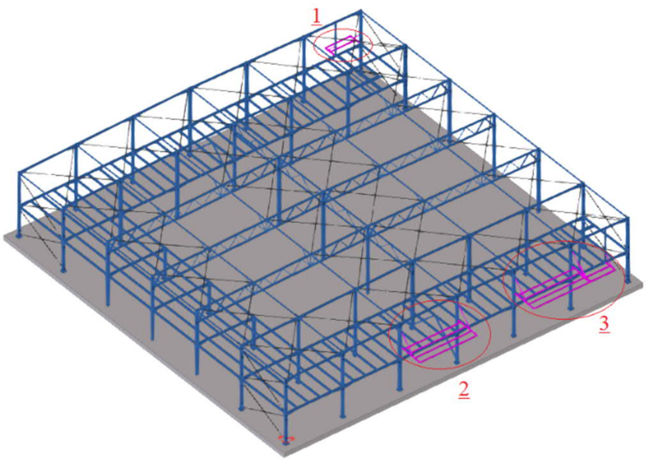
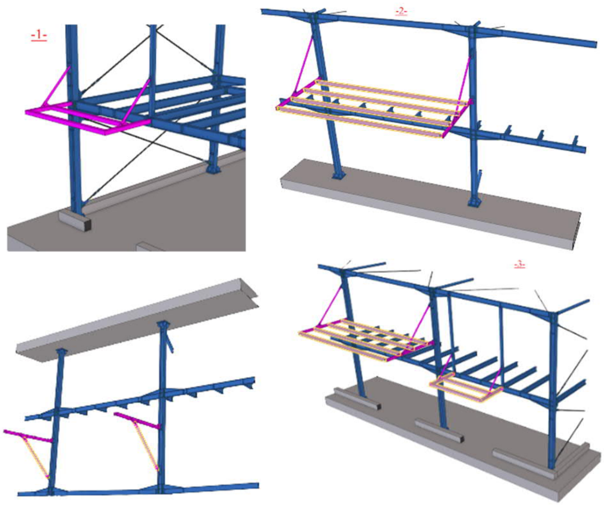
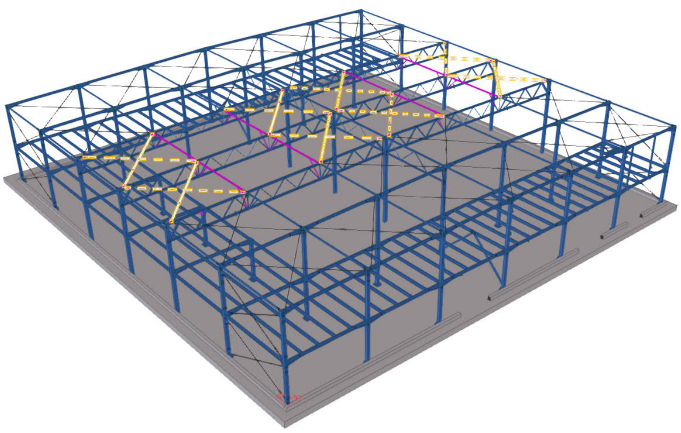
Deconstruct longitudinal studs	
	Deconstruction of longitudinal struts from the intermediate zone of the structure.
Deconstruct marginal roof bracings system	
	Deconstruction of marginal roof bracing of the structure.
Deconstruct marginal transversal members	
	Deconstruction of rafters from the marginal part of the structure.

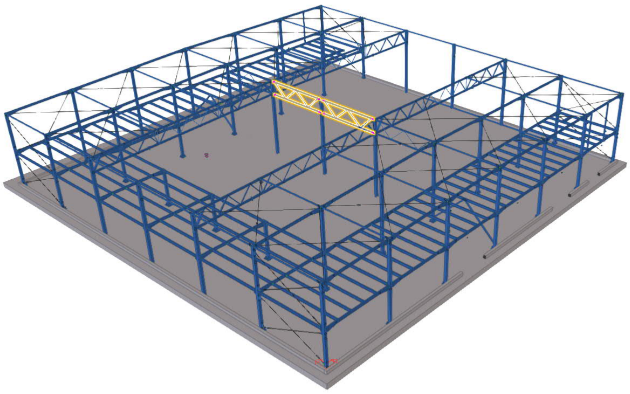
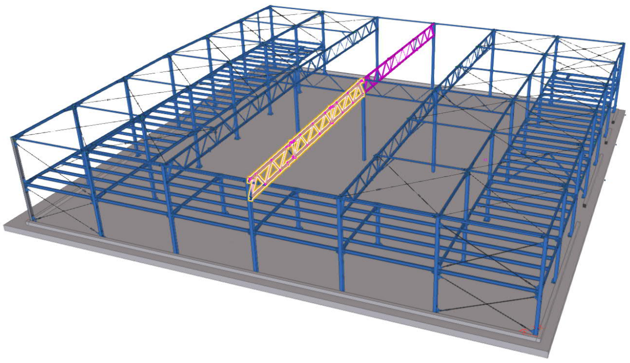
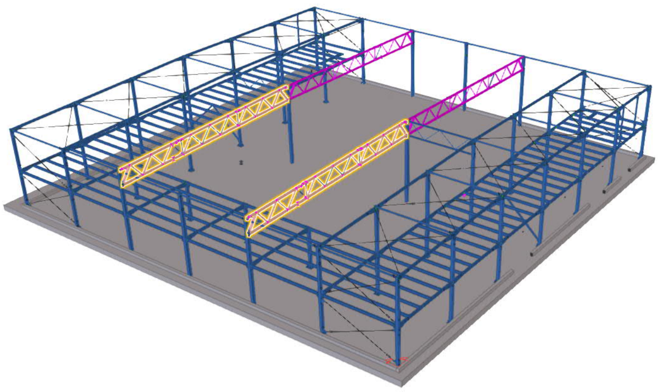
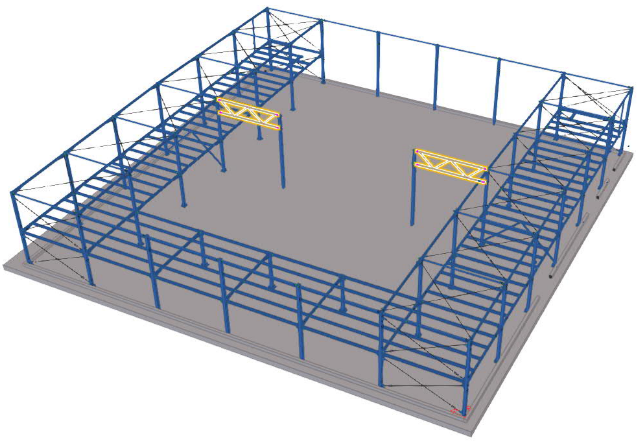
<table>
<tr><th colspan="2">Deconstruct longitudinal members and wall/vertical bracings</th></tr>
<tr><td></td><td>Deconstruction of longitudinal wall/vertical bracing of the structure.</td></tr>
<tr><th colspan="2">Deconstruct all remaining free columns</th></tr>
<tr><td></td><td>Deconstruction of columns of the structure.</td></tr>
</table>

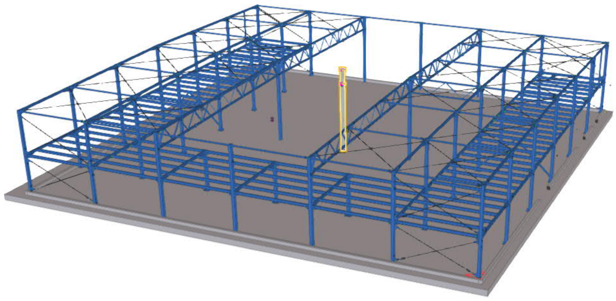
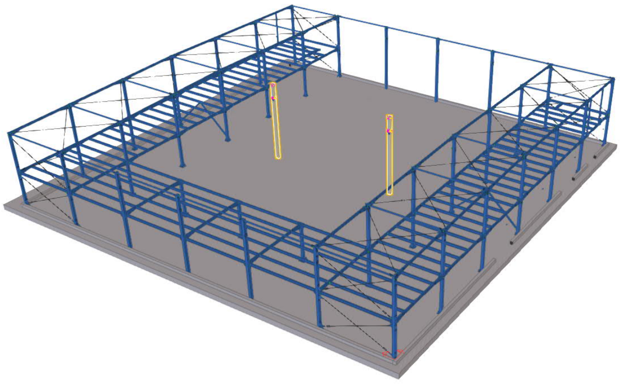
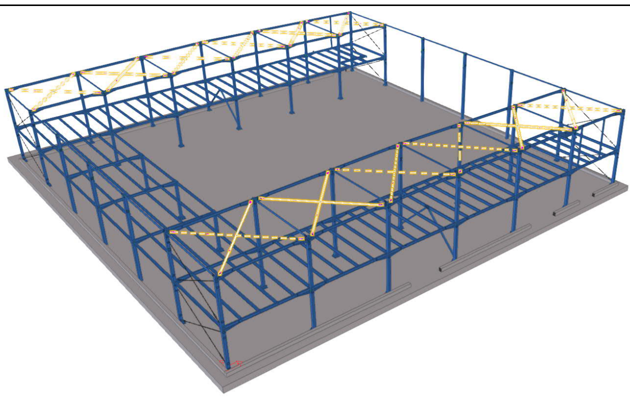
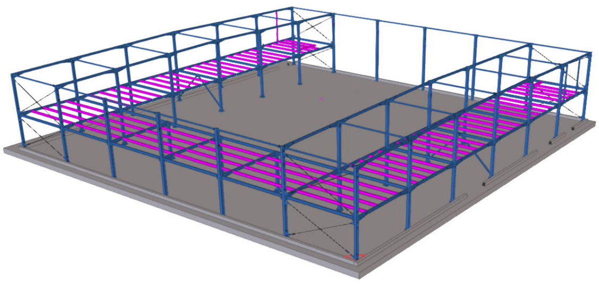
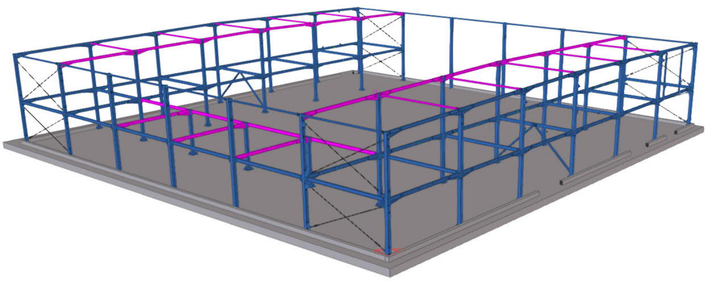
Annex B: Detailed example of the deconstruction of a SSB made of hot-rolled steel profiles for columns, truss girders with secondary structure and sandwich panel claddings

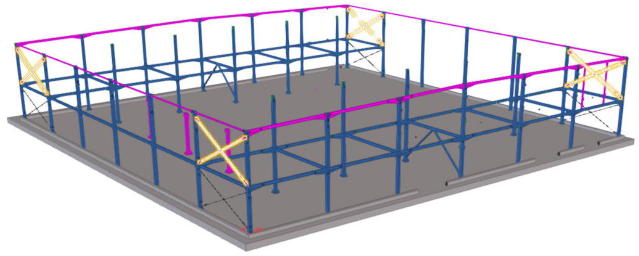
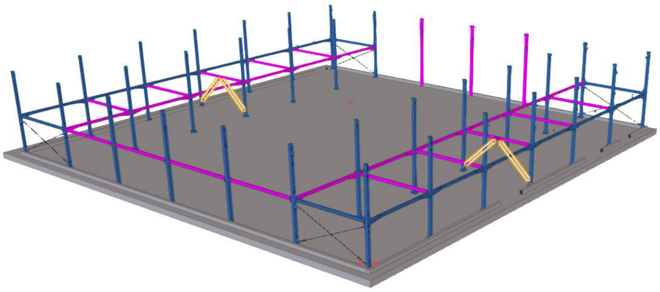
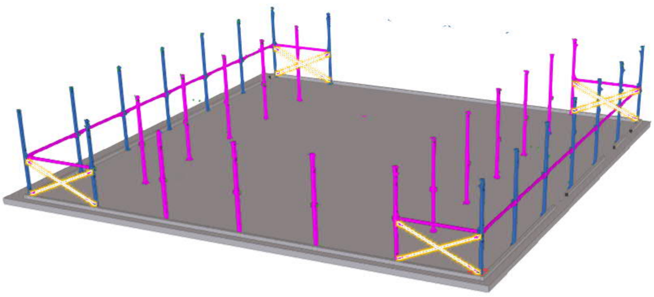
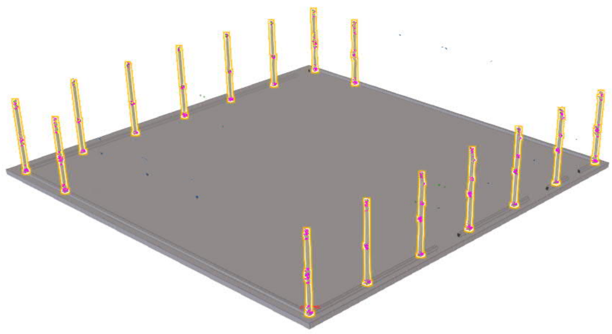
Hot-rolled steel profiles columns and truss girders structure	Comments
	This is an example of how to deconstruct a SSB structure made of hot-rolled steel columns and truss girders. The bracing system is independent of the secondary structure and sandwich panel cladding.
Deconstruction of sandwich panels for roof and walls	
Deconstruct flashing elements & gutters	
	First, the deconstruction of all flashing elements and gutters is necessary. The scheme is described in this row (figures from the left). Materials may be deposited near the structure prior to their final stocking.

Deconstruct wall cladding	
	Wall cladding has to be deconstructed in order to have access to the structure. Special tools like clamps with special clamping shoes can be used for the lowering of sandwich panels. Sandwich panels may be deposited near the structure prior to their final stocking.
Deconstruct roofing system	
 	Roofing system will start after the deconstruction of the wall cladding. Dismantling the roof sandwich panels usually starts at one of the end walls. Special tools like clamps with special clamping shoes can be used for the lowering of sandwich panels.

Deconstruction of the secondary steel structure	
Deconstruct the side rails structure plus the frames of windows, doors and gates	
	Deconstruction of side rails structure plus frames for windows, doors, gates and gable posts etc.
Deconstruction of the main steel structure	
Deconstruct roof bracings system	
	Deconstruction of the main steel structure is starting with roof bracing system. Inner zones of the roof bracing system are deconstructed first leaving structure parts stabilized by the rest of the bracings.

Deconstruct central longitudinal members	
	Deconstruction of longitudinal trusses from the central part of the structure.
Deconstruct transversal members	
 	Deconstruction of transversal trusses from the central and intermediate part of the structure.
Deconstruct longitudinal members	
	Deconstruction of longitudinal trusses from central part of the structure.

Deconstruction of inner column	
 	Deconstruction of inner columns of the structure
	Deconstruction of marginal roof bracings system
Deconstruct intermediate floor	
 	Deconstruction of intermediate floor secondary beams. Deconstruction of the main rafters from the office zone.

<table>
<tr><th colspan="2">Deconstruct longitudinal members and wall/vertical bracings</th></tr>
<tr><td>

</td><td>Deconstruction of longitudinal struts and wall/vertical bracings</td></tr>
<tr><th colspan="2">Deconstruct all remaining free columns</th></tr>
<tr><td></td><td>Deconstruction of all remaining free marginal columns</td></tr>
</table>

2017-2020

PROGRESS

PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

Research Fund for Coal and Steel

Grant agreement No: 747847

Quality verification protocol

May 2020

Deliverable: D2.3 – Quality verification protocol

Confidentiality: Public

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Executive summary

The environmental advantages of re-using reclaimed structural steel are considerable, compared to the common practice of recycling by re-melting scrap. There are also potential cost savings compared to the use of new steel.

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.

In 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, as described in Section 6.1. Assembling groups in this way allows certain material properties to be established by testing (using destructive procedures) one or more representative members from the group.

If material properties are assessed based on the procedure proposed in section 7.3, it is recommended that the only modification necessary for structural design is to verify buckling resistance using a modified value for γ_{M1}. This might lead to changes in the structural solution required for a given design scenario (for example additional restraints might be required) but not necessarily a change in member size, as member buckling might not be the critical verification.

This protocol notes that 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.

This protocol recommends that re-certified and re-fabricated reclaimed structural steelwork can be CE Marked in accordance with EN 1090.

Contents

1. Objective, scope and summary of procedures

The objective of this protocol is to facilitate the increased uptake of structural steel reuse. Reuse involves reclaiming steelwork, establishing material properties, maintaining records of the reclaimed material and declaring material properties. This protocol also covers the use of material manufactured to an alternative specification, *i.e.* not manufactured to a European product standard.

The scope of this protocol covers steel reclaimed from any geographical location, as material characteristics are established by test. The document has been prepared to facilitate reuse in any country which has adopted the Eurocode suite of Standards.

The scope of this protocol is limited to steelwork:

- erected after 1970;
- which has not been subject to fatigue, e.g. not reclaimed from bridges;
- which has not been subject to significant strains, e.g. plastic hinges;
- without significant loss of section due to corrosion;
- which has not been exposed to fire.

This protocol anticipates that the primary use of reclaimed steelwork will be as plain members, i.e. with existing connections removed or redundant, used within a new structure. However, the reuse of steelwork with existing connections is not excluded, nor the reuse of a complete (or partial) structure, re-erected in a different location.

1.1 Drivers for re-use of structural steelwork

Structural steel sections are robust and dimensionally stable elements that are generally bolted together to form structural assemblies which are inherently demountable. As such, structural steel is seen as an obvious candidate for reclamation and reuse as opposed to the current, common practice of recycling by remelting. Reusing structural steel yields significant environmental savings compared to recycling.

There is growing pressure on the construction industry to be more resource efficient, reduce waste and to lower embodied carbon impacts. More recently, circular economy concepts are being promoted, particularly at the EU level, with a roadmap developed to support a shift towards a resource efficient, low carbon European economy. Increased structural steel reuse will support both of these aims and stimulate new business opportunities in the EU in particular, by substituting steel imports.

Although new steel and scrap steel prices are volatile, analysis reveals that the long-term price differential between the cost of UK structural steel and scrap sections is over £300 per tonne. This represents the potential profit opportunity through structural steel reuse. Although additional costs (relative to recycling) will be incurred through deconstruction, storage, testing, re-fabrication, reconditioning, etc. structural steel reuse can yield cost savings or at least provide an economical feasible alternative to the use of ‘new’ structural steel.

1.2 Reclaim, stock and re-use process

Although the procedures described in this protocol relate to steel sections reclaimed from an existing structure, the process is equally applicable to unused 'new' steel, for example, resulting from a cancelled project. Fabricated (but not erected) steel is likely to have known provenance and comprehensive documentation, which will be reflected in less onerous design constraints compared to reclaimed steelwork without documentation. If steel has been fabricated but not erected, it is likely that material properties and fabrication procedures will be documented and can be assumed to be appropriate. This is especially true for steelwork fabricated since July 2013, when CE marking of structural steelwork according to EN 1090 [1] [3] became mandatory.

The overall process from reclamation of steelwork to re-use in another structure is summarised below. Subsequent Sections and the Annexes provide more detail.

Overall process

1. A building is offered for salvage of the steelwork for reuse. Considerations include the acceptability of the source material, (see Section 5.2), the demountability of the structure, the increased cost of careful demolition, *etc.*
2. A business case is established between the stockholder and the company responsible for demolition.
3. Important details of the anticipated reclaimed steel are recorded as described in Section 5.2.
4. Reclaimed steelwork is received by the stockholder, grouped and listed as described in Section 6.1. The necessary grouping has an important impact on the extent of testing required.
5. Members are inspected and tested in accordance with Section 7, with the information appended to the stock data. The testing regime involves non-destructive and destructive testing, with the opportunity to make conservative assumptions about certain material characteristics. The seller of the stock is responsible for declaring the necessary characteristics as the material is sold.
6. Material is sold (as constituent products; structural element or a structure), with an accompanying declaration of the material characteristics by the holder of the reclaimed stock. The declaration covers all relevant material properties which allow the fabricated reclaimed steelwork to be CE marked to EN 1090 (see Section 2).
7. Certification of weldings by a stakeholder or a new fabricator in order to CE marked structural elements or structures; for existing structures without documentation, welds need to be tested;
8. Structural design and member verification are completed with certain modifications, following the recommendations provided in Section 4.

1.3 Alternative specification of source material

Unused, unfabricated steel might be placed on the market having been manufactured to an alternative material standard, for example steel manufactured to an American, or offshore material or manufacturing standard. This unused material would be expected to have appropriate original certification/documentation declaring the material properties. A declaration of the material properties must be provided by the stockholder.

If the steel can be shown to comply in all respects with a weldable structural steel reference Standard (as listed in Section 1.2.2 of EN 1993-1-1 [2]), and tolerances within the limitations of EN 1090-2, the steel can be used in design, using the procedures specified in EN 1993-1-1 and without modification of the γ_{M1} value as proposed for reclaimed steelwork, as long as the steelwork was never erected.

1.4 Classification of reclaimed steelwork

Within the scope of the project, three different reclaimed steel classes are defined, for which different testing and design requirements are proposed. The three reclaimed steel classes are:

- **Class A** – Material documentation is available;
- **Class B** – Material documentation is not available. A comprehensive assessment of material, member and section properties and characteristics is undertaken to produce new documentation;
- **Class C** – Material documentation is not available. Conservative assumptions are assumed for the design.

Examples of steelwork classified as “Class A” include steelwork reclaimed from a cancelled project (never erected) or steelwork reclaimed from different sources, for which documentation is available. For cases where documentation is available but the steelwork was already erected and disassembled, a conservative value of γ_{M1} is recommended in combination with an assessment of geometric tolerances (essentially bow imperfections). An optional testing procedure for Class A steel is proposed with the intent of confirm the traceability of the reclaimed steelwork (rather than to justify material characteristics).

It is envisaged that “Class B” steel will cover (currently) most of the practical applications of reclaimed steelwork. “Class B” steel deals with reclaimed steelwork with no documentation for which material re-certification is required. Recommendations from EN 1090-2 section 5.1 need to be followed to achieve such re-certification. “Class B” steel requires a comprehensive testing procedure where relevant material characteristics are justified and geometry tolerances are inspected against EN1090-2 requirements. The testing procedure comprehends a combination of non-destructive and destructive tests together with inspection of geometric tolerances. Conservative measures for the value of γ_{M1} are recommended, as some uncertainty in the member and section imperfections (other than bow) are recognized. Even with inspection, the procedures used to assess geometric tolerances will certainly be less reliable in comparison with “new” steel.

“Class C” steel is only recommended for projects that represent a low risk for human safety, as higher uncertainty in material characteristics is recognized. “Class C” steel envisages that no testing is undertaken (instead conservative material properties are assumed based on the location and age of the structure). If welding is necessary, CEV (carbon equivalent value, see section 2.5.7) may be assessed by non-destructive tests. It is required that geometric tolerances according to EN1090-2 are assessed (usually during fabrication; straightening can be performed). Conservative measures for the value of γ_{M1} are recommended for this approach. CE marking is not envisaged using the Class C reclaimed steel approach. However, this may change in the future based on recent initiatives from the European Union to facilitate the circularity of construction products [127]. It is expected that the Construction Products Regulation (CPR) may be revised in the future to facilitate the reuse of steel (and other construction products).

The material partial factor is adjusted with a factor $k_{\gamma Mi}$. $\gamma_{Mi,mod}$ is obtained using $K_{\gamma Mi}$ x γ_{Mi}, where γ_{Mi} shall be obtained from EN 1993-1-1 or the National Annex for use in a country. The $K_{\gamma Mi}$ values can be defined for different regions/countries. For in-situ reuse of steelwork erected after 1970, the conservative value of γ_{M1} is not recommended (i.e. $k_{\gamma M1}$ =1).

A summary of the three reclaimed steel classes is presented in Figure 1.1.

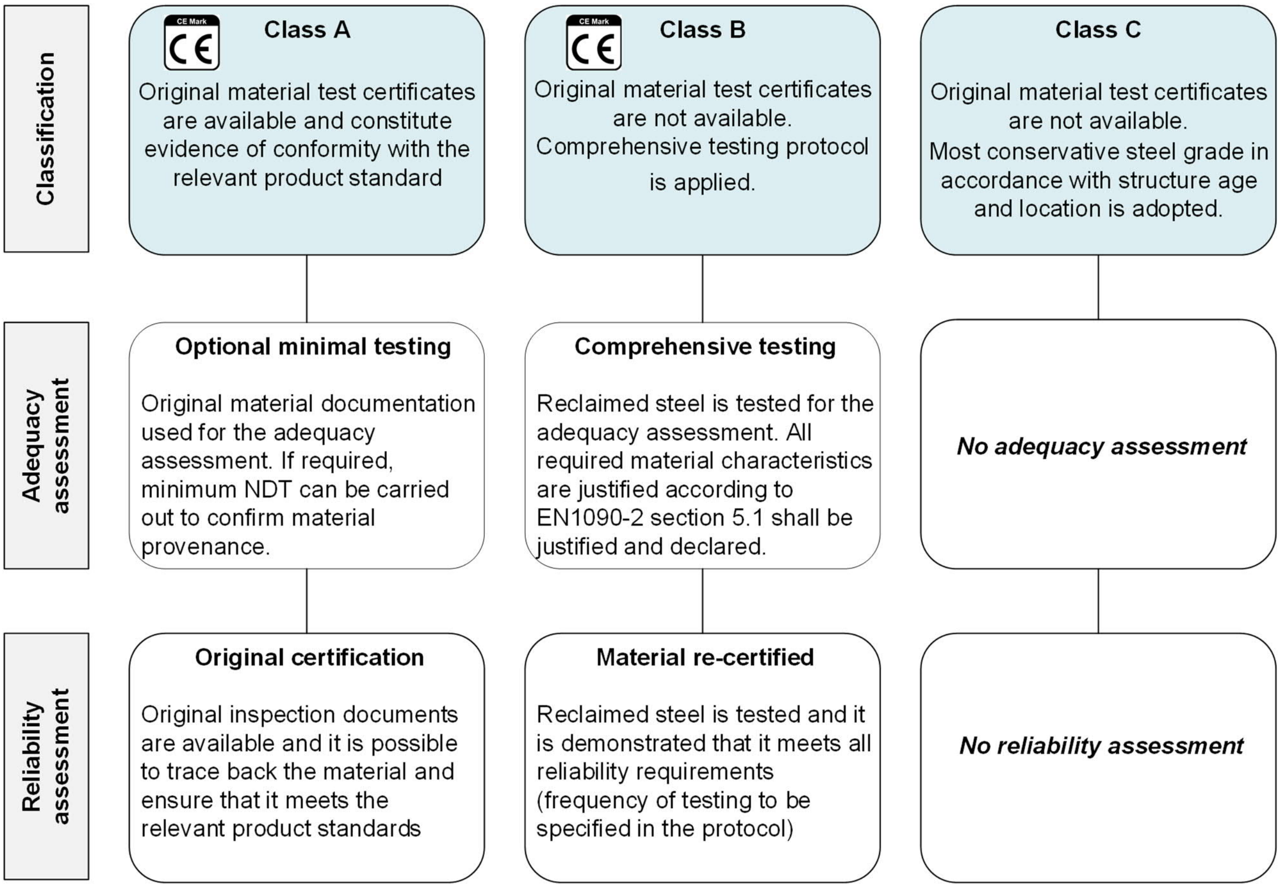


Figure 1.1 - Overall framework for classification of reclaimed steel material

To use the existing steelwork, it is necessary to undertake the following assessments:

- ***Adequacy assessment:*** intended to assess the necessary material characteristics according to material/product standard or EN 1090-2 section 5.1;
- ***Reliability assessment:*** intended to justify that the reliability requirement for the design procedures according to the Eurocodes are met.

The testing and design process for each of the reclaimed steel classes is presented in Figure 1.2 and Table 1.1.

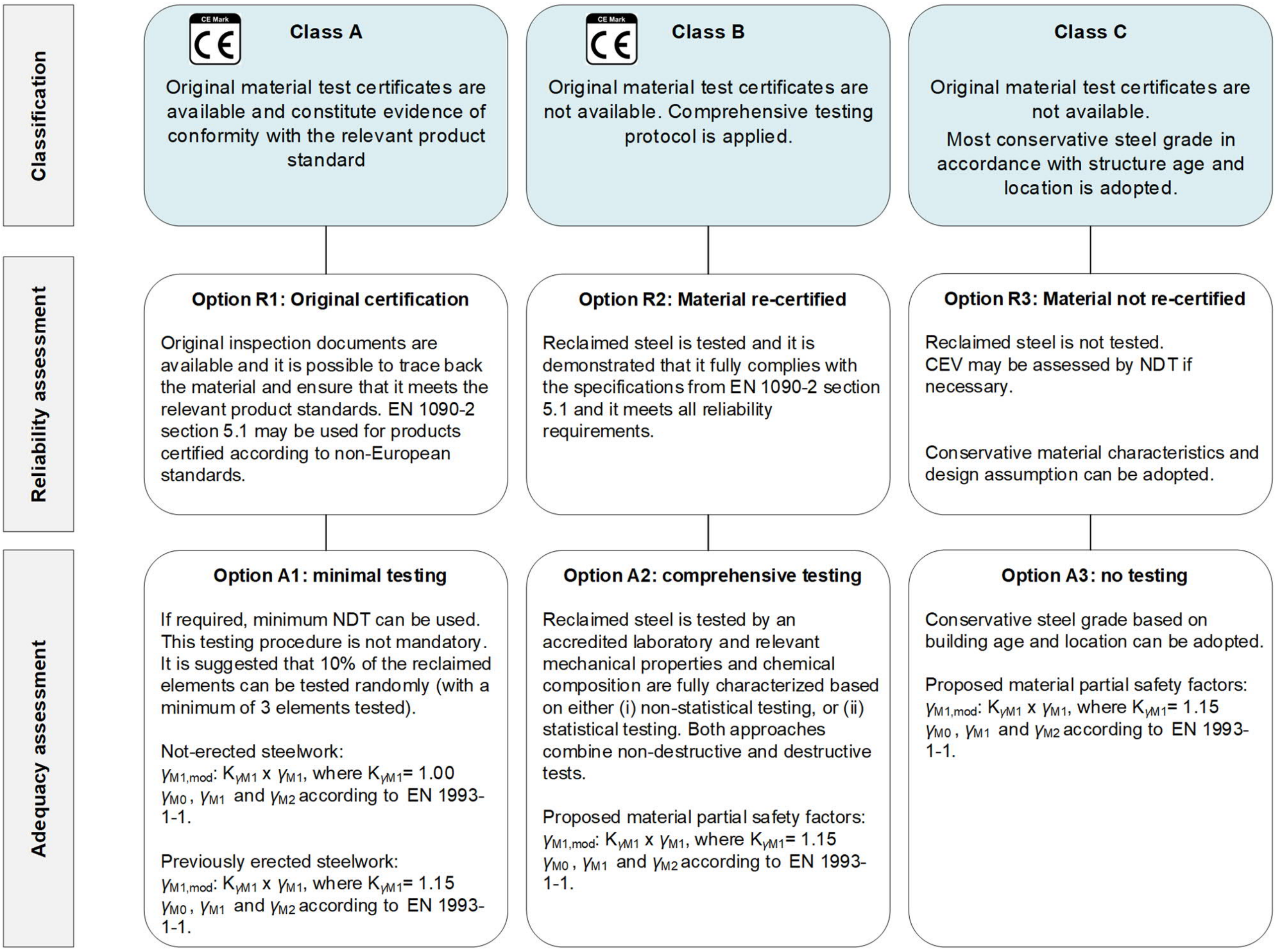


Figure 1.2 - Overall framework for classification of reclaimed steel material with design considerations.

Table 1.1. *Resume of reuse-protocol for steelwork erected after 1970*

Property/procedure	**Reclaimed steelwork class**		
	Class A	Class B	Class C
Test programme	Minimal (optional)	Comprehensive	No testing
Adequacy assessment	Yes	Yes	No
Reliability assessment	Yes	Yes	No
% of NDT	10% (randomly) – with a minimum of 3 tests per group	100%	-
Minimum number of DT	-	1 for CC1 and CC2, 3 for CC3	-
Geometric tolerances	Visual inspection or assessed if steelwork was previously erected	Assessed	Assessed
CE marking	Yes	Yes	No
Global analysis	Elastic	Elastic	Elastic
Section analysis	Elastic/plastic	Elastic/plastic	Elastic/plastic
$k_{\gamma M0}$	1.00	1.00	1.00
$k_{\gamma M1}$	1.00/1.15[1, 2]	1.15[2]	1.15[2]
$k_{\gamma M2}$	1.00	1.00	1.00
CC1 structures	Yes	Yes	Yes
CC2 structures	Yes	Yes	Not recommended
CC3 structures	Yes	Yes	Not recommended

1 – For the cases where the steelwork was never erected the value of $K_{\gamma M1}$=1 can be used;

2 – For in-situ reuse of steelwork erected after 1970, the conservative value of γ_{M1} is not recommended (i.e. $k_{\gamma M1}$ =1)

NDT – Non-destructive testing; DT – Destructive testing; CC – Consequence class according to EN 1990 [4]; $k_{\gamma Mi}$ – The material partial factor is adjusted with a factor $k_{\gamma Mi}$. $\gamma_{Mi,mod}$ is obtained using $K_{\gamma Mi}$ x γ_{Mi}, where γ_{Mi} shall be obtained from EN 1993-1-1 or the National Annex for use in a country. The $K_{\gamma Mi}$ values can be defined for different regions/countries.

1.5 Overall assessment, testing and design processes flowchart

The flowchart in Figure 1.3 illustrates the process of reusing structural steel from a building first erected (using new steel) after 1970. The flowchart also maps each individual step/action to the relevant document section.

PROGRESS D2.1 [88] provides a pre-deconstruction audit (collecting documentation, visual inspection, leading to an initial decision about the reusability of the steel). This protocol provides complementary guidance for the pre-deconstruction audit in Section 5.

Pre-deconstruction audits are required so that relevant building documentation is collected and the feasibility of reusing the existing steelwork is assessed. This protocol provides complementary guidance for two phases: (i) preliminary assessment and (ii) comprehensive assessment.

Preliminary assessment is intended to confirm or adapt the proposed reuse scenario or simply classify the steelwork as not appropriate for reuse. Limited resources are allocated for this step, in terms of inspection and testing.

After completing the preliminary assessment, a comprehensive assessment must be undertaken. The comprehensive assessment implies additional inspection and eventual testing to justify the material properties of the reclaimed steel.

For Class A reclaimed steel, testing is not mandatory as material documentation exists.

Testing is mandatory for Class B reclaimed steel. Class B may be seen as the standard case of an existing building with no material documentation and for which CE marking is required.

Class C reclaimed steel can rely on conservative assumptions for the material properties but a more thorough inspection of the structure (or individual elements) is still required to evaluate the admissibility of the reclaimed steel.

After the pre-deconstruction audit, some of the existing members may be classified as not suitable for reuse, which should be sent for recycling.

If building documentation and/or material certificates are not available, it will be necessary to produce that documentation. Class C does not require testing, but documentation referring to the assumed properties is still required.

Depending on the reuse scenario, documentation for the existing structure may be also necessary (for example, the case of on-site or relocation reuse where no original documentation is available).

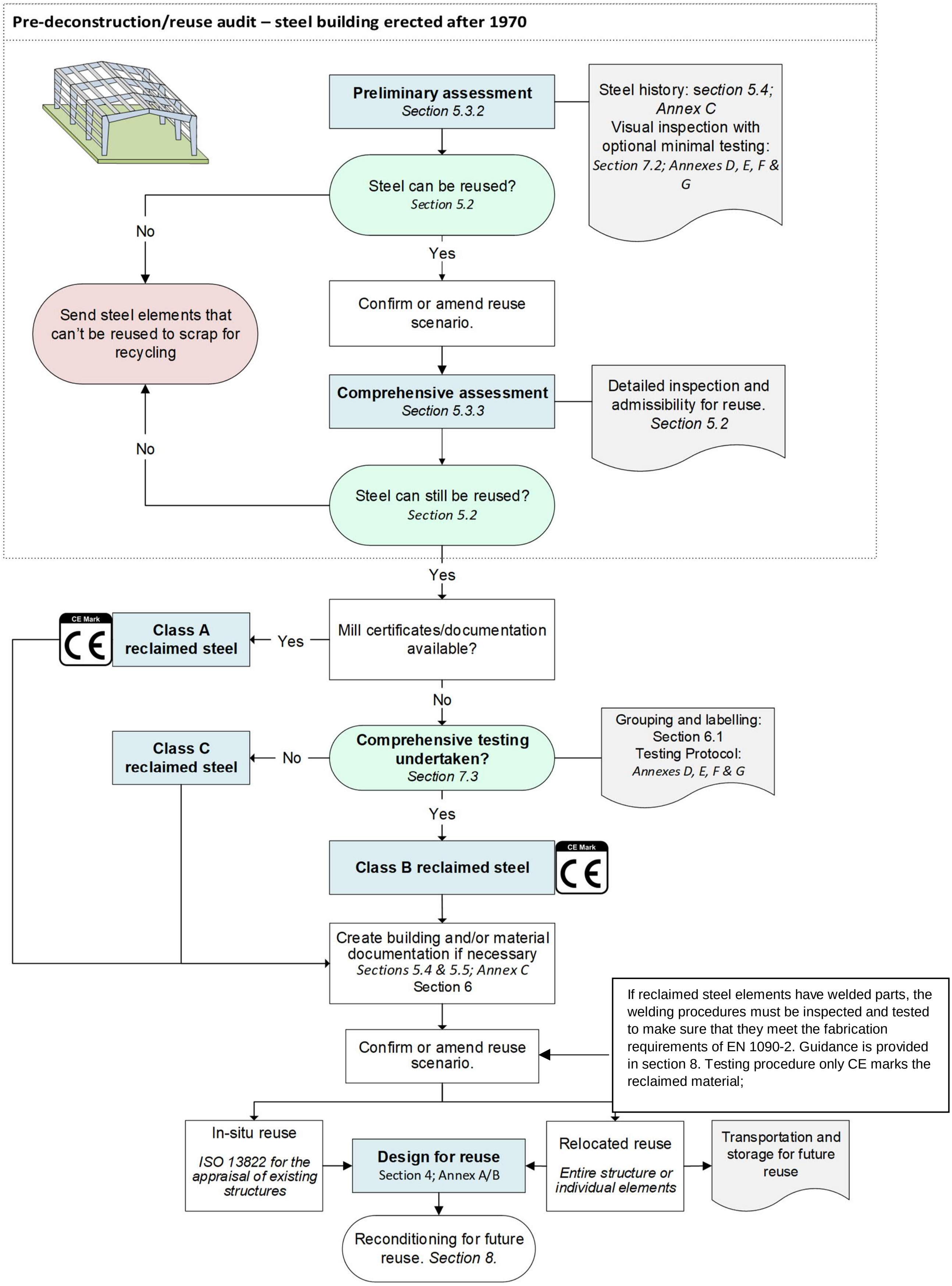


Figure 1.3 - Overall assessment, testing and design processes flowchart

1.6 Summary of testing programmes flowchart

The following flowchart presents the available testing procedures covered in this protocol. The applications of the reclaimed steelwork based on the test programme are described and the flowchart also maps each individual step/action to the relevant document section.

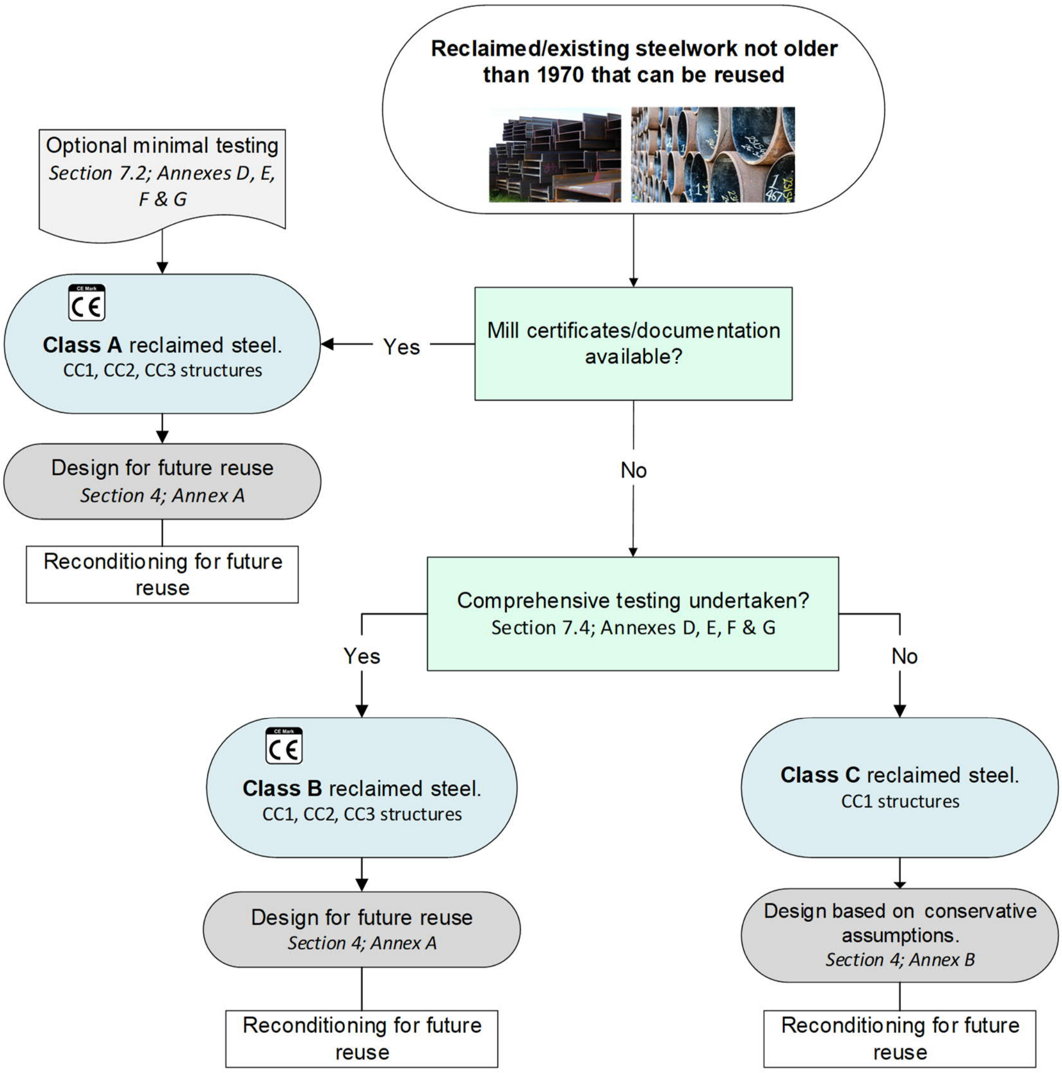


Figure 1.4 - Testing flowchart

If reclaimed steel elements have welded parts, the welding procedures must be inspected and tested to make sure that they meet the fabrication requirements of EN 1090-2. Guidance is provided in section 8. Testing procedure only CE marks the reclaimed material.

2. CE marking of reclaimed structural steelwork

2.1 CE Marking

CE Marking of structural steelwork is addressed in EN 1090-1 [1]. Basic material (rolled sections, plate, *etc.*) must be CE Marked to the relevant product standard and the fabricated steelwork must be CE Marked to EN 1090-1.

Steel manufacturers declare that their products meet the relevant product standard; steelwork contractors declare that the fabricated steelwork meets the requirements of the execution standards EN 1090-1 [1] and EN 1090-2 [3].

EN 1090-2 generally anticipates that 'new' steelwork is used in construction works. Reclaimed steelwork must clearly be treated differently, as it might have been manufactured to a withdrawn Standard and is generally unlikely to have any documented test results from the time of manufacture. EN 1090-2 sanctions the use of other materials by stating that: "*If constituent products that are not covered by the standards listed are to be used, their properties are to be specified. The relevant properties to be specified shall be taken from the following list":*

a) Strength (yield and tensile);

b) Elongation;

c) Stress reduction of area requirements (STRA), if required;

d) Tolerances on dimensions and shape;

e) Impact strength or toughness, if required;

f) Heat treatment delivery condition;

g) Through thickness requirements (Z-quality), if required;

h) Limits on internal discontinuities or cracks in zones to be welded if required.

In addition, if the steel is to be welded, its weldability shall be declared as follows:

i) Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608 or;

j) A maximum limit for the carbon equivalent of the steel, or;

k) A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated."

EN 1090-2 requires that documentation must be used to declare the relevant material characteristics. It is mandatory that this documentation is provided by the holder of the reclaimed stock when selling it.

2.2 CE Marking of reclaimed steel

There will be no difference in the fabrication processes, procedures, standards or tolerances for either new steel or reclaimed steel. It is therefore appropriate that re-fabricated, reclaimed structural steelwork can be CE Marked in accordance with EN 1090.

In addition to careful control of the fabrication process, material properties must be declared according to EN 1090-2 clause 5.1. When using reclaimed steel, this is the stockholder's responsibility.

The previous statement is related to plain reclaimed elements without any welding procedures. If reclaimed steel elements have welded parts, the welding procedures must be inspected and tested to make sure that they meet the fabrication requirements of EN 1090-2. Guidance is provided in Section 8.

2.3 Declaration of properties

The purpose of declaring material properties is so that the material used in construction meets the appropriate product standard and that properties required by design are confirmed, *e.g.* the required material strength assumed in the member verifications has actually been provided.

Generally, a structural designer specifies certain material characteristics (which have been assumed in the design process), which are then confirmed as actually used in the structure by the declaration of properties. With reclaimed structural steel, the relationship may be reversed, so that the design verifications are based on the properties (either tested or conservatively assumed) of the reclaimed elements. In either approach the objective of the declaration of material properties is to ensure that the design assumptions are compatible with the material being used.

The requirements of EN 1090-2 and the testing regime for reclaimed steelwork are discussed in Section 2.4.

2.4 Material properties to be declared for reclaimed steelwork

The test regime described in Section 7 is intended to allow the necessary material properties according to EN 1090-2 clause 5.1, to be declared, based on dimensional survey, by non-destructive tests, by destructive tests or by making conservative assumptions. A summary of the necessary material properties and recommended assessment procedures is presented in *Table 2.1*.

Table 2.1**.** *Material properties to be declared for reclaimed steelwork according to EN 1090-2*

<table>
<tr><th>Item</th><th>Property</th><th>To be declared</th><th>Procedure</th></tr>
<tr><td>a)</td><td>Strength (yield and tensile)</td><td>Yes</td><td>Determined by destructive and non-destructive tests.</td></tr>
<tr><td>b)</td><td>Elongation</td><td>Yes</td><td>Determined by destructive tests.</td></tr>
<tr><td>c)</td><td>Stress reduction of area requirements (STRA)</td><td>If required</td><td>Generally, not required to be declared.</td></tr>
<tr><td>d)</td><td>Tolerances on dimensions and shape</td><td>Yes</td><td>Based on dimensional survey.</td></tr>
<tr><td>e)</td><td>Impact strength or toughness</td><td>If required</td><td>If required, determined by destructive tests. Conservative assumption as the default.</td></tr>
<tr><td>f)</td><td>Heat treatment delivery condition</td><td>Yes</td><td>Conservative assumption as the default.</td></tr>
<tr><td>g)</td><td>Through thickness requirements (Z-quality)</td><td>If required</td><td>Generally, not required to be declared.</td></tr>
<tr><td>h)</td><td>Limits on internal discontinuities or cracks in zones to be welded</td><td>If required</td><td>Generally, not required to be declared.</td></tr>
<tr><td colspan="4">In addition, if the steel is to be welded, its weldability shall be declared as follows:</td></tr>
<tr><td>Item</td><td>Property</td><td>To be declared</td><td>Procedure</td></tr>
<tr><td>i)</td><td>Classification in accordance with the materials grouping system defined in CEN ISO/TR 15608 [5], or</td><td rowspan="3">Yes</td><td>Not applicable for reclaimed steelwork.</td></tr>
<tr><td>j)</td><td>A maximum limit for the carbon equivalent of the steel, or;</td><td>Maximum to be declared from manufacturer’s test certificates.</td></tr>
<tr><td>k)</td><td>A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated</td><td>Determined by non-destructive and destructive tests.</td></tr>
</table>

Section 2.5 provides a commentary on each material property that must be declared.

2.5 Commentary on the required properties

2.5.1 Strength

Yield strength and ultimate strength should be determined by non-destructive and destructive tests. The use of non-destructive tests is limited to establishing the steel grade. The declared yield strength and ultimate strength should be the values specified in product Standards appropriate for that grade, not the values determined from the tests. Because the protocol is limited to steel used in construction after 1970, the yield strengths and ultimate strengths taken from the product Standard are considered to be reliable.

Non-destructive testing is also used to identify any inconsistencies between members within a group. Within this protocol, a group is a number of reclaimed members, having the same form, original function, size and details, from the same building and being less than 20 tonnes in total. More details on member grouping are given in Section 6.1.

Destructive tests are used to establish the yield strength and ultimate strength of one or more representative samples from the group (see Section 7) to confirm that the material grade for the group has been correctly identified.

2.5.2 Elongation

The use of reclaimed steelwork is limited to applications where significant ductility is not required, *i.e.* plastic global analysis is not recommended, and is limited to the reuse of relatively 'modern' steel (see Section 5.2). The demands on elongation are therefore limited, and likely to be met by the reclaimed steelwork covered by the scope of this protocol (see also Section 4.3).

Elongation must be specified according to EN 1090-2 clause 5.1 and determined by destructive testing.

Historical review of steel elongation

Based on historical data for old steels and iron (see Annex J), the Eurocode ductility requirements are likely to be fulfilled for the reclaimed steelwork. It is unlikely that steelwork erected after 1970 does not comply with the minimum elongation requirements currently imposed by the Eurocodes. Even wrought iron (produced since 1900) was showing approximately 15% elongation at failure, which is adequate for common structural applications. The previous UK material standards for structural steel such as BS 15 (version from 1948) [28] provided a minimum elongation value of 16% for the available structural steels. Later, BS 4360 (version from 1969) [29] reported a minimum elongation at failure of 19% for the available structural steels. However, elongation needs to be declared according to EN1090-2 and therefore a minimum destructive test is required to establish this material property. The testing programme will be discussed in section 7.

2.5.3 Tolerances on dimensions and shape

Reclaimed elements can be checked against geometric tolerances according to the relevant product standard. Elements within tolerance are acceptable and satisfy the assumptions made in the design Standard. This means that a reclaimed element can be labelled as a “IPE500” if the dimensions and tolerances of a “IPE500” according to the EN 10365 [7] and EN 10034 [8], respectively are justified and documented.

Table 2.2 lists the Standards to be used when assessing dimensions and tolerances.

Table 2.2**.** *Dimensions and tolerances for structural steelwork*

Products	**Dimensions**	**Tolerances**
I and H sections	EN 10365 [7]	EN 10034 [8]
Hot-rolled taper flange I sections	EN 10365	EN 10024 [9]
Channels	EN 10365	EN 10279 [10]
Equal and unequal leg angles	EN 10056-1 [11]	EN 10056-2 [12]
T Sections	EN 10055 [13]	EN 10055 [13]
Plates, flats, wide flats	-	EN 10029 [14]/ EN 10051 [15]
Bars and rods	EN 10017 [16], EN 10058 [17], EN 10059 [18], EN 10060 [19], EN 10061 [20]	EN 10017, EN 10058, EN 10059, EN 10060, EN 10061
Hot finished hollow sections	EN 10210-2 [21]	EN 10210-2
Cold formed hollow sections	EN 10219-2 [22]	EN 10219-2
Fabricated profiles and member bow imperfections	EN 1090-2	EN 1090-2

However, there is no limitation to use reclaimed steelwork with bespoke dimensions, i.e. members for which tolerances from *Table 2.2* are not met, as long as the design considers measured section properties rather than tabulated standard section sizes. Member bow imperfections still need to be assessed and justified. See also Annex H.

2.5.4 Through thickness requirements

Through thickness properties are generally not required for reclaimed sections, such as beams or columns. Some joint details may require the steel plate to have specific through thickness properties. If through thickness properties are required, reclaimed plate must be tested as specified in EN 1993-1-10 [6].

2.5.5 Impact strength or toughness

Impact strength or toughness (commonly known as the Charpy value) might be required for a specific project, such as for thick, highly stressed steelwork exposed to low temperatures. However, for internal steelwork which is not subjected to fatigue, a conservative assumption about the material toughness is appropriate. The conservative assumption means that a minimum Charpy V-notch impact value of 27 J at 20°C is assumed if no testing is performed. See also section 4.6.

If material toughness must be determined, destructive tests are required in accordance with the requirements of the relevant Standard, *e.g.* Clause 10.2.2 of EN 10025-1 [24].

2.5.6 Heat treatment delivery condition

Heat treatment delivery conditions have an impact on, for example, the grain size, residual stresses, etc. Practically, this condition will have implications while designing hollow sections. Hollow sections for structural applications are cold formed to EN 10219 [23] [22] or hot finished to EN 10210 [24] [21]. The heat treatment delivery condition will influence the level of residual stresses present in the hollow section, which means that different buckling curves exist for cold formed and hot finished products. It is clear that cold formed will have higher residual stresses, which in turn will lead to a more conservative buckling curve while designing the member. Conservatively, it is recommended that all reclaimed hollow sections are assumed to be cold formed according to EN 10219, as this property cannot be easily tested.

2.5.7 Declaration of chemical composition

Chemical composition is important to establish the durability and particularly the weldability of the reclaimed structural steel. The stockholder must provide a declaration of chemical composition, based on non-destructive and destructive tests. The chemical composition declaration must provide measures of certain chemical elements according to the relevant Standard. The intent of this declaration is to enable the carbon equivalent value (CEV) to be calculated, which is a key measure of weldability.

The chemical composition declaration must provide measures of the relevant chemical elements according to the appropriate material standard (see Table 2.3).

Table 2.3. Chemical composition of reclaimed steel: required data

Products	Dimensions
Open sections	EN 10025 parts 2 [25], 3 [26] or 4 [27] sections 7.2
Hollow sections	EN 10219-1 section 6.6

3. Quality and accreditation of stockists

Stockists should be ideally accredited to ISO 9001 [70].

Any personal responsible for non-destructive tests procedures should be ideally accredited/certified by ISO 9712 [71]. For quality management systems auditing ISO 19011 [70] can be followed.

Any tests carried out to establish whether the mechanical properties of the steel products are appropriate should be undertaken by a laboratory certified to EN ISO IEC 17025 [125] by a certification body. The tests should be carried out in accordance with the requirements for mechanical properties given in EN 10025 or EN 10219, as appropriate.

Test for materials would need to be undertaken as follows:

- By a test house with accreditation to ISO/IEC 17025,
- In accordance with the test methods and procedures given in the product standard (EN 10025 or EN 10219, as examples),
- Test reports should be issued in the form of specific Inspection Certificate in accordance with EN 10204.

See also section 7.4.

4. Design recommendations

This section summarises the recommendations for structural design and verification of reclaimed structural steel members.

4.1 Structure scope for the reclaimed steel elements

This protocol has been prepared on the basis that reclaimed carbon steel can be used in Consequence class 1, 2 or 3 structures (see Table B1 of EN 1990 [4]) if a comprehensive testing procedure is undertaken according to section 7.3. Use of reclaimed steelwork in Consequence class 3 structures places additional requirements on the testing regime to determine material characteristics.

Reclaimed steel should not be used in structures subjected to fatigue, or in plastically analysed structures which rely on the formation of plastic hinges (plastic global analysis).

The reuse of reclaimed steel elements in areas where the seismic actions is relevant is only recommended if the reclaimed steel elements are used at least under one of the following conditions: (i) as members of the secondary seismic system (not resisting the horizontal loads), such as a pin-ended floor beam, or (ii) as elements part of a low-dissipation structure (Low Ductility Class) with a behaviour factor of 1, according to EN 1998-1 [134].

4.2 Global analysis

Designers should not undertake plastic global analysis, as this demands a high level of ductility. Although elongation of steel will be demonstrated by test, it is still considered prudent to restrict practice to elastic global analysis.

4.3 Ductility and residual strains

Careful visual inspection of every reclaimed member, and assessment against the tolerances referenced in Section 2.5.3, should ensure that the element has not undergone excessive/plastic deformation. A similar careful inspection to ensure that no evidence of plastic local deformations in connecting elements (plates) or signs of local (plate) buckling is found is also recommended.

If the inspection is satisfactory, the level of residual strains, and reserves of ductility, may be assumed as no different to that of ‘new’ steel.

As stated, plastic global analysis is not recommended when reclaimed steel is reused. The recommendations for seismic design stated in section 4.1 are also intended to limit the level of ductility requited for the reclaimed steel elements.

The limitations on the ratio between the ultimate strength (f_u) and the yield strength (f_y) as well as the minimum elongation appropriate for elastic global analysis are given in EN 1993-1-1 (or in the National Annex to the same standard).

4.4 Cross sectional resistance

Reclaimed steel is assumed to be sufficiently ductile to permit the use of a plastic cross-sectional resistance, for example, in bending or shear. The design resistances presented in EN 1993-1-1 should be used.

For cross sectional resistance, recommended values for γ_{M0} and γ_{M2} according to the National Annex for use in a country should be used for steelwork (erected after 1970) that complies with this testing protocol.

Further guidance and background are provided in Annex A.

4.5 Buckling resistance

4.5.1 Class A reclaimed steelwork

For Class A reclaimed steel, for cases where the steelwork was never erected, the value of γ_{M1} provided by EN 1993-1-1 (or to the National Annex for use in a country) is recommended.

To envisage future reusability, the steelwork may be designed using $K_{\gamma M1} = 1.15$. This is aligned with the design recommendation proposed for reusable single-storey buildings according to D3.1 [89].

For 'new' steel, for example from a cancelled project - not erected, which has appropriate documentation, the current value of γ_{M1} from the appropriate National Annex to EN1993-1-1 (or to the National Annex for use in a country) can be used.

For the cases where the steelwork was previously erected, a modified value of $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ ($K_{\gamma M1}$ =1.15) is recommended, which reflects the increased uncertainty when using reclaimed steel. This recommendation is excluded for in-situ reuse.

Justification for this recommendation is given in Annex A.

4.5.2 Class B and C reclaimed steelwork

For reclaimed steel from Class B, a modified value of $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ ($K_{\gamma M0}$ =1.15) is recommended, which reflects the increased uncertainty when using reclaimed steel [68]. Justification for this recommendation is given in Annex A. This recommendation is excluded for in-situ reuse.

4.6 Steel toughness and sub-grade

It is assumed that all steel used in construction since 1970 has a minimum Charpy V-notch impact value of 27 J at 20°C, which corresponds to the JR subgrade according to EN 10025. The reclaimed steel sub-grade may be assumed to be JR without testing.

Clause 5.1 of EN 1090-2 states that a declaration of steel subgrade is not mandatory. Where the declaration of the reclaimed steel subgrade is required, for example, for external steelwork exposed to low temperatures, the steel subgrade needs to be determined by testing. Testing and relevant documentation is a stockholder responsibility.

Since the scope for the re-use of reclaimed steel is limited to structures where fatigue is not a design consideration (Section 4.1), the limiting thickness values presented in SCI Publication P419 [30] are recommended for use in the UK. SCI P419 adopts the procedures of the Eurocode, but reduces the calculated crack growth for applications where fatigue is not a design consideration.

Recommended thickness values for outside the UK, are presented in Section 4.7.

For internal steelwork used in the most onerous circumstances (“Combination 10” – see below):

S275 JR – the limiting thickness is 77.5 mm

S355 JR – the limiting thickness is 35 mm

For external steelwork used in the most onerous circumstances (“Combination 10”):

S275 JR – the limiting thickness is 32.5 mm

S355 JR – the limiting thickness is 16.5 mm

“Combination 10” refers to the column identification provided in Table 2 and Table 3 of PD 6695-1-10 [31] and Table 5.1 and Table 5.2 of SCI P419.

The preceding values fully respect the requirements of the UK National Annex. For less severe details, and lower stress levels, *i.e.* a lower combination, the limiting thickness increases and SCI P419 should be consulted for a less onerous value.

4.7 Revised thickness limits for use outside the UK

The thickness limits given in SCI P419 and summarised in Section 4.6 are only appropriate for the UK, as they include all the provisions of the UK National Annex to EN 1993-1-10.

Table 4.1 follows the same format as Table 2.1 of EN 1993-1-10, but adopts the reduced crack growth assumed in SCI publication P419. The values in Table 4.1 can be used in countries other than the UK, when fatigue is not a design consideration, subject to any requirements of the specific National Annex of the country of construction.

Table 4.1. *Limiting thickness values when fatigue is not a design consideration*

Steel grade	Sub Grade	Charpy energy CVN		Reference temperature, T_{Ed} (°C)																				
				10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
		at T (°C)	J_{min}	$\sigma_{Ed} = 0.75 f_y(t)$							$\sigma_{Ed} = 0.5 f_y(t)$							$\sigma_{Ed} = 0.25 f_y(t)$						
S235	JR	20	27	200	200	200	195	125	87	63	200	200	200	200	200	200	161	200	200	200	200	200	200	200
	J0	0	27	200	200	200	200	200	195	125	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S275	JR	20	27	200	200	200	133	91	64	47	200	200	200	200	200	170	121	200	200	200	200	200	200	200
	J0	0	27	200	200	200	200	200	133	91	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	M,N	-20	40	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S355	JR	20	27	200	177	114	77	54	40	30	200	200	200	200	147	104	76	200	200	200	200	200	200	200
	J0	0	27	200	200	200	177	114	77	54	200	200	200	200	200	200	147	200	200	200	200	200	200	200
	J2	-20	27	200	200	200	200	200	177	114	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	K2,M, N	-20	40	200	200	200	200	200	200	177	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S460	Q	-20	30	200	200	200	200	147	96	65	200	200	200	200	200	200	187	200	200	200	200	200	200	200
	M, N	-20	40	200	200	200	200	200	147	96	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL	-40	30	200	200	200	200	200	200	147	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	ML, NL	-50	27	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL1	-60	30	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
S690	Q	0	40	200	137	89	58	40	28	20	200	200	200	174	115	78	55	200	200	200	200	200	200	200
	Q	-20	30	200	200	137	89	58	40	28	200	200	200	200	174	115	78	200	200	200	200	200	200	200
	QL	-20	40	200	200	200	137	89	58	40	200	200	200	200	200	174	115	200	200	200	200	200	200	200
	QL	-40	30	200	200	200	200	137	89	58	200	200	200	200	200	200	174	200	200	200	200	200	200	200
	QL1	-40	40	200	200	200	200	200	137	89	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	QL1	-60	30	200	200	200	200	200	200	137	200	200	200	200	200	200	200	200	200	200	200	200	200	200

4.8 Connection design

This protocol anticipates that the primary use of reclaimed steelwork will be as plain members, *i.e.* with existing connections removed or redundant. However, to reuse of part of structures or entire structures can rely on similar principles.

If new connections to the reclaimed steelwork require welding of some components, the carbon equivalent value (CEV) will be required in order to develop appropriate welding procedures. The chemical composition of the steelwork is a mandatory declaration according to clause 5.1 of EN 1090-2. The declared CEV should be the maximum value determined from the non-destructive and destructive tests (see Annex E). A high CEV will generally not be detrimental unless the joint has a high combined thickness (the sum of the thickness of all the elements meeting at the joint).

If connections are to be re-used, previous research indicates that it may be assumed that the strength of the weld material is at least equal to the base steelwork [32]. This advice does not cover workmanship – it is recommended that any existing welds that are to be reused are carefully inspected and tested (see also section 8.5).

UK - review of fabrication processes:

It is likely that the steelwork was manufactured and erected following guidelines that were imposed by the applicable standards in place at the time of construction. For the UK, previous to EN 1090, the National Structural Steelwork Specification for Building Construction (NSSS [33]) was providing the best practice for fabrication and erection of structural steelwork (first published in 1989). Before NSSS, BS 449 [34] (1969 version), provided procedures for weld testing and welders certification according to BS 2645 (published in 1956) [73]. Consequently, it is expected that no major issues/defects will be found in steelwork erected in the UK after 1970. However, testing of welds on reclaimed steel elements is recommended for the cases where fabrication documentation is not available (see also section 8.5). This background is intended to help inform the decision whether or not to test existing welds.

Romania - review of fabrications processes:

For Romania, previous to EN 1090, implemented in 2014, the Romanian Institute for Standardization through STAS 767/0-88 [158] provided the technical requirements for fabrication and erection of non-industrial, industrial and agricultural buildings. The first edition of this standard was issued in 1977. The standard C150-99 [159] provided rules for welding execution, for NDT testing and welders certification. Before the 1999 edition of C150, two other editions were issued, one in 1972 (C150-72) and another one in 1984 (C150-84).

Portugal - review of fabrications processes:

The first Portuguese standard to cover design, execution and erection of steel structures was the RSAE standard published in 1965. General rules for execution were being provided, covering riveted, welded and bolted connections. For welding procedures, it was clearly stated that only accredited personnel were allowed to perform such operations. I was stated that in 1965, a set of standards were already issued for public comments covering welding procedures and accreditation of welding personnel. A comprehensive list of product standards was provided, listing standards issued between 1956 and 1962, covering steel properties, hot rolled products, tensile testes, Charpy tests, bolts, rivets mong other topics.

Strengthening existing welded connections:

A fillet weld may be strengthened by adding weld layers in order to achieve the necessary dimensions. Where an old weld is strengthened, the design procedure must rely on the properties of the old weld [32] – that can be assumed as equal to the base steelwork.

Incomplete penetration on the root side can be found on existing but welds. Other types of defects can also occur on the root side of the weld, such as concave root surface, cracks, porosity, melt-through, etc. All these areas can be removed by grinding or routing, and to ensure a complete assessment of all defects, a penetrant test shall be undertaken before repairing the weld. After the defect is removed, the area for welding must be prepared by removing all rough edges on the ground area. After a repair is made, the weld needs to be re-inspected. Required NDT according to EN1090-2 for final acceptance of the weld must be completed after repairing the weld.

4.9 Design of existing structures for future reuse

4.9.1 Introduction

The design of structures using reclaimed structural steel shall follow the recommendations of ISO 13822 [124].

Sections 4.9.3/0 proposes adapted values for the combination of action while designing with existing structures. An existing structure can be a structure subjected to a new structural application or to fulfil the new codes regulations (in-situ reuse) or a structure that was relocated and exposed to a different load level (relocated reuse).

Section 4.9.5 provides a summary of existing guidance about the design of existing structures.

4.9.2 Assessment of performance [122]:

Structures designed and constructed based on existing/old codes/standards, or in accordance with good workmanship when no code applied, may be considered safe for the future use, provided that simultaneously:

- Careful inspection does not reveal any evidence of significant damage, distress or deterioration or displacements;
- The structural system is reviewed, including investigation of critical details checking them for stress transfer;
- The structure has demonstrated satisfactory performance during a sufficiently long time (say more than 15 years) for extreme actions and for the occurrence of environmental effects;
- There will be no changes to the structure and in its use that can significantly affect the actions;
- Predicted deterioration considering the present condition and planned maintenance ensures sufficient durability;
- There have been no changes for a sufficiently long time, which could significantly increase the actions on the structure or affect its durability; and no such changes are anticipated.

If a structure is kept at its original location with a similar application (in-situ reuse), there is no reason to increase the required levels of safety. This means that values of $K_{\gamma M1}$ for existing carbon steel elements erected after 1970 may be taken as equal to 1. The value of $K_{\gamma M1}$ is related to the uncertainty of multiple transportation, disassembly, erection processes as well as in testing procedures to assess geometric imperfections. This uncertainty is not present if the building remains at its original location.

However, the condition of existing steel elements must be assessed, evaluating material properties and geometric tolerances as specified in the current protocol. Bow imperfections may be evaluated for existing columns. The bow tolerance according to EN 1090-2 and second order effects due to the strut action must be considered for the in-service load to calculate the value of actual bow imperfection.

Tolerances based on previous and current UK and Romanian practice are given in *Table 4.2*.

Table 4.2. Review of geometrical tolerances for individual members in the UK and Romania:

Products	**Dimensions**				
	BS4 (1962) - [131]	**Dorman Long (1964) - [129]**	**NSSS (1994) - [130]**	**EN 1090-2 (2018)**	**STAS 767/0-88 [158]**
Beam	*L*/961	*L*/961	*L*/1000 or 3 mm	*L*/1000	*L*/1000, but max. 15 mm *L*/1000, but max. 15 mm *L*/1000, but max. 15 mm
Column up to (but not including) 9.14 m	*L*/714	*L*/961	*L*/1000 or 3 mm	*L*/1000	
Column up to 13.72 m	*9.5mm*	*L*/961	*L*/1000 or 3 mm	*L*/1000	
Columns over and equal to 13.72 m	*L*/961 – 4.75, with *L* in mm	$9.5\,\mathrm{mm} + 3.175 \cdot \frac{L-13.72}{3.05}$, with *L* in m	*L*/1000 or 3 mm	*L*/1000	

4.9.3 Combinations of actions (Proposal 1)

The application of the partial factor method requires the definition of the design values of the actions, material and product properties, geometrical data, and model uncertainties. The design values for actions, Q_d, are obtained from the characteristic values, Q_k, based on a 50-year reference period and a corresponding target reliability. The target value of the reliability index β is related to the probability of failure, P_f, corresponding to a specified reference period, as follows:

$$\beta = -\Phi^{-1}(P_f) \tag{4.1}$$

Where Φ^{-1} is the inverse standardised normal distribution.

The general actions on single-storey buildings defined in EN 1991-1-1, i.e. densities, self-weight, and imposed loads, are not sensitive to the reference period, and therefore the usual 50-year reference period can still be used. For actions of natural origin, e.g. snow loads and wind actions, EN 1991 gives adjusted values for reference periods other than the 50-year period in (i) Annex D of EN 19991-1-3 for snow loads, and (ii) Note 4 in Clause 4.2 in EN 1991-1-4 for wind loads.

EN 1990 defines three Consequence Classes (CC), depending on the consequences of failure or malfunction of the structure, which are associated with three different Reliability Classes (RC) as follows:

- CC1: *low* consequence for loss of human life, and economic, social or environmental consequences *small or negligible*, associated with RC1 ($\beta_{50\text{-year}} = 3.3$),
- CC2: *medium* consequence for loss of human life, economic, social or environmental consequences *considerable*, associated with RC2 ($\beta_{50\text{-year}} = 3.8$),
- CC3: *high* consequence for loss of human life, or economic, social or environmental consequences *very great*, associated with RC3 ($\beta_{50\text{-year}} = 4.3$).

It is also noted that designs with the partial factors given in the Eurocodes generally leads to a RC2 structure with a β value greater than 3.8 for a 50-year reference period.

The design working life of the structure is not explicitly linked to the consequence class in EN 1990, and can be understood as an assumed period of time for which a structure is to be used for its intended purpose without any major repair being necessary. Clause 2.3(1) of EN 1990 gives the following categories together with indicative design working life for permanent structures:

- Category 3, with a notional design working life of 15~30 years,
- Category 4, with a notional design working life of 50 years,
- Category 5, with a notional design working life of 100 years.

Structures designed to the Eurocodes should perform and remain fit for the appropriate working life. Typical buildings are designed for a working life of 50 years, i.e. category 4, for a *normal degree of reliability* and RC2 ($\beta_{50\text{-year}} = 3.8$). If the design working life is limited, say to 25 years, it may be reasonable to specify a *lower than normal degree of reliability*, $\beta_{50\text{-year}} < 3.8$, but $\beta_{50\text{-year}} \geq 2.5$, which is the limit value for human safety. Likewise, if the design working life is increased, say to 100 years, then $\beta_{50\text{-year}} > 3.8$, corresponding to a *higher than normal degree of reliability*. It should also be highlighted that these β indices and the corresponding probability of failure are only notional values that do not necessarily represent actual failure rates. Gulvanessian et al. [74] clearly explain that the

β indices are used as operational values for code calibration purposes and comparison of reliability levels of structures that naturally depend on the design working life, and are used in the whole system actions – resistances – partial factors.

Clause 2.2(6) of EN 1990 states that the different measures to reduce the risk of failure may be interchanged to a limited extent provided that the required reliability level is maintained. When designing with reclaimed steel, it may be necessary to compensate for a slightly lower partial factor by a high level of quality management and control. This is an example of reliability differentiation by the requirements of the quality levels.

Reliability differentiation may also be applied through (i) the partial factors for actions γ_F, or (ii) the partial factors for resistance, γ_M, which is further elaborated next. The first option is usually preferred.

The partial factors for actions cater for the variability of loading, i.e. loads may be greater than expected, and also loads used to counteract overturning may be less than intended.

A multiplication factor K_{FI} is then applied to the partial factors for unfavourable actions in fundamental combinations for persistent design situations, see Clause 6.4.2.2(3) of EN 1990 and Table 4.3. Notation in the table is as follows, and γ_F are the recommended values:

$G_{k,j,sup}$ is the upper characteristic (superior) value of permanent action j

$G_{k,j,inf}$ is the lower characteristic (inferior) value of permanent action j

$Q_{k,1}$ is the leading variable action

$Q_{k,i}$ is the accompanying variable action i

$\psi_{0,i}$ is a combination factor (for variable action i)

ξ is a reduction factor for unfavourable permanent actions, defined in the National Annexes for use in a country.

It is common practice to lower the required safety level when evaluating and upgrading existing structures, as long as the limits for human safety are not exceeded, see Refs. [75] [76]. This is justified by the fact that, for existing structures, a shorter design life is assumed. Likewise, for designs with reclaimed steelwork, it is reasonable to consider a shorter design life, to up to 30 years – say 15 years (category 3 above), which corresponds to RC1. This leads to a multiplication factor of 0.9. It is recommended, however, that the fundamental combinations of actions are assessed based on Eq. (6.10) of EN 1990, top line in Table 4.3, as highlighted, which leads to a higher value of reliability as compared to Eqs. (6.10a) and (6.10b) of EN 1990.

Table 4.3. Design values of actions for strength (STR) according to EN1990.

Reuse	**Persistent and transient design situations**	**Permanent actions**		**Leading variable action**	**Accompanying variable actions (i > 1)**
		Unfavourable	**Favourable**		
15-30 notional design working life (K_{FI} = 0.9)	**Eq. 6.10**	**1.215 $G_{k,j,sup}$**	**1.0 $G_{k,j,inf}$**	**1.35 $Q_{k,1}$**	**1.35 $\psi_{0,i}$ $Q_{k,I}$**

It was suggested that combinations factors could be slightly reduced when using reclaimed steel (or while dealing with existing steelwork/structures) by assuming a lower expected structure life time. This option may require higher level of quality management control and inspection to the structure.

For a new building, standard EC0 reliability requirements must be met (even if individual reclaimed elements are used). The examples where the lower partial factors for a notional design working life of 15-30 years can be used are existing buildings (in situ reuse) or the cases where the building is relocated to a different location.

For the cases where a new structure is designed, while promoting the use of reclaimed elements, it's possible to adjust the influence areas of the reclaimed elements (for example, by adjusting the spacing of a floor beam or frame) so that the load level is acceptable according to the standard reliability requirement for a notional design working life of 50 years.

4.9.4 Combinations of actions (Proposal 2)

The following proposed values were derived based on EN1990. Detailed procedures are presented in D3.1 [89]. Table 4.4 shows the benchmark load factors from EN1990 for a CC2 structure. The point of exploring a more complex approach (in comparison with proposal 1) is that in fact two possible scenarios could be included:

One for assessing existing structures, where the absolute minimum values for human safety according to can be specified. A building inspection every 5 years is recommended. This case would be more suitable for in-situ reuse – see Table 4.5;

- An alternative for acceptance of reclaimed materials and relocation, shortening the lifetime of the structure, as introduced in section 4.9.3. This is obtained by assuming a β=3.3. The additional benefit is to offer a different load factor for permanent loads on single storey buildings. A building inspection every 15 years is recommended (Table 4.6).

The uncertainty relating to permanent loads for single storey building is quite low. Steelwork has very small tolerances. Designers always make allowance for the self-weight of the connections (say between 7-15% of the self-weight of the structure; this can be adjusted after the fabrication model is undertaken), so no concern about the self-weight of the connections as well. Cladding may be inspected and one knows with high confidence their self-weight. As there is little uncertainty about the values for these two self-weight loads, a value of α_E=-0.28 [123] may be assumed to reflect that option in the FORM (first order reliability method) according to EN 1990.

Table 4.4 - Suggested partial safety factors for load for ULS – Base model for target *β=3.8.*

CC2 – EN1990	β	*Distribution*	w_i	α_E	α_T	N	γ_{Ed}	$\gamma_{q/g}$	$\gamma_{G/Q,\beta=3.8}$	$\gamma_{G/Q,calc,EC}$
Permanent loads	3.8	Normal	0.10	-0.70	-	-	1.05	1.27	1.33	1.35
Permanent loads(5)	3.8	Normal	0.10	-0.28	-	-	1.05		1.162	~1.20
Time invariant variable - Imposed	3.8	Gumbel	0.22	-0.70	1.00	10	1.05	1.43	1.50	1.50
Time variant variable - Wind	3.8	Gumbel	0.35	-0.70	0.50	50	1.05	1.51	1.59(2)	~1.50(4)
Time variant variable - Snow	3.8	Gumbel	0.30	-0.70	0.50	50	1.05	1.47	1.54(3)	~1.50(4)

Table 4.5 - Suggested load factors for the ultimate limit state – Minimum for human safety and reuse.

CC0 – Limit Human Safety	β	*Dist.*	w_i	α_E	α_T	N	γ_{Ed}	$\gamma_{q/g}$	$\gamma_{G/Q}$	$\gamma_{G/Q,calc,0}$	$\gamma_{G/Q,calc}$
Permanent loads	2.5	Normal	0.10	-0.70	-	-	1.05	1.18	1.23	1.25	1.25
Permanent loads(1)	2.5	Normal	0.10	-0.28	-	-	1.05	1.07	1.12	1.15	1.15
Time invariant variable - Imposed	2.5	Gumbel	0.22	-0.70	1.00	10	1.05	1.17	1.23	1.25	1.25
Time variant variable - Wind	2.5	Gumbel	0.35	-0.70	0.50	50	1.05	1.18	1.24	1.24	1.25
Time variant variable - Snow	2.5	Gumbel	0.30	-0.70	0.50	50	1.05	1.16	1.22	1.22	1.25

Table 4.6 - Suggested load factors for the ultimate limit state – Suitable for reuse.

CC2 – Suitable for reuse	β	*Dist.*	w_i	α_E	α_T	N	γ_{Ed}	$\gamma_{q/g}$	$\gamma_{G/Q}$	$\gamma_{G/Q,calc,0}$	$\gamma_{G/Q,calc}$
Permanent loads	3.3	Normal	0.10	-0.70	-	-	1.05	1.23	1.29	1.30	1.30
Permanent loads (1)	3.3	Normal	0.10	-0.28	-	-	1.05	1.09	1.15	1.15	1.15
Time invariant variable - Imposed	3.3	Gumbel	0.22	-0.70	1.00	10	1.05	1.32	1.39	1.40	1.40
Time variant variable - Wind	3.3	Gumbel	0.35	-0.70	0.50	50	1.05	1.37	1.44	$1.44 \cdot K_{\beta,W}$	1.40(4)
Time variant variable - Snow	3.3	Gumbel	0.30	-0.70	0.50	50	1.05	1.34	1.41	$1.41 \cdot K_{\beta,s}$	1.40(4)

Notes:
1 – *It is proposed in reference [123] to consider α_E=-0.28 for the permanent loads;*
2 – *Equivalent to β=3.50 to obtain $\gamma_{Q,W}$ = 1.50 or a $w_{Q,W}$ = 0.25 (0.25 is a low value for the wind load);*
3 – *Equivalent to β=3.65 to obtain $\gamma_{Q,S}$ = 1.50 or a $w_{Q,S}$ = 0.25 (0.25 is a low value for the snow load);*
4 – *The fact that values for new structures are higher for snow and wind the model used to calculate partial safety factors for existing/reusable structures makes the process conservative. Values for wind and snow in are corrected according to the ratio $\gamma_{G/Q,calc,EC}/\gamma_{G/Q,\beta=3.8}$ for the wind and snow loads: $K_{\beta,W}$=1.50/1.59=0.95; $K_{\beta,s}$=1.50/1.54=0.98.*
5 *– This may be an option if certain conditions are met such as: reports of on-site claddings weight, where the design values of claddings were justified. This value can be used also for steel self-weight. Additional permanent load shall use 1.35.*

The influence of β for the material factors is disregarded on these examples. This can be justified by the fact that the material factors have a low dependency of β because they usually have low coefficient of variation and rely on a normal distribution. The critical differences are always related with time dependant variable loads that use Gumbel distributions (such as wind or snow loads).

4.9.5 Further references for designing existing structures:

- SAMCO Final Report 2006; F08a Guideline for the Assessment of Existing Structures [135]
- Probabilistic Model Code, Parts 1 to 4, Basis of design, Load and resistance models [136];
- New European Technical Rules for the Assessment and Retrofitting of Existing Structures [137];
- Assessment of Existing Steel Structures: Recommendations for Estimation of Remaining Fatigue Life [138];
- Innovative methods for the assessment of existing structures [139];
- Structural Appraisal of existing buildings Part 1 Requirements for structural appraisal [140];
- Structural Appraisal of existing buildings Part 2 Preparing for structural appraisal [141];
- Structural Appraisal of existing buildings Part 3 Structural appraisal procedures [142];
- Structural Appraisal of existing buildings Part 4 Additional considerations and information sources [143];
- Appraisal of Existing Structures, Institution of Structural Engineers [144];
- NEN 8700 – Assessment of existing structures in case of reconstruction and disapproval – Basic Rules [145].
- NEN 8701 – Assessment of existing structures in case of reconstruction and disapproval – Actions [146].
- Eurocodes and structural safety of the existing buildings – considering the publication of the Dutch NEN 8700 [147].
- Assessment criteria for Existing Structures [148].
- Limit states criteria for structural evaluation of existing buildings [149].
- Safety acceptance criteria for existing structures [150].
- Safety philosophy for existing structures and partial factors for traffic loads on bridges [151].
- Probabilistic assessment of existing structures [152].
- Background documentation Eurocode 1 ENV Part 1; 1996 [153].
- Handbook for the Structural Assessment of Large Panel System (LPS) [154];
- Design Manual for Roads and Bridges standards: Volume 0, 1, 2 and 3 [155];
- Reliability analysis for structural design [156];
- Commentary and worked examples to EN 1993-1-10: Material toughness and through thickness properties and other toughness-oriented rules in EN 1993 [157];
- Guideline for Structural Condition Assessment of Existing Buildings, ASCE Standard Guideline, SEI/ASCE 11-99 [160];
- Guideline SIA 462:1994 Assessment of the structural safety of existing buildings, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 1994 [161];
- Standard SIA 269/3:2011 Existing Structures – Steel Structures, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 2011 [32];
- Basics for assessment of existing structures (Milan Holický, Editor), Klokner Institute, Czech Technical University in Prague, 2013 [162].

5. Assessment of reclaimed steelwork for reuse

5.1 Introduction

All structural steel reclaimed for reuse, is to be inspected and tested if no appropriate documentation and traceability are available. Central to the testing regime is the grouping of fundamentally identical members into groups, whereby one (or more) members are assumed to be representative of the entire group, thus moderating the requirements (and costs) for testing. The data to be recorded, initially and after subsequent testing, is set out in Annex B.

Without traceability of each component, the value of the reclaimed material will be compromised. It is important therefore for material stockists to maintain full traceability of the reclaimed steelwork, including the grouping and labelling of members. A permanent unique physical label/mark is recommended for each member.

5.2 Admissibility of reclaimed steelwork

The following scope for reclaimed steel is necessary to complement recommendations in this protocol:

Table 5.1. Admissibility of reclaimed steelwork

Admissibility of reclaimed steelwork checklist
Steelwork no older than 1970 (to use Eurocode rules);
No built-up members (unless welds are tested);
No spliced members (the individual lengths of a member with a bolted or welded splice can be disassembled/cut and reclaimed; otherwise, welds need to be tested);
No significant section loss due to corrosion (loss exceeding 5% of the element thickness is considered significant - [32]);
No signs of fire exposure;
No evidence of plasticity observed in the steel surface or coating;
Members must meet the geometric tolerances of EN 1090-2 (straightening can be performed if tolerances are not met).

The limitation to steel produced after 1970 relates to the material properties assumed by modern design Standards. Steel from 1970 was considered as part of the Eurocode programme and the development of product and design Standards. It is therefore assumed that structural steel produced after 1970 meets the material properties assumed in product Standards such as EN 10025 and EN 10219.

Review of other international standards

Swiss Standard SIA 263 (first published in 1956) can be seen as benchmark for accepting reclaimed steel as appropriate for design according to modern design standards. SIA 263 (2013) [35] follows the Eurocodes philosophy for analysis and design. The Swiss standard for existing steel structures SIA269/3 [32] accepts modern design procedures for steel fabricated after 1956.

Therefore, it is sensible to point out that steelwork reclaimed after 1970 can be designed according to Eurocode principles with an appropriate level of reliability.

5.3 Assessment of the existing steelwork

5.3.1 Introduction

Assessment of the reclaimed steelwork begins before the existing structure is deconstructed, with the collection of relevant data. It is recommended to follow the procedure outlined in the EU Construction and Demolition Waste Management Protocol [36] and EU Waste Audit Guideline [37]. According to the Guideline, the audit consists of the steps described in Figure 5 (documentation research, field survey, condition evaluation and recommendations) and its results shall be recorded in a report.

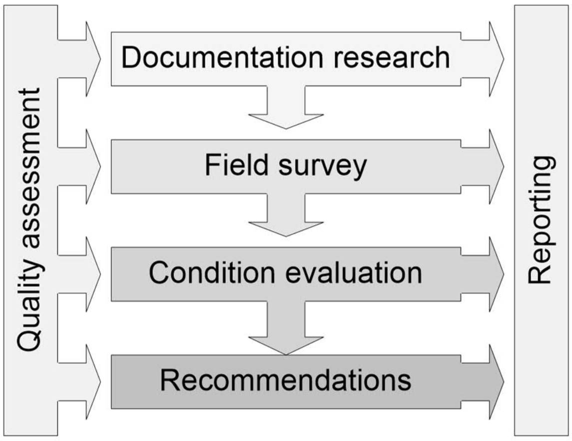


Figure 5. Waste/material audit process [37]

The following text describes the assessment of reusable constructional steelwork to be tested according to this protocol. The complete pre-deconstruction audit procedure including checklists, reporting templates and guidance for non-reusable materials and waste (including hazardous waste) is part of Deliverable D2.1 of PROGRESS project [38].

Section 5.4 describes the initial data to be collected and Section 7 the general principles of the recommended testing regime. In addition to the assessment of the steel elements, the preliminary assessment should consider the method of deconstruction and a safe method of work. Safe and efficient deconstruction methods are addressed in D2.1 [88].

Before the on-site assessment, data about the existing structure is to be collected and analysed. Construction documents of interest include design drawings, specifications, material test records, and quality assurance reports covering original construction and subsequent modifications to the structure. Section 5.4 provides guidance for this process.

5.3.2 Preliminary assessment: documentation research and general examination

The preliminary assessment shall be performed by an experienced chartered engineering, with possible contributions from personnel with fabrication and erection expertise. The preliminary assessment is a very important step, as it is intended to evaluate the feasibility of reclaiming and reusing the existing steelwork. This assessment needs to consider the expected reuse scenario. The main purpose of this step is to avoid effort and associated costs of a careful inspection, deconstruction and documentation of an existing building which offers limited opportunities for steel reuse. A preliminary overall visual inspection of the building is recommended before undertaking any further recommendations described on the current section.

In the first phase, a study of the available collected documentation is envisaged prior to any field assessment. Available engineering reports, including any previous inspection, maintenance or records of possible modifications shall be also reviewed. Specifications (including possible original Welding Procedure Specifications), shop drawings, erection drawings, and construction records shall be reviewed where available.

The construction date must be identified, as well as the likely materials to be found in the existing building when documentation is not available. Using a similar process, the likely standards that were used for the structural analysis and design shall be identified.

Whenever the structural elements are not visually exposed, measures should be specified to expose a sufficient number of elements for the preliminary assessment (only a representative/limited number of elements need to be exposed - *Table 5.2*).

For the preliminary field assessment, visual inspection and possibly non-destructive tests can be undertaken. An evaluation of the existing structural concept and the adequacy of the existing steelwork and design for the possible future reuse may be undertaken. Mechanisms and nature of possible structural failure shall be evaluated and documented. The preliminary assessment will make sure that any field operation is appropriate and safe for the personal.

A quantitative/empirical evaluation of the existing steelwork is undertaken within this step. It is expected that photographic records and a representative field survey will be created. Hand sketches can be used to describe the structural concept and relevant details. Preliminary calculations may be undertaken based on existing documentation data or based on preliminary material properties assessed by a minimal testing (based on non-destructive tests – procedure according to Section 7.2) to assess the adequacy of the expected reuse scenario.

All collected data must be presented in a report, where any concern/issue found must be documented. Based on the date of construction, the expected (or preliminary tested) steel properties as well as the possible/likely design codes must be clearly identified. The report shall define any urgent safety measures required for the existing building.

Building documentation is extremely valuable for the reuse of existing steelwork. However, it is necessary to ensure that the collected information is updated and refers to the as-build structure. The consistency of the collected documentation must therefore be assessed not only for building geometry and section sizes but also for details (i.e. joints). Table 5.1 proposes guidance to check the compliance of existing building documentation and the as-built structure. For structures with detailed construction drawings, a limited on-site inspection is recommended. For other cases, where no documentation is available, a more detailed on-site inspection is recommended.

For the cases where documentation is available, but no compliance/agreement is found according to the on-site inspection, the percentage of details and members/cross sections to be checked must be the ones suggested to the cases where no documentation is available (see *Table 5.2*).

Cross-sections should be checked against available documentation. If building documentation is not available, the cross-sections should be compared against relevant catalogues according to be building age and location. Geometric tolerances should be allowed for while assessing the cross-sectional dimensions of existing steelwork (see *Table 2.2*).

Table 5.2. Details to be checked for each group of elements (per floor) – Preliminary assessment

<table>
<tr><th>Detailed construction drawings/documentation available:</th><th>Percentage of details to be checked:</th><th>Percentage of members checked for cross section dimensions</th><th>Building dimensions and structural solution</th></tr>
<tr><td>Yes (limited on-site inspection recommended)</td><td>10% (min 3 different detail types) – details selected randomly</td><td>10% (min 3 different sections) – members selected randomly</td><td rowspan="2">Minimum inspection for a typical single storey building (say a typical frame):
• Span;
• Eaves height;
• Apex height;
• Frames spacing;
• Vertical and roof bracing arrangement;
• Eaves struts;
• Fly bracings;
• Etc.</td></tr>
<tr><td>No (comprehensive on-site inspection recommended)</td><td>25% (min 5 different detail types) – details selected randomly</td><td>25% (min 5 different sections or all sections) – members selected randomly</td></tr>
<tr><td colspan="4">Note: percentages to be applied to a group of elements with same geometric and load history/structural application (see section 6.1 for grouping definition); by way of example, for a portal frame, the three types of details to be checked can be column-base, apex and eaves connections. Different section can be columns, rafters and vertical and roof bracings.</td></tr>
</table>

The preliminary inspection of a limited number of details and members is intended to assess the geometry and condition of the existing steelwork. The inspection should look for any evidence that may indicate that the steelwork is not good for reuse, being a more detailed inspection not recommended. Problems such as excessive corrosion, excessive/plastic deformation of the structural elements, excessive plastic deformations on the connecting elements, evidence of local or member buckling, fabrication defects, etc.

For the preliminary assessment, tested or inspected elements must be identified and labelled with a physical and reliable method. Each label shall be unique (e.g. number, barcode, QR code or RFID tag) so the original location of each of the components within the building is known.

If any structural element is classified as non-reusable in the current condition, it can be repaired/refurbished or sent for recycling.

5.3.3 Comprehensive assessment: detailed survey and testing

The comprehensive assessment shall be implemented after completing the preliminary assessment described in Section 5.3.2. If the preliminary assessment is satisfactory then the following recommendations for a more comprehensive assessment may be followed.

The consistency of the collected information should be re-assessed according to Table 5.3.

With the comprehensive assessment, a detailed evaluation of the existing structural elements condition is undertaken. A comprehensive visual inspection of all structural elements must be undertaken. This should seek to evaluate the condition of the existing steelwork concerning section loss due to corrosion, excessive/plastic deformation of the structural elements, plastic local deformations in connecting elements (plates), signs of local (plate) or member buckling (evidence of plastic loading history), fabrication defects, damage due to impact loadings, etc.

Table 5.3. Details to be checked for each group of elements (per floor, if applicable).

Detailed construction drawings/documentation available:	**Percentage of details to be checked:**	**Percentage of members checked for cross section dimensions**	**Building dimensions and structural solution**
Yes (limited on-site inspection recommended)	25% (min 5 different detail types) – details selected randomly	25% (min 5 different sections up to all different section) – members selected randomly	Minimum inspection for a typical single storey building (say a typical frame): • Span; • Eaves height; • Apex height; • Frames spacing; • Vertical and roof bracing arrangement; • Eaves struts; • Fly bracings; • Etc.
No (comprehensive on-site inspection recommended)	100%	100%	
Note: percentages to be applied to a group of elements with same geometric and load history (see section 6.1 for grouping definition); as example, for a portal frame the three types of details to be checks can be base connections, apex and eaves. Three different section can be columns, rafters and vertical bracings.			

The evaluation of the coating condition (including blistering, rusting, cracking, flaking or chalking) shall be undertaken. Coating toxicity should also be assessed and documented, justifying that the existing system can be reused (if applicable; for example, reuse of elements with intumescent painting is not recommended) - see also section 8.2.Depending of the reuse scenario, structural elements may need to be exposed, which means that careful deconstruction (and partial demolition of non-structural elements) may be required.

It is recommended that all reusable elements are permanently and physically identified and labelled with a reliable method. Each label shall be unique (e.g. number, barcode, QR code or RFID) so that the original building, building location and location of each component will be known.

If adequate documentation is not available, drawings and eventually a 3D BIM model can be produced (depending on the reuse scenario for the reclaimed steelwork). This is clearly not the case if individual elements are intended to be reclaimed for future reuse applications.

If any structural element is classified as non-reusable in the current condition, it can be repaired/refurbished or sent for recycling.

After the comprehensive assessment, only reusable elements are grouped (see section 6.1) and made available for testing (if required). The necessity of testing is related to the available documentation and the future reuse scenario. Based on the reclaimed steel classification (A, B or C), appropriate testing procedures shall be implemented according to Section 7. Testing procedures described in Section 7 shall be used (if required) to justify the material properties.

5.4 Data collection and documentation

Before deconstruction and reclamation of the steelwork, data about the existing structure is to be collected and analysed, and visible parts of steelwork assessed.

Design and inspection documents contain important information that can be used for a thorough assessment of the existing structure. It shall be verified that the documents are correct and, in that context, that they are updated to include information of any previous intervention on the structure.

Other evidence, such as the occurrence of significant earthquake events, fires, significant snow/wind loads, changes in soil conditions, corrosion, and misuse of the structure, shall be recorded and documented.

Building owner, designers, fabricators and on-site contractors, and neighbours can be contacted to collect available information.

The process should try to provide answers to the following topics:

- Collect drawings, CAD drawings, 3D models, mill certificates, photographic evidence etc. for the as-build structure;
- Collect information about the design such as calculation notes, loading history, etc.;
- Records of interventions (e.g. expansions, modification, etc.);
- Records from any possible incident in the building/area: fire, earthquakes, etc.;
- Inspection and maintenance records;
- Date and place of construction of the original building;
- Building owner's manual (O&M manual);
- Identify fabricator, erector, designers, architects and other actors.

The following data should be recorded from the existing structure and steelwork in a report:

- A description of the structure and its use. This should include a description of how the building is stabilised;
- The age of the structure, which may be from records, or local/anecdotal information;
- A preliminary listing of the steel members;
- A preliminary inspection of the members for damage, obvious repairs, significant corrosion, etc.;
- Any evidence of plasticity.

5.5 Inspection requirements undertaken by the stockholder

After reclamation, the responsibility of the holder of the stock is to inspect every member and maintain records that include:

- Dimensions (cross section and length);
- Straightness (assessed against the tolerances – EN1090-2);
- Any significant loss of section;
- Signs of damage, or plastic strain.

The stockholder shall keep records of the data collected from the assessment of the existing steelwork.

5.6 Commentary about EN 1998-3

Among current European design recommendations, EN 1998-3 [90] is one of the few normative references that addresses the assessment of existing structures. The guidance is rather general, and intended essentially for an assessment of earthquake resistance of structures. In addition, safety issues arising from other loads should be addressed. Following, a commentary about the procedure proposed in EN 1998-3 is provided.

In order to substantiated the admissible analysis method and estimate the confidence factor, EN1998-3 establishes three knowledge levels about the inspected structure, based on the amount and quality of information/documentation available and performed tests. This section is intended to provide specific guidance for steel structures. The three levels are presented in Table 3.1 of EN 1998-3 (see - *Table 5.4*).

Table 5.4***. Knowledge levels and corresponding methods of analysis (EN1998-3).***

Knowledge Level	Geometry	Details	Materials	Analysis	CF
KL1	From original outline construction drawings with sample **visual** survey ***or*** from **full** survey	Simulated design in accordance with relevant practice ***and*** from **limited** *in-situ* inspection	Default values in accordance with standards of the time of construction ***and*** from **limited** *in-situ* testing	LF- MRS	CF_{KL1}
KL2		From incomplete original detailed construction drawings with **limited** *in-situ* inspection ***or*** from **extended** *in-situ* inspection	From original design specifications with **limited** *in-situ* testing ***or*** from **extended** *in-situ* testing	All	CF_{KL2}
KL3		From original detailed construction drawings with **limited** *in-situ* inspection ***or*** from **comprehensive** *in-situ* inspection	From original test reports with **limited** *in-situ* testing ***or*** from **comprehensive** *in-situ* testing	All	CF_{KL3}

NOTE The values ascribed to the confidence factors to be used in a country may be found in its National Annex. The recommended values are $CF_{KL1} = 1{,}35$, $CF_{KL2} = 1{,}20$ and $CF_{KL3} = 1{,}00$.

The Knowledge Levels (KL) are established considering the available information about the structure, concerning the topics of: **geometry, details and materials**.

Based on the achieved Knowledge Level (KL), the confidence factors CF is selected, which is intended to increase the safety of the design process. To determine material properties for capacities for comparison with demand in safety verification, the mean values obtained from in-situ tests and additional sources of information, shall be divided by the confidence factor (CF). Hence, in direct safety verifications the strength is reduced by CF. Conversely, for properties to be used in calculation of the force capacity of ductile components, with the purpose of establishing a failure hierarchy between brittle and ductile components, the mean value of materials shall be multiplied by the confidence factor (CF). Hence, for the purpose of failure hierarchy the strength of the weaker element is increased by CF. The value of CF is only equal to 1 for a Knowledge level 3 (KL3), for which detailed information about geometry, details and materials are required.

The assessment and testing programmes recommended in this protocol are in agreement with the KL3. Therefore, the factor CF would, in this case, be equal to 1. For KL2 and KL3, the confidence factors would be 1.20 and 1.35 respectively.

For a knowledge level 3 (KL3), the following requirements are specified:

i) Geometry: *"the overall structural geometry and member sizes are known either (a) from a comprehensive survey or (b) from the complete set of outline construction drawings used for both the original construction and any subsequent modifications. In case (b), a sufficient sample of both overall geometry and member sizes should be checked on site; if there are significant discrepancies from the outline construction drawings, a fuller dimensional survey is required."*

ii) Details: *"the structural details are known either from comprehensive in-situ inspection or from a complete set of detailed construction drawings. In the latter case, limited in-situ inspections in the most critical elements should be performed to check that the available information corresponds to the actual situation."* This procedure would be relevant for a reuse scenario where the building is entirely reused, or for the cases where the connections are intended to be reused based on the information from the construction drawings.

iii) Materials: "information on the mechanical properties of the construction materials is available either from comprehensive in-situ testing or from original test reports. In this latter case, limited in-situ testing should be performed." The comprehensive testing is represented by the protocol proposed in section 7 for Class B reclaimed steel. The limited testing can be related to the testing procedure described on section 7 for Class A steel.

EN 1998-3 recommends the percentages of inspected details and tested elements according to *Table 5.5*.

*Table 5.5***.** Minimum requirements for inspection and testing according to EN1998-3. Values per floor.

	Inspection (of details)	Testing (of materials)
	For each type of primary element (beam, column, wall):	
Level of inspection and testing	Percentage of elements that are checked for details	Material samples per floor
Limited	20	1
Extended	50	2
Comprehensive	80	3

EN 1998-3 3.4.3.1 states that non-destructive testing can be used but not in isolation. This consideration is fulfilled for Class B steel (related to the proposed comprehensive testing procedure), for which no material documentation is available.

For the inspection of details, the percentages of elements to be inspected based on Table 5.3 are in agreement with the recommendation to achieve KL3 knowledge level (*Table 5.5*).

As stated in the defined scope of this protocol, the use of reclaimed structural steel elements in a primary seismic structural system is not recommended. For other cases, for example, when the assessment of an existing building is undertaken, at least one destructive test is recommended per type of primary element per floor for a CC2 structure. For CC3 structures, three destructive tests are recommended per type of primary element per floor.

Further guidance for seismic applications, can be found in the following references:

- AISC 342 [77];
- ASCE/SEI 41-17 [78].

6. Responsibilities of the holder of stock

The organisation holding the reclaimed steel stock has important responsibilities in relation to the examination and testing of the steelwork, including maintaining the grouping of reclaimed members, keeping of comprehensive records and formal declarations of material properties when the reclaimed steelwork is distributed into the supply chain.

A listing of the necessary records is provided in Annex B.

6.1 Member grouping – test unit

Reclaimed steel members are to be considered as a group, provided they are from the same original source structure and meet the following requirements:

- Structural steel erected after 1970;
- Of the same serial size;
- Same structural function, e.g. rafters, floor beams, columns, bracings, etc.;
- Identical detailing (length, connections, etc.).
- Local stiffeners are not considered as detrimental for grouping.

If steelwork originally manufactured to an alternative specification/product standard (other than the EN standards), is to be placed on the market (see Section 2.3), material manufactured to different product standards should not be mixed within a group – the source and manufacturing standard of all material in a group should be consistent.

A group should comprise a maximum of 20 tonnes. Several groups of 20 tonnes will be required if large numbers of the same member are reclaimed. Grouping in this way allows certain material characteristics to be established for the group by testing one or more representative members from the group.

In this protocol, the concept of a ‘group’ has special significance, as outlined above. In product standards such as EN 10025-2, a similar term is ‘test unit’, indicating a collection of steel products of a specified total maximum weight of the same form, grade and quality and delivery condition. A ‘test unit’ can contain products of various thickness, whereas in this protocol, a ‘group’ is limited to members of the same serial size. In product standards, tests are specified to be undertaken from samples in the test unit; in this protocol, tests are specified to be undertaken from samples in the group.

6.2 Records

Records must be maintained for each group of reclaimed structural steel members, including:

- Details of the source structure;
- Unique identification of the group to which reclaimed members belong;
- Unique identification of every single element within the group;
- Records of physical inspection, including tolerances on cross-section and bow imperfections;
- Hardness test result and consequent material grade for each individual member;
- Destructive tensile test results for yield strength, ultimate strength and elongation;
- Non-destructive and destructive tests to determine the chemical composition and CEV;
- Any assumed material properties such as sub-grade or heat treatment delivery conditions.

6.3 Declarations

When reclaimed steelwork is distributed into the supply chain, it must be accompanied by a formal declaration, following the requirements of EN 1090-2 section 5.1.

The declaration must make clear which properties have been assumed, and which have been determined by test, noting that the determination is by group and in accordance with this protocol.

7. Test programmes

7.1 Introduction

This section describes the tests to be undertaken by the holder of the reclaimed steelwork. It is required that the company holding the stock maintains appropriate records of test results, and makes appropriate formal declarations of the test results when the steel is sold.

A listing of the data to be recorded is given in Annex C.

Details of the testing requirements are presented in Annex E to Annex H, as shown in *Table 7.1*.

Table 7.1*. Testing requirements*

Characteristic to be determined	**Annex**
Yield strength, ultimate strength and elongation	Annex E
Impact toughness (if required)	Annex F
Product analysis to determine CEV	Annex G
Section dimensions and member straightness	Annex H

The different testing procedures are:

- Minimal testing;
- Comprehensive testing.

Minimal testing is not intended to determine unknown material characteristics, but instead to make sure that the available documentation matches the related steelwork. Comprehensive testing is intended to re-certify the reclaimed steel according to EN1090-2 section 5.1.

The minimal testing requirements can be applied to Class A steel but is not mandatory. Comprehensive testing is related to Class B structural reclaimed steelwork, allowing for re-certification and consequent CE marking of the steelwork.

A summary of the recommended testing procedures is shown in *Table 7.2*.

Table 7.2*. Testing procedures*

Type of material testing	**Steel class**	**Documentation**	**Purpose**	**Relevant Annexes**
Minimal	Class A	Available	Confirm traceability of materials	E.3, G.2
Comprehensive	Class B	Not-available	Re-certification of the reclaimed steel	E.3, E.7, G.2, G.3 H.1, H.3

7.2 Minimal testing

Minimal testing is intended for the cases where material documentation is available (Class A steel) or to perform a preliminary assessment of existing steelwork. Minimal testing can also be used as part of a preliminary assessment as described in section 5.3.2.

The optional minimal testing is intended to confirm that a certain existing material documentation is related to a certain group of steel elements. Only non-destructive tests are recommended. A summary of the minimal testing procedure is presented in *Table 7.3*.

It should be noted that this procedure is intended to "new" steelwork for which documentation is available.

Table 7.3. *Recommendations for minimal testing*

Characteristic to be determined	**Type of testing**	**Percentage of elements to be tested**	**Annex**
Tensile and yield strength	Non-destructive	10% - with a minimum of 3 tests per group.	E.3
Chemical composition (CEV)	Non-destructive		G.2

7.3 Comprehensive testing

The recommendations for comprehensive testing require 100% non-destructive testing of the reclaimed structural members in combination with non-statistical or statistical destructive testing.

The non-destructive testing of all reclaimed members establishes that a group of members (see Section 6.1) can be represented by destructive test results from one or more representative members from the group.

Non-statistical testing requires just one destructive test, taken from a member in each group, to confirm the results obtained from the non-destructive tests. Non-statistical testing is recommended for Consequence class 1 or 2 structures. Non-statistical testing is equivalent to the requirements for 'new' steel specified in the product Standard.

Statistical testing requires more destructive testing to assess material characteristics in accordance with EN 1990. Statistical testing is recommended for reclaimed steel to be used in Consequence class 3 buildings, or when the provenance or quality of the original source material is considered to be unreliable. Statistical testing exceeds the requirements for 'new' steel specified in the product Standard.

Table 7.4 relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition to Consequence class.

Table 7.4. Testing approach related to Consequence class [68].

Consequence class	**NDT to establish yield strength, ultimate strength and CEV**	**Minimum number of DT to establish yield strength, ultimate strength and CEV and elongation**	**Acceptance approach**
CC1	All members to be subject to non-destructive tests	1	Non-statistical (maximum value of CEV)
CC2		1	Non-statistical (maximum value of CEV)
CC3		3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)

7.4 Identification, inspection documents and traceability

Clause 5.2 in EN 1090-2 states that: “The properties of supplied constituent products shall be documented in a way that enables them to be compared to the specified properties. Their conformity with the relevant product standard shall be checked in accordance with Cl 12.2.”

Inspection documents previously/also known as mill or test certificates, are supplied with all new rolled steel sections and plate supplied to the steelwork contractor. EN 10204 [72] defines the different types of inspection documents that include Type 2.1, 2.2, 3.1 and 3.2 certificates.

An important distinction exists between specific and non-specific inspection certificates.

- **Non-specific inspection** is defined (in EN 10204) as inspection carried out by the manufacturer in accordance with his own procedures to assess whether products defined by the same product specification and made by the same manufacturing process, are in compliance with the requirements of the order or not. Types 2.1 and 2.2 are based on non-specific inspection. The products inspected are not necessarily the products actually supplied.
- **Specific inspection** is defined as inspection carried out, before delivery, according to the product specification, on the products to be supplied or on test units of which the products supplied are part, in order to verify that these products are in compliance with the requirements of the order. Type 3.1 and 3.2 inspection documents are based on specific inspection. A type 3.2 certificate means that products where tested by a third-party accredited entity.

The type of inspection document required for (new) hot-rolled structural steels is set out in Table B.1 in EN 10025-1. Only the steel manufacturer can provide an inspection document to EN 10204. However, clause 12.2.1 of EN 1090-2 states that:

“Documents supplied with constituent products in accordance with the requirements of Clause 5 shall be checked to verify that the information on the products supplied matches those in the component specification. These documents include inspection certificates, test reports, declaration of compliance as relevant for plates, sections, hollow sections, welding consumables, mechanical fasteners, studs etc.”.

Test reports and declarations of compliance can be provided by the stockholder, not just by the original manufacturer. EN 1090-2 also gives requirements for inspection documents for metallic products in Table 1. It is clear that if the inspection is intended to guarantee a minimum characteristic yield strength, an inspection document 3.1 is needed as a minimum requirement.

For reclaimed steel, as group characteristics are justified for the group of reclaimed elements itself, the documentation provided by the stockholder will provide the same level of reliability of a 3.1 or 3.2 certificate. If destructive tests are performed by an external accredited laboratory, a document equivalent to a certificate 3.2 can potentially be issued.

Clause 5.2 in EN 1090-2 states that: “For EXC3 and EXC4, constituent products shall be traceable at all stages from receipt to hand over after incorporation in the works. This traceability may be based on records for batches of product allocated to a common production process, unless traceability for each individual constituent product is specified. For EXC2, EXC3 and EXC4, if differing grades and/or qualities of constituent products are in circulation together, each individual constituent product shall be designated with a mark that identifies its grade and its quality. Methods of marking shall be in accordance with that for components given in 6.2 (EN1090-2). If marking is required, unmarked constituent products shall be treated as nonconforming product.”.

The distinction between Execution Class 2 and 3 is important in the context of traceability and identification of steel products. Note that EXC2 is the most common execution class for most buildings.

Cl 6.2 in EN 1090-2 addresses identification of steel components and states: “At all stages of manufacturing each piece or package of similar pieces of steel components shall be identifiable by a suitable system. Identification may be achieved as appropriate by batching or by the shape and the size of the component or by the use of durable and distinguishing marks applied in a way not producing damage. Chiselled notches are not permitted.”.

To deal with reclaimed steel, it is essential that the stockist implement an efficient component tracing system and digital records for each individual member and group. More information about data records and traceability can be found in Annex C.

8. Fabrication issues

8.1 General comments

All fabricated steelwork should conform to the requirements of EN 1090-2.

8.2 Existing coatings on reclaimed steelwork

In most situations, it is envisaged that any existing coatings on reclaimed steelwork should be entirely removed prior to fabrication. The reuse of steelwork with its original protection is likely to be limited to situations when the entire structure is dismantled, relocated and reconstructed, largely in its original form.

If the reuse of steelwork with its existing corrosion protection is contemplated, the following issues should be considered:

- Existing corrosion protection systems are likely to need remedial work after dismantling the structure, and after any fabrication activity,
- Existing corrosion protection systems might contain hazardous substances, prohibited under current legislation,
- Although corrosion protection systems for internal steelwork might be more durable than originally anticipated, the original level of protection is likely to have diminished and to be less than recommended under current guidance.

Fire protection coatings are highly sensitive to humidity and their specification is uniquely linked to the original member. For both of these reasons, no reliance should be placed on existing fire protection coatings.

For the cases where the existing coating system needs to be removed, the following international standards may be used:

- EN ISO 8501: Visual assessment of surface cleanliness [41];
- EN ISO 8502: Tests for the assessment of surface cleanliness [42];
- EN ISO 8503: Surface roughness characteristics of blast-cleaned steel substrates [43];
- EN ISO 8504: Surface preparation methods [44].

The coating system shall be defined according to EN ISO 12944-2 [39] and EN ISO 12944-5 [40].

For the evaluation of degradation of coatings, ISO 4628 which is divided into 9 parts, can be used:
- ISO 4628-1: Part 1: General introduction and defect designation system [79]
- ISO 4628-2: Part 2: Assessment of degree of blistering [80]
- ISO 4628-3: Part 3: Assessment of degree of rusting [81]
- ISO 4628-4: Part 4: Assessment of degree of cracking [82]
- ISO 4628-5: Part 5: Assessment of degree of flaking [83]
- ISO 4628-6: Part 6: Assessment of degree of chalking by tape method [84]
- ISO 4628-7: Part 7: Assessment of degree of chalking by velvet method [85]
- ISO 4628-8: Part 8: Assessment of degree of delamination and corrosion around a scribe [86]
- ISO 4628-10: Part 10: Assessment of degree of filiform corrosion [87]

8.3 Reclaimed members with corrosion

High levels of corrosion are not accepted as geometric properties of the cross section may be compromised. However, small levels of localized corrosion may be accepted if the geometric properties of the cross section are not diminished more than 5% of the minimum thicknesses specified by the product standard of manufacturers tables [32]. The 5% allowance shall be added to geometric tolerances.

For other cases, where corrosion reduces considerably the thickness of a plate, measured thicknesses may be used for structural design purposes.

The evaluation of the effects of corrosion shall be measured after appropriate surface treatment according to EN ISO 12944-4 [46].

8.4 Bolt holes and welds in reclaimed steel

The reuse of members with holes for structural bolts is permitted if all geometric and design requirements according to EN 1993-1-1 and EN 1993-1-8 [45] are fulfilled.

If bolt holes are located within the critical cross-section and reduce the cross-section by more than 15%, the net cross-sectional properties should be used in member verification.

As a detailing recommendation for reclaimed steel with existing holes, new connections within 100 mm of existing holes should be avoided.

If present, larger holes, *e.g.* for the passage of services, must be assessed on an individual basis during member verification.

In general, it is recommended that redundant welded fittings, *e.g.* stiffeners or cleats, need not be removed.

8.5 Existing connections

Special care is needed if existing connections are to be re-used. In particular, any welding should be subject to careful inspection and testing.

The steel grade of connecting plates and other fittings should be assessed by non-destructive tests following the recommendations in Appendix C. The steel elongation is assumed to be at least equal to that obtained for the main structural members.

As a general recommendation, at least the same amount of weld testing required by EN 1090-2 (Table 24) should be applied to reclaimed steel elements. Visual inspection of 100% of the welds is mandatory.

Bearing in mind that values from Table 24 of EN 1090-2 are seen as a minimum, the following minimum number of connections to be tested may be also considered:

Table 8.1**.** *Suggested minimum percentage of welds to be tested [47].*

Total number of connections	**Number of connections to be tested**	**Total %**
6	3 (minimum)	50%
10	4	40%
15	5	33%
20	6	30%
30	8	27%
40	10	25%
50	12	24%
75	16	21%
100	20	20%
200	30	15%
300	40	13%
500	60	12%
1000	100	10%
2000	150	8%

Example:

Consider a group of haunched rafters from a portal framed structure with pinned bases subjected to gravity loading. Four types of critical welds may be identified (see Figure 8.1):

1. Welds between the beam web and the end plate on eaves connections;
2. Eaves connections: welds between the top flange of the rafter and the end plate;
3. Apex connection: welds between of the bottom flange of the rafter/haunch and the end plate;
4. Welds between the haunch/beam web and the end plate on apex connections.

Each one of these welds represent a possible test sample. To test 15% of the welds, from a test unit with 50 rafters from 25 frames (200 critical connections, see *Table 8.1*), 30 welds should be tested (that respects a minimum of 30 welds inspected). These 30 welds should be selected randomly from the critical welds identified in connections 1, 2, 3 or 4 above. Every weld to be tested should ideally be selected from different elements.

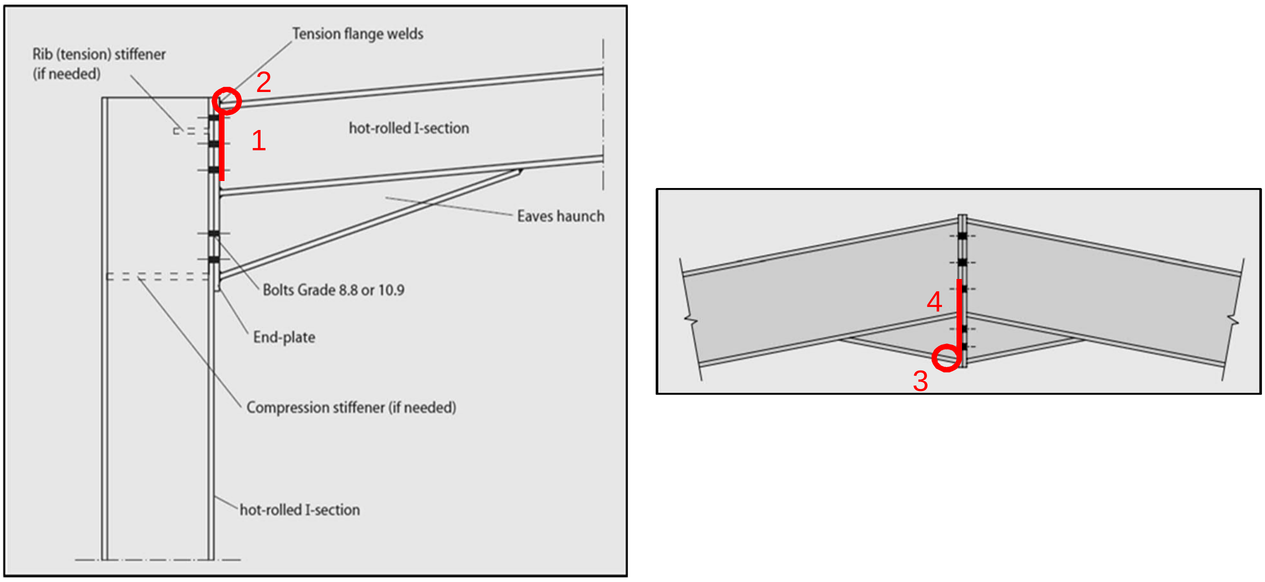


Figure 8.1 – Examples of critical weld details that can be tested.

References

[1] EN 1090-1:2009+A1:2011. Execution of steel structures and aluminium structures. Requirements for conformity assessment of structural components, BSI;
[2] EN 1993-1-1:2005+A1:2014. Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings, BSI;
[3] EN 1090-2:2018. Execution of steel structures and aluminium structures Technical requirements for steel structures, BSI;
[4] EN 1990:2002+A1:2005. Eurocode. Basis of structural design, BSI;
[5] PD CEN ISO/TR 15608:2017. Welding. Guidelines for a metallic material grouping system, BSI;
[6] EN 1993-1-10:2005. Eurocode 3. Design of steel structures. Material toughness and through-thickness properties, BSI;
[7] EN 10365:2017. Hot rolled steel channels, I and H sections. Dimensions and masses, BSI;
[8] EN 10034:1993. Structural steel I and H sections. Tolerances on shape and dimensions, BSI;
[9] EN 10024:1995. Hot rolled taper flange I sections. Tolerances on shape and dimensions, BSI;
[10] EN 10279:2000. Hot rolled steel channels. Tolerances on shape, dimension and mass, BSI;
[11] EN 10056-1:2017. Structural steel equal and unequal leg angles. Dimensions, BSI;
[12] EN 10056-2:1993. Specification for structural steel equal and unequal angles. Tolerances on shape and dimensions, BSI;
[13] EN 10055:1996. Hot rolled steel equal flange tees with radiused root and toes. Dimensions and tolerances on shape and dimensions, BSI;
[14] EN 10029:2010. Hot-rolled steel plates 3 mm thick or above. Tolerances on dimensions and shape, BSI;
[15] EN 10051:2010. Continuously hot-rolled strip and plate/sheet cut from wide strip of non-alloy and alloy steels. Tolerances on dimensions and shape, BSI;
[16] EN 10017:2004. Steel rod for drawing and/or cold rolling. Dimensions and tolerances, BSI;
[17] EN 10058:2018. Hot rolled flat steel bars and steel wide flats for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
[18] EN 10059:2003. Hot rolled square steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
[19] EN 10060:2003. Hot rolled round steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
[20] EN 10061:2003. Hot rolled hexagon steel bars for general purposes. Dimensions and tolerances on shape and dimensions, BSI;
[21] EN 10210-2:2019. Hot finished steel structural hollow sections. Tolerances, dimensions and sectional properties, BSI;
[22] EN 10219-2:2019. Cold formed welded steel structural hollow sections. Tolerances, dimensions and sectional properties, BSI;
[23] EN 10219-1:2006. Cold formed welded structural hollow sections of non-alloy and fine grain steels. Technical delivery requirements
[24] EN 10210-1:2006. Hot finished structural hollow sections of non-alloy and fine grain steels. Technical delivery requirements, BSI;
[25] EN 10025-2:2019. Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, BSI;
[26] EN 10025-3:2019. Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels, BSI;

[27] EN 10025-4:2019. Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels, BSI;
[28] BS 15:1948. Structural steel, BSI;
[29] BS 4360-2:1969. Specification for weldable structural steels metric units, BSI;
[30] SCI P419 Brittle fracture selection of steel sub-grade to EN 1993-1-10;
[31] PD 6695-1-10 Recommendations for the design of structures to BS EN 1993-1-0, BSI, 2009;
[32] SIA 269/3:2011. Existing structures – Steel structures, SIA Zurich.
[33] National Structural Steelwork Specification, BCSA Publication No. 57, 1st edition, 1989;
[34] BS 449-2:1969. Specification for the use of structural steel in building. Metric units, BSI;
[35] SIA 263:2013. Construction en acier, SIA Zurich;
[36] European Commission, EU Construction & Demolition Waste Management Protocol, September 2016
[37] European Commission, Guidelines for the waste audits before demolition and renovation works of buildings, May 2018,
[38] Kamrath, P., Sansom, M., Ungureanu, V., Hradil, P., Safe and efficient deconstruction, Deliverable D2.1 of PROGRESS project, May 2020.
[39] EN ISO 12944-2:2017. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Classification of environments, BSI;
[40] EN ISO 12944-5:2018. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Protective paint systems, BSI;
[41] EN ISO 8501, Preparation of steel substrates before application of paints and related products. Visual assessment of surface cleanliness. Parts 1 to 4, BSI;
[42] EN ISO 8502, Preparation of steel substrates before application of paints and related products. Tests for the assessment of surface cleanliness. Parts1 to 12, BSI;
[43] EN ISO 8503, Preparation of steel substrates before application of paints and related products. Surface roughness characteristics of blast-cleaned steel substrates. Parts 1 to, BSI;
[44] EN ISO 8504, Preparation of steel substrates before application of paints and related products. Surface preparation methods. Parts 1 to 3, BSI;
[45] EN 1993-1-8:2005. Eurocode 3. Design of steel structures. Design of joints, BSI;
[46] EN ISO 12944-4:2017. Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Types of surface and surface preparation, BSI;
[47] FEMA 352:2000. Recommended Postearthquake Evaluation and Repair Criteria for Welded. Steel Moment-Frame Buildings; Federal Emergency Management Agency USA.
[48] EN ISO 19650-1:2018. Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling.
[49] EN 17412. Building Information Modelling. Level of Information Need. Concepts and principles. Part 1: Concepts and principles;
[50] EN ISO 6507-1:2018. Metallic materials. Vickers hardness test. Test method, BSI.
[51] EN ISO 6507; all parts. Metallic materials. Vickers hardness test, BSI.
[52] EN ISO 6508; all parts. Metallic materials. Rockwell hardness test, BSI.
[53] EN ISO 6505; all parts. Metallic materials. Brinell hardness test, BSI.
[54] An Evaluation of Mechanical Properties with the Hardness of Building Steel Structural Members for Reuse by NDT Masanori Fujita * and Keiichi Kuki; Metals 2016;
[55] EN ISO 377:2017. Steel and steel products. Location and preparation of samples and test pieces for mechanical testing, BSI.
[56] EN ISO 6892-1:2016. Metallic materials. Tensile testing. Method of test at room temperature, BSI.

[57] EN ISO 148-1:2016. Metallic materials. Charpy pendulum impact test. Test method, BSI.
[58] EN ISO 14284:2002. Steel and iron. Sampling and preparation of samples for the determination of chemical composition, BSI.
[59] SCI P138 – "Appraisal of existing Iron and Steel Structures", M. Bussell, 1997.
[60] BCSA - "Historical structural steelwork handbook", Publication 11/84, W. Bates, 1984.
[61] EN 10025-1:2004; Hot rolled products of structural steels. General technical delivery conditions, BSI.
[62] EN 10025-2:2019; Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, BSI.
[63] EN 10025-3:2019; Hot rolled products of structural steels. Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels, BSI.
[64] EN 10025-4:2019; Hot rolled products of structural steels. Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels, BSI.
[65] Standardisation of safety assessment procedures across brittle to ductile failure modes (SAFEBRICTILE) RFCS project RFSR-CT-2013-00023;
[66] EN ISO 18265:2013 Metallic materials. Conversion of hardness values, BSI.
[67] Pavlina, E.J., Van Tyne, C.J.; Correlation of Yield Strength and Tensile Strength with Hardness for Steels; ASM International; JMEPEG (2008) 17:888–893;
[68] SCI P427 – Structural Steel Reuse: assessment, testing and design principles, The Steel Construction Institute, 2019;
[69] BS EN ISO 9001 – Quality management systems. Requirements; 2015, BSI.
[70] ISO 19011 – Guidelines for auditing management systems; 2018, BSI.
[71] BS EN ISO 9712 – Non-destructive testing. Qualification and certification of NDT personnel, 2012, BSI.
[72] BS EN 10204; Metallic products. Types of inspection documents, 2004;
[73] BS 2645-2:1956; Tests for use in the approval of welders. Manual metal arc and oxy-acetylene welding of mild steel and low alloy steel pipelines and pipe assemblies, BSI;
[74] Gulvanessian H, Calgar JA, Holický M (2012). Designer's guide to Eurocode: basis of structural design EN 1990, ICE Publishing, Thomas Telford, London (2nd edition).
[75] Steenbergen RDJM, Vrouwenvelder ACWM (2010). Safety philosophy for existing structures and partial factors for traffic loads on bridges, Heron 55(2), 123-140.
[76] Matthews S (2012). Structural appraisal of existing buildings, including for a material change of use, Part 3: Structural appraisal procedures, BRE-DG 366, Building Research Establishment, UK.
[77] AISC 342 – 2019 (draft): "Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings"
[78] ASCE/SEI 41-17 – 2017: "Seismic Evaluation and Retrofit of Existing Buildings"
[79] BS EN ISO 4628-1:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. General introduction and designation system;
[80] BS EN ISO 4628-2:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of blistering, BSI;
[81] BS EN ISO 4628-3:2016, Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of rusting, BSI;

[82] BS EN ISO 4628-4:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of cracking, BSI;

[83] BS EN ISO 4628-5:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of flaking, BSI;

[84] BS EN ISO 4628-6:2011; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of chalking by tape method, BSI;

[85] BS EN ISO 4628-7:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of chalking by velvet method, BSI;

[86] BS EN ISO 4628-8:2012; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of delamination and corrosion around a scribe or other artificial defect, BSI;

[87] BS EN ISO 4628-10:2016; Paints and varnishes. Evaluation of degradation of coatings. Designation of quantity and size of defects, and of intensity of uniform changes in appearance. Assessment of degree of filiform corrosion;

[88] PROGRESS: Provisions for greater steel reuse; Research Fund for Coal and Steel Grant agreement No: 747847; Deliverable 2.1; Safe and efficient deconstruction, 2019;

[89] PROGRESS: Provisions for greater steel reuse; Research Fund for Coal and Steel Grant agreement No: 747847; Deliverable 3.1; Summary of design practices for reusable buildings and products, 2019;

[90] BS EN 1998-3:2005; Eurocode 8. Design of structures for earthquake resistance. Assessment and retrofitting of buildings;

[91] *BS EN ISO 19650-1*:2018; Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling; BSI.

[92] *BS EN ISO 19650-2*:2018; Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling; BSI.

[93] prEN 17412 – Building information modelling – Level of information needed – concepts and principles;

[94] prEN ISO 23387-1 Building Information Modelling (BIM) — Data templates for construction objects used in the life cycle of any built asset — Concepts and principles;

[95] ISO/DIS 20887 – Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles requirements and guidance.

[96] ISO 19272:2015; Low alloyed steel — Determination of C, Si, Mn, P, S, Cr, Ni, Al, Ti and Cu - Glow discharge optical emission spectrometry (routine method); BSI, 2015.

[97] BS EN 13018:2016 Non-destructive testing. Visual testing. General principles; BSI;

[98] BS EN ISO 13385-1:2019; Geometrical product specifications (GPS). Dimensional measuring equipment. Design and metrological characteristics of callipers; BSI;

[99] BS EN ISO 13385-2:2011; Geometrical product specifications (GPS). Dimensional measuring equipment. Calliper depth gauges. Design and metrological characteristics, BSI;

[100] BS EN ISO 3452-1:2013; Non-destructive testing. Penetrant testing. General principles; BSI;

[101] BS EN ISO 23277:2015; Non-destructive testing of welds. Penetrant testing. Acceptance levels;

[102] BS EN ISO 15549:2019; Non-destructive testing. Eddy current testing. General principles, BSI;

[103] BS EN ISO 17643:2015; Non-destructive testing of welds. Eddy current examination of welds by complex plane analysis, BSI;
[104] BS EN ISO 17640:2018 Non-destructive testing of welds. Ultrasonic testing. Techniques, testing levels, and assessment
[105] BS EN ISO 17636; all parts; Non-destructive testing of welds. Radiographic testing. X- and gamma-ray techniques, BSI;
[106] BS EN ISO 17638:2016 Non-destructive testing of welds. Magnetic particle testing
[107] BS ISO 19272:2015; Low alloyed steel. Determination of C, Si, Mn, P, S, Cr, Ni, Al, Ti and Cu. Glow discharge optical emission spectrometry (routine method), BSI;
[108] BS EN 1090-4:2018; Execution of steel structures and aluminium structures. Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications, BSI;
[109] BS EN 10346:2015; continuously hot-dip coated steel flat products for cold forming. Technical delivery conditions, BSI;
[110] BS EN 10143:2006; continuously hot-dip coated steel sheet and strip. Tolerances on dimensions and shape;
[111] BS EN 13523-1:2017; Coil coated metals. Test methods. Film thickness, BSI;
[112] BS EN 13523-6:2002; Coil coated metals. Test methods. Adhesion after indentation, BSI;
[113] BS EN 13523-7:2014; Coil coated metals. Test methods. Resistance to cracking on bending (T-bend test), BSI;
[114] ASTM E112 – 13; Standard Test Methods for Determining Average Grain Size;
[115] CWA 15627:2007; Small punch test method for metallic materials, BSI;
[116] BS EN 1993-1-3:2006; Eurocode 3. Design of steel structures. General rules. Supplementary rules for cold-formed members and sheeting, BSI;
[117] CHETTOE, C.S., DAVEY, N. and MITCHELL, G.R. The strength of cast-iron girder bridges Journal of the Institution of Civil Engineers, 1943 to 44 22 (8), 243 to 307;
[118] TWELVETREES, W.N. Structural iron and steel Fourdrinier, 1900;
[119] ANGUS, H.T. Cast iron: physical and engineering properties (2nd edition) Butterworth, 1976;
[120] BS EN ISO 17637:2016; Non-destructive testing of welds. Visual testing of fusion-welded joints, BSI.
[121] DD ENV 1993-1-1:1992; Eurocode 3. Design of steel structures. General rules and rules for buildings (together with United Kingdom National Application Document), BSI;
[122] JRC - New European Technical Rules for the Assessment and Retrofitting of Existing Structures; 2015;
[123] Assessment criteria for Existing Structures; Nico P.M. Scholten; Prof. Ton C.W.M. Vrouwenvelder; Structural Engineering International 1/2010.
[124] ISO 13822:2010, Bases for design of structures - Assessment of existing structures;
[125] ISO/IEC 17025 Testing and calibration laboratories, 2017;
[126] BS EN 1561:2011; Founding. Grey cast irons, BSI.
[127] https://www.ym.fi/download/noname/%7BBDABB0AD-55DB-4B66-8F8C-AA6141A7B4E5%7D/153256; Circular Economy in the Construction Sector - Council Conclusions (adopted 28 November 2019); General Secretariat of the Council On: 28 November 2019; Brussels, 28 November 2019
[128] CWA 17316: 2018; Smart CE marking for construction products; CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels;
[129] Dorman Long & CO Ltd (1964). Handbook for constructional engineers, Fanfare Press Ltd, London, UK.
[130] The British Constructional Steelwork Association (1994). National structural steelwork specification for building construction, 3th Ed., 203, London, UK
[131] BS 4 Part 1;1962. Specification for structural steel section; Part 1: Hot Rolled sections;
[132] https://www.youtube.com/watch?v=NCORhUAfgcY;

[133] BS EN 14509:2013; Self-supporting double skin metal faced insulating panels. Factory made products;
[134] CEN – European Committee for Standardisation (2004). EN 1998 Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings (incorporating CEN corrigenda July 2009, Jan. 2011, and March 2013, and CEN amendment A1:2013), Brussels, Belgium.
[135] SAMCO Final Report 2006 F08b Guideline for Structural Health Monitoring F08b Guideline for Structural Health Monitoring Dir. u. Prof. Dr. W. Rücker, Dipl.-Ing. F. Hille, Dipl.-Ing. R. Rohrmann Federal Institute of Materials Research and Testing (BAM), Division VII.2 Buildings and Structures Unter den Eichen 87, 12205 Berlin, Germany;
[136] Probabilistic Model Code, Parts 1 to 4, Basis of design, Load and resistance models, Examples, JCSS, 2001-2002.
[137] JRC - New European Technical Rules for the Assessment and Retrofitting of Existing Structures. Prospect for CEN Guidance, 2015.
[138] JRC - Assessment of Existing Steel Structures: Recommendations for Estimation of Remaining Fatigue Life; B. Kühn, M. Lukić, A. Nussbaumer, H.-P. Günther, R. Helmerich, S. Herion, M.H. Kolstein, S. Walbridge, B. Androic, O. Dijkstra, Ö. Bucak; Joint Report Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250) Editors: G. Sedlacek, F. Bijlaard, M. Géradin, A. Pinto and S. Dimova Background documents in support to the implementation, harmonization and further development of the Eurocodes; 2008.
[139] Innovative methods for the assessment of existing structures, Dimitris Diamantidis, University of Applied Sciences in Regensburg, Faculty of Civil Engineering Milan Holický, Czech Technical University in Prague, Klokner Institute, 2013.
[140] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 1 Requirements for structural appraisal; Stewart Mathews; 2012;
[141] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 2 Preparing for structural appraisal; Stewart Mathews; 2012;
[142] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 3 Structural appraisal procedures; Stewart Mathews; 2012;
[143] BRE DIGEST DG366; Structural Appraisal of existing buildings Part 4 Additional considerations and information sources; 2012;
[144] Appraisal of Existing Structures, Institution of Structural Engineers, 2010;
[145] NEN 8700 - Assessment of existing structures in case of reconstruction and disapproval – Basic Rules, 2011;
[146] NEN 8701 Assessment of existing structures in case of reconstruction and disapproval – Actions, 2011;
[147] Eurocodes and structural safety of the existing buildings – considering the publication of the Dutch NEN 8700, Dr. Nico P.M. Scholten (Expertcenter Regulations in Building); Prof.Ton C.W.M. Vrouwenvelder (TNO Built Environment and Geosciences); 4th International Conference CIVIL ENGINEERING`13 Proceedings Part II Building and renovation, 2013.
[148] Assessment criteria for Existing Structures; Nico P.M. Scholten (Expert center Regulations in Building); Prof.Ton C.W.M. Vrouwenvelder (TNO Built Environment and Geosciences); Structural Engineering International 1/2010.
[149] Allen D E. Limit states criteria for structural evaluation of existing buildings. Canadian Journal of Civil Engineering, 1991, 18 (6) 995–1004.
[150] Diamantidis D and Bazzuro P. Safety acceptance criteria for existing structures. Workshop on ‘Risk Acceptance and Risk Communication’, Stanford University, US, March 2007.

[151] Steenbergen R D J M and Vrouwenvelder A C W M. Safety philosophy for existing structures and partial factors for traffic loads on bridges. Heron, 2010, 55 (2) 123–140.
[152] Joint Committee on Structural Safety (JCSS). Probabilistic assessment of existing structures, RILEM Report 32, edited by D Diamantidis. Cachan, France, RILEM Publications s.a.r.l., 2001.
[153] JCSS, Background documentation Eurocode 1 ENV Part 1: Basis of Design, ECCS, Report No 94, 1996.
[154] BRE Report 511 "Handbook for the Structural Assessment of Large Panel System (LPS) Dwelling Blocks for Accidental Loading" defines revised performance requirements (updating those given in MHLG Circulars 62/68 and 71/ 68) and provides technical guidance on structural appraisal procedures that may be employed.
[155] DMRB - "Design Manual for Roads and Bridges" standards: Volume 0 (Introduction and General Requirements), Volume 1 (Highway Structures: Approval Procedures and General Design), Volume 2 (Highway Structures: Design (Substructures and Special Structures), Materials) and Volume 3 Highway Structures: Inspection and Maintenance). http://www.standardsforhighways.co.uk/ha/standards/dmrb/index.htm
[156] Reliability analysis for structural design; Milan Holický, Sun Press, 2009;
[157] Commentary and worked examples to EN 1993-1-10 "Material toughness and through thickness properties" and other toughness oriented rules in EN 1993; G. Sedlacek, M. Feldmann, B. Kühn, D. Tschickardt, S. Höhler, C. Müller, W. Hensen, N. Stranghöner W. Dahl, P. Langenberg, S. Münstermann, J. Brozetti, J. Raoul, R. Pope, F. Bijlaard Joint Report Joint Report Prepared under the JRC – ECCS cooperation agreement for the evolution of Eurocode 3 (programme of CEN / TC 250) Editors: M. Géradin, A. Pinto and S. Dimova Background documents in support to the implementation, harmonization and further development of the Eurocodes;
[158] STAS 767/0-88 (1988). Steel Structures. General technical requirements for quality of non-industrial, industrial and agricultural buildings. Romanian Institute for Standardization (including the previous version STAS 767/0-77);
[159] C150-99 (1999). Code for the quality of welded steel joints in civil, industrial and agricultural constructions, MLPAT – Ministry for Public Works and Territorial Administration (including the previous versions C150-84 and C150-72).
[160] Guideline for Structural Condition Assessment of Existing Buildings, ASCE Standard Guideline, SEI/ASCE 11-99;
[161] Guideline SIA 462:1994 Assessment of the structural safety of existing buildings, Swiss Society of Engineers and Architects SIA, Zurich, Switzerland, 1994;
[162] Basics for assessment of existing structures (Milan Holický, Editor), Klokner Institute, Czech Technical University in Prague, 2013.
[163] REAE - Regulamento de Estruturas de Aço para Edifícios - Decreto n.º 46160, Diário do Governo n.º 15/1965, Série I de 1965-01-19, 1965.

Annex A Design recommendation for Classes A & B reclaimed steel

A.1 ENV 1993-1-1 background

The data used to develop the Eurocode material factors reviewed material test results taken between 1969 and 1989. In ENV 1993-1-1, a value of γ_{M1} = 1.10 was initially proposed, with values of γ_{M0} = 1.00 for major axis bending and γ_{M0}= 1.10 for minor axis bending. The introduction of a different approach for lateral torsional buckling curves allowed the reduction from γ_{M1} = 1.10 to γ_{M1} =1.00. Later, it was proposed that by considering strain hardening, it was possible to justify the use of γ_{M0} = 1.00 for both major and minor axis bending. These are the material factors currently recommended by the Eurocode.

A.2 The value of γ_{M1}

The buckling resistance of a member is based on the design strength, the cross-sectional properties and a choice of buckling curve. The choice of buckling curve is associated with an initial imperfection which allows for physical imperfections, residual stresses, cross sectional variations, *etc*.

The procedures recommended in this protocol are intended to ensure that the assumed design strength is conservative. Members must meet the dimensional and straightness tolerances in EN 1090-2, meaning that the choice of buckling curve is the same for both new and reclaimed steel. Since the reclaimed steel is limited to steel used in construction after 1970, it is assumed that the residual stresses will not be significantly different from the stresses present when the design models in ENV 1993-1-1 were developed and calibrated.

Nevertheless, some degree of uncertainty is inevitably associated with the use of reclaimed steelwork. In addition to member straightness, other imperfections in the cross sections or torsional imperfections can contribute to a reduced resistance due to the increase of second order effects. Even if all geometric tolerances are satisfied, a degree of uncertainty will remain as the assessment processes are likely to be less reliable than those undertaken for the continuous production of new steel today. A conservative value of γ_{M1} is suggested in this protocol to address this uncertainty.

The recommended value for $\gamma_{M1,mod}$ is based on increasing the target reliability index (β) from 3.8 to 4.3 for a 50-year reference period (see Table B2 of EN 1990). The recommendation for $\gamma_{M1,mod}$ (for all steel grades) is based on principles expressed in EN 1990 with a conservative assumption for the partial factor associated with the uncertainty of the resistance model (γ_{Rd}=1.15).

The recommended value of $\gamma_{M1,mod}$ for Class B reclaimed steel (or Class A reclaimed steel previously erected) is given by:

$\gamma_{M1,mod} = k_{\gamma M1} \times \gamma_{M1,}$ where $k_{\gamma M1}$ = 1.15. For the UK and based on the recommended value of γ_{M1} in EN 1993-1-1, $\gamma_{M1,mod}$ = 1.15.

Adoption of $\gamma_{M1,mod}$ will only have an impact on the design of members where buckling is the critical verification. For members subject to buckling, it might be necessary to introduce additional intermediate restraints if the original buckling resistance is to be maintained in the redesigned reclaimed steel member.

For the cases where in situ reuse is applied, i.e., steelwork is not disassembled and re-erected, the value of $k_{\gamma M1}$ = 1 is recommended for steelwork erected after 1970.

A.3 The values of γ_{M0} and γ_{M2}

As ENV 1993-1-1 was based on tests performed on steel produced as early as 1969, it is reasonable to assume that there are no concerns with cross section resistance for reclaimed steel from the subsequent decades.

No change in the recommended value for γ_{M0} or γ_{M2} is therefore proposed for verification of cross sections in accordance with EN 1993-1-1. The cross-sectional resistance depends on dimensional characteristics and material strength, which have both been verified/justified for every reclaimed member.

A.4 Consequence class 1 structures

The recommended value of $k_{\gamma M1} = 1.15$ should be used for Consequence class 1 structures.

The recommended values of $k_{\gamma M1}$ should be used for Consequence class 1 structures such as agricultural buildings. It is recommended that the factor $K_{FI} = 0.90$ (see EN 1990 Table B3) is applied to all partial factors if designing a Consequence class 1 structure using reclaimed steel.

A.5 Consequence class 2 structures

The recommended value of $k_{\gamma M1} = 1.15$ should be used for Consequence class 2 structures.

A.6 Consequence class 3 structures

The recommended value of $k_{\gamma M1} = 1.15$ should be used for Consequence class 3 structures.

Although EN 1990 allows designers to apply the factor $K_{FI} = 1.10$ to all partial factors (see EN 1990 Table B3) when designing a Consequence class 3 structure, normal practice in the UK is to increase design supervision and inspection during execution (Tables B4 and B5 of EN 1990) as an alternative to the K_{FI} factor.

Annex B Design recommendation for Class C reclaimed steel

B.1 Introduction

For the cases where CE marking is not mandatory, conservative assumptions about the material properties may be used for the analysis and design. However, this approach is only recommended for Consequence class 1 structures (CC1). The conservative material properties provided in Table B.1 may be used.

Table B.1 – Recommended material properties for non-tested structural steel.

Material	Period of erection	f_y [N/mm^2]	f_u [N/mm^2]	G [N/mm^2]	E [N/mm^2]	ε_{uk} [%]	v	ρ [kg/m^3]	α_T $[10^{-6}/°_C]$
Steel – Members	Erected after 1970	235	360	81000	210000	25	0.30	7850	10
Steel – Welds	Erected after 1970	-	360	-	-	-	-	-	-

These values are proposed based on historical steel and iron data provided in Annex J.

Based on the building's age and location, local standards may be used to set the conservative value for yield strength. Check Annex I for details about withdrawn European product standards.

The visual appearance of old steel is described in Annex J.3.

B.2 The value of γ_{M1}

Please check section A.2.

B.3 The values of γ_{M0} and γ_{M2}

Please check section A.3.

B.4 Connections

If no testing is undertaken (Class C steel), the reuse scenario must ideally avoid welding procedures. Moment resisting connections are also not recommended as they usually require welding.

For the cases where welding procedures are mandatory, a value for the CEV of 0.51 may be assumed (this value is a reference from BS 4360 from 1969 [29]).

Non-destructive tests are recommended to assess the value of CEV.

B.5 Consequence class 1 structures

The recommended values of $k_{\gamma Mi}$ should be used for Consequence class 1 structures such as agricultural buildings. It is recommended that the factor K_{FI} = 0.90 (see EN 1990 Table B3) is applied to all partial factors if designing a Consequence class 1 structure.

Annex C Data records and information

C.1 Data records

The following data should be recorded and associated with each reclaimed structural member:

Building information:

- Building age, location;
- Form of construction, *e.g.* braced, continuous, *etc.*
- Any related information, such as drawings, modifications, records, etc.

Individual members:

- Section size,
- Length,
- Group (see Section 6.1),
- Member individual identification,
- Tolerance check (section dimensions and bow imperfections)
- Comments, *e.g.* stiffeners or fabricated features,
- Coating; Coating type (and thickness if determined); condition of coating,
- Material properties;

Material properties shall be determined by non-destructive tests and/or by destructive tests. The test results, together with any determined values, shall be recorded for the following properties:

- ✓ Yield and ultimate strengths (non-destructive and destructive tests),
- ✓ Elongation (destructive tests),
- ✓ Chemical composition (non-destructive and destructive tests),
- ✓ Carbon Equivalent Value (CEV),
- ✓ Impact toughness (by destructive tests, if required).

– Conservative assumptions may be made to define:

- ✓ Impact toughness (assumed, if not tested),
- ✓ Heat treatment (assumed).

– The product standard used to infer the relevant material properties shall be stated (e.g. EN 10025 or EN 10219).

Stockholder records:

- Stockholder details (name and other relevant information);
- Internal report/documentation number (based on stockholder records);
- Other quality records (testing laboratories, etc.).

Annex A from the deliverable D2.1 also gives recommendations for the data that should be recorded.

CWA 17316 [128] provides guidance for smart CE marking for construction products, mainly proposing an efficient way to trade and exchange information. CWA 17316 may be used to store the relevant information in a format that facilitates exchange between project actors and between stockholders and those actors.

C.2 Component tracking and digital information

A physical component tracking is often implemented during fabrication and erection processes. However, the component tracking is often lost and not preserved during the life time of the building. It is advised that a form of physical component tracking must be preserved during the lifetime of the building, linked with a digital model where the relevant building and member information can be kept. This measure will facilitate the application of reclaimed steelwork without the need for further testing.

Bar codes, QR codes or Radio frequency identification (RFI) provide an efficient and reliable method of component tracking. This technology can be used as a digital passport for each reclaimed member. It is also possible to store the relevant information needed for future life cycles in a simple QR code, bar code or RFID.

Annexes Figure 1. Examples of component tracking with RFID and QR codes.

The level of information that a 3D BIM model needs to accommodate is a responsibility of all project actors. The ISO standards BS EN ISO 19650-1 [91] and BS EN ISO 19650-2 [92] introduced the concept of level or information need (LOIN), for which is suggested that each project actor must define the relevant information to be stored for the purpose of the element on a specific project. Within the scope of the project, the concept will be discussed from a structural engineering point of view.

The following standards offer some general guidance to specify the LOIN of an element:

- prEN 17412 [93];
- prEN ISO 23387-1 [94];
- ISO/DIS 20887 [95].

However, these standards are rather general for the concept of LOIN. For the definition of LOIN, the actor should try to answer question related to the object such as “who”, “why”, “how”, “when” or relevant numerical quantities for a specific purpose. The process can be performed for topics such as responsibilities, material/product properties/characteristics and geometry, reusability, sustainability, health and safety, costs, structural analysis outcome, appearance/coating, on-site position, labelling, ID, linked documentation, etc.

Following, key concepts from a structural engineering point of view will be presented. These concepts are also generic and are only intended to point out a way forward for the procedure. The following categories for the information that can be stored are proposed:

Table C.2 Proposed information categories for the definition of the LOIN: general definition.

Context	For each life cycle: the context/time where/when the structural member has been used;
Project actors	For each life cycle: actors involved from relevant disciplines;
Purpose	For each life cycle: the purposes of the member;
Identification	For each life cycle: the identity of the structural steel member and its traceability to the digital information;
Structural design	For each life cycle: relevant design conditions and design outcome for the building and element;
Fabrication & erection	For each life cycle: records from fabrication and procedures and the quality of those procedures;
Provenance & characteristics	Full traceability of the member material, including records and certificates;

Table C.3 Proposed information categories for the definition of the LOIN: detail

Context	For each life cycle: project name and description, site name and address, construction date, etc.
Project actors	For each life cycle: architects, engineers, contractors, etc.
Purpose	Features such as load bearing, structural function (beam, column bracing), condition (permanent, temporary), etc.
Identification	For each life cycle: member unique identification number, location (say floor number, bloc number, building), and other relevant visual property (such as colour); Member ID, section serial size
Structural design	Building behaviour factor for seismic design, fire rating, critical temperature, fire protection thickness, UF (utilization factor), studs detailing (spacing, height, number/section, material, etc.), floor frequency, deflection (total and imposed), project loading (say total floor permanent and imposed loads), wind action (peak pressure), snow load, type of connections (say pinned, fixed or assumed elastic stiffness), etc.
Fabrication & erection	For each life cycle: fabrication company, fabrication date, standard for fabrication quality (say EN1090-2), any relevant fabrication records, erection company, erection date, any other relevant erection record;
Provenance & characteristics	New steel: producer, mill certificate identification/number/ID, material product standard (say EN10025-2 or EN10210-1), delivery condition according to EN 10204, steel grade and sub grade, through thickness quality (Z), heat treatment delivery condition, geometry product standards (say EN 10365 and EN 10034); Reclaimed steel: entity responsible for the re-certification (stockholder), reference standard (say EN10025-2 or EN10219-1), grade and subgrade, all necessary properties according to EN 1090-2 section 5.1 (measured/determined values), reference to the stockholder internal re-certification document number, element product standards (say EN 10365 and EN 10034), straightness according to EN 1009-2;

The following information may be used as a reference for reclaimed elements in a BIM model (example of a reclaimed steel member being reused on a second life cycle):

Table C.4 Key items for reuse while defined the level of information needed of a model.

Item	**Commentary**
Steel origin	“Reclaimed-UK” or “New-UK”
Date of first erection	1975
Local of first erection	Leeds
Steel Fabricator first erection	“Fabricator 1”
Structural design first application	“Consultants 1”
Date of second erection	2019
Local of second erection	London
Structural design second application	“Consultants 2”
Steel Fabricator second erection	“Fabricator 2”
Fabricator ID from second erection	“CL01”
Stockholder/manufacturer	This item can represent also the steel producer for new steel.
Stockholder/manufacturer certificate number	This item can represent also the material certificate number from the producer for new steel.
Steel grade and subgrade	“S355JR”, Exact wording as in the material standard.
Material in compliance with the standard	“EN10025-2” – This may not be applicable; for example, if the minimum elongation according to the code is not justified. Alternative would be EN1090-2 5.1
Design yield strength (N/mm^2)	355
Design tensile strength (N/mm^2)	470
Recorded yield strength (N/mm^2)	405
Recorded tensile strength (N/mm^2)	520
Recorded elongation at failure (%)	23
Measured Carbon Equivalent Value (CEV)	0.45
Profile size	IPE500, or as in the product standard.
Section Dimensions	“EN 10365”, or another relevant standard
Section Tolerances	“EN 10034”, or another relevant standard

Guidance form CWA 17316 may be used to facilitate the exchange information.

Some data from table C.5 can also be seen as important data to be store in a QR code for example as a permanent physical component tracking.

Table C.5 Proposed information to be stored on a permanent physical component tracking.

Item	**Commentary**
Steel Origin Locale	Reclaimed-UK
Steel Origin Date	1975
Steel Fabricator (current application)	Fabricator name
Fabricator ID	C10
Structural design (current application)	Consultant name
Stockholder	Stockholder name
Stockholder certificate number	Report/certificate number
Steel grade and subgrade	S355JR
Material in compliance with the standard	EN1090-2 cl. 5.1
Design yield strength (N/mm^2)	355
Design tensile strength (N/mm^2)	470
Measured yield strength (N/mm^2)	405
Measured tensile strength (N/mm^2)	520
Measured elongation at failure (%)	23
Measured Carbon Equivalent Value (CEV)	0.45
Profile size	IPE500
Section Dimensions	EN 10365
Section Tolerances	EN 10034
Example of a real possible QR code for component tracking: https://www.the-qrcode-generator.com/	Origin: Reclaimed-UK Steel Age: 1975 ID: C10 Fabricator: Name Designer: Name Stockholder: Name Stockholder Certificate: AA001 Steel Designation: S355JR Material Standard: EN1090-2 cl. 5.1 Design yield (MPA): 355 Design tensile (MPA): 470 Measured Yield (MPA): 405 Measured Tensile (MPA): 520 Measured Elongation (%): 23 Measured CEV: 0.45 Profile: IPE500 Dimensions: EN 10365 Tolerances: EN 10034

Annex D Review of inspection and testing techniques

D.1 Inspection techniques

The inspection techniques appropriate to this protocol are summarised in the table below. These simple techniques will assist in the determination of the general condition of the structure and help define a suitable sampling and testing procedure. In practice, this is combined with detailed measurements. The following information can be gathered:

- The age of the structure and any modifications or repairs,
- Materials with which the structure has been built or modified,
- The geometry and structural configuration of the building, size of members and details of the joints.

In the case of reuse of the entire primary structure, the inspection of the building includes further detail. The section dimensions of components at critical locations should be measured. Dimensions of joints and their connectors should be recorded, including weld sizes. Inspection of all welds needs to be carried out. Additionally, for all critical parts, the resistance of which are related to geometric imperfections, detailed measurement of deviations should be made in accordance with EN 1090-2.

Table D.6 Inspection techniques

Technique	Description	Comments/Value
Visual inspection	Examination for corrosion, cracks, deformities, damage, etc.	Essential. General assessment of the physical condition of the structure. Will not reveal fine or subsurface cracks. General provisions are given in EN 13018 [97].
Field survey	Geometrical survey of positions and sizes of members and details.	Essential in absence of drawings, and to (i) check for modifications and repairs, (ii) determine the cross-section dimensions, straightness, verticality, deformation and deflection of members.
Dimensional inspection	Measurements using Vernier callipers, micrometres, three-dimensional laser scanning, ultrasonic measurements, etc.	Essential in absence of original structural drawings. Geometric data collection, size of members. For equipment and tools see e.g. EN ISO 13385-1 [98] and EN ISO 13385-2 [99].

D.2 Non-destructive and minimum invasive testing for material properties

Non-destructive hardness testing is suitable for estimating the ultimate tensile strength of the steel. The table below summarizes some of the alternative non-destructive techniques that can be used to assess the properties of reclaimed steel.

Table D.7 Potential NDT techniques

Technique	Description	Comments/Value
Hardness testing	Diameter of imprint measured when hardened steel ball is pressed against a smooth surface with known force.	Provides hardness number, e.g. Vickers according to ISO 6507 [51] hardness, which is a guide to yield and ultimate strength of the material. Vickers test method is stated on EN 1090-2. Other alternatives are Rockwell ISO 6508 [52] and Brinell ISO 6505 [53] test methods.
Positive metal identification	Uses X-ray Fluorescence and optical emission spectrometry to establish the metallic alloy composition, and grade identification by reading the quantities by percentage of its elements.	Essential for characterisation of weldability of steel structural members, as a function of the carbon equivalent. Provides additional information on the type and associated physical properties of steel and about its alloying materials. ISO 19272 [104].
Instrumented indentation testing	Instrumented indentation apparatus uses similar technique as hardness test with measured load and penetration in repeated loading and unloading cycles.	Output of the indentation test includes stress-strain relationship, elastic modulus, hardness and stiffness.
Small punch testing	Small punch test uses ceramic ball pressed against the face of small circular specimen (diameter 8 mm, thickness 0.5 mm). The stress-strain relationship is then derived from the measured load versus ball displacement.	Calculation according to prEN 15627 can be used to predict yield and tensile strength of the steel. The equivalent stress-strain relationship of the tensile coupon may be obtained by more advanced Finite Element Modelling.

D.3 Non-destructive testing of welds

NDT is generally carried out by operating equipment close to, against or fixed to the surface of the structure, and has a major advantage that it does not damage the structure, and eliminates the need for destructive sampling, and subsequent laboratory testing. The table below sets out some of the techniques that can be used during the examination phase. NDT techniques can be useful to locate and/or size defects.

Table D.8 Potential NDT techniques

Technique	Description	Comments/Value
Visual inspection	Covers the visual examination of fusion welds in metallic materials. The examination is normally performed on welds in the as-welded condition but exceptionally, the examination may be carried out at other stages during the welding process.	Ensures minimum quality control for every welded connection. BS EN 17637 [120].
Penetrant testing	Dye highlight surface breaking cracks.	Indicates surface cracks in members not otherwise visible to the naked eye, approximately 25 μm. Surface defects may be accurately detected. EN ISO 3452-1 [100] gives the general principles for this technique. For welds, see EN ISO 23277 [101]
Eddy current welding inspection	Eddy current methods are used for non-destructively locating and characterising discontinuities in magnetic or nonmagnetic electrically conducting materials.	Essential to detect surface and near-surface cracks. Only applicable to simple geometries. Will not detect sub-surface embedded defects. General principles are given in EN ISO 15549 [102] and for welds see EN ISO 17643 [103].
Ultrasonic testing	Transducer converts electrical energy into ultra-high frequency sound waves which are reflected by defects and recorded.	Suitable for detecting embedded planar defects, including cracks, lack of fusion of welds, lamellar tearing, hydrogen cracking. EN 17640 [104].
Magnetic particle inspection	Magnetic particle inspection uses magnetisation of questionable cross sections in electrically conductive materials. For visualization of the magnetic field, a suspension usually with fluorescent steel splinters is used.	This inspection method can be used for detection of surface cracks in ferromagnetic materials only. Cracks in nonmagnetic material or in sandwiched elements cannot be detected. The method can be applied as quality control of precise setting of drilled holes to stop active fatigue cracks. EN 17638 [106] can be pointed out as a reference.
Radiographic inspection	Radiographic inspection (x-ray, γ-ray, e.g. with Iridium source) is applied to detect cracks and flaws in built-up sections to evaluate sandwiched members. The radiographic source is located on one side of the built-up element, the radiosensitive film, detector or digital storage unit on the other side of the inspected cross section.	The radiographic or γ-ray inspection is the only method with validated feasibility during laboratory tests and on-site for detection of internal failure or of cracks in the middle of sandwiched elements. EN ISO 17636 [105] can be pointed out as a reference.

D.4 Destructive testing for material properties

DT techniques require retrieving small samples from the existing structure. Potential DT techniques are identified in the table below. Samples for testing are extracted by cutting or drilling. It is important to consider the likely value of the test results in relation to possible damage to the structure, e.g. embrittlement following heating when sample is removed by flame cutting, and whether indirect methods might be appropriate. Mechanical and metallurgical properties can usually be established from laboratory testing on the same sample. Information about obtaining samples from steel can be found in relevant standards, e.g. for steel see EN 10025.

Table D.9 Potential DT techniques

Technique	Description	Comments/Value
Tensile testing	Tensile tests on meaningful samples providing yield and ultimate tensile strength, modulus of elasticity, uniform elongation, and elongation at failure.	For test details see EN ISO 6892-1 [56]
Chemical composition analysis	Testing for carbon, silicon, manganese, sulphur, and phosphorus.	Essential for material identification and to check the weldability of the steel as a function of the carbon equivalent, as well as the impurity levels. Tests are carried out on drilling swarf or scrapings Provides further information on the type and associated physical properties of steel. See EN ISO 14284 [58].
Small punch testing	The stress-strain relationship can be also obtained by small-punch test of small sample.	Small punch testing is standardised but the method should be calibrated against the tensile tests of full-size specimen, see CWA 15627 [115].
Charpy impact test	Brittleness and notch ductility at a range of temperatures determined by measuring the energy required to fracture a standard U- or V-notched sample with a blow from a pendulum.	Desirable. Allows characterisation of the steel sub-grade when material certificates are not available. For test details see EN ISO 148-1 [57]. Impact toughness can be also tested on sub-sized specimen and the results recalculated to match the behaviour of the full-sized tests.
Metallography	Determination of the average grain size	Determination of internal structure of the material by microscopic examination of a sample with one flat surface. See ASTM E 112 [114].

Annex E Testing: strength and elongation – reliability assessment

E.1 Introduction

Within this protocol, material strength and elongation are assessed by both destructive and non-destructive tests. In the following section guidance is provided on both types of testing.

E.2 Measured strength and assumed steel grade – reliability assessment

The results of non-destructive and destructive tests should be compared with the values presented in Table E.10 in order to determine the steel grade. The values in Table E.11 have been developed from reference [65]. Minimum values are established by reducing the mean value by 1.64 times the standard deviation for each steel grade.

Table E.10 Steel grade identified from test results [65].

Steel grade	**Yield strength (N/mm^2)**		**Ultimate strength (N/mm^2)**			**Standard**
	Minimum	Mean	Minimum	Mean	f_u / f_y mean	
S235	267	293	397	432	1.47	EN 10025-2; EN 10219
S275	313	343	452	492	1.43	EN 10025-2; EN 10219
S355	391	426	505	540	1.26	EN 10025-2; EN 10219
S460	490	529	560	594	1.12	EN 10025-3/4; EN 10219

The values in Table *E.9* are appropriate for steel with thicknesses between 3 mm and 60 mm.

The minimum values were obtained by reducing 1.64 standard deviation from the mean value. The following material characteristics were considered:

Table E.11 Steel grade data according to reference [65].

Steel grade	**Yield Strength**		**Tensile Strength**	
	Mean X characteristic value	COV	Mean X characteristic value	COV
S235	1.25	0.055	1.20	0.050
S275	1.25	0.055	1.20	0.050
S355	1.20	0.050	1.15	0.040
S460	1.15	0.045	1.10	0.035

Every element within a group must comply with the minimum yield strength from Table *E.10* in order for the associated grade to be assumed.

By assuming the minimum yield and tensile strength values from Table *E.10*, the adequate reliability levels are met when designing with the Eurocodes. It is noted that one must not consider characteristic measured values from tests for structural design. This means that for a test programme that justifies minimum characteristic values of 391 and 505 N/mm^2 for yield and tensile strength respectively, the designer must consider that the material (according to EN10025-2) has a yield strength of 355 N/mm^2 and 470 N/mm^2 for tensile strength (for plate thicknesses between 3 and 100mm).

E.3 Non-destructive hardness tests

Every reclaimed member is to be subjected to a non-destructive hardness test in order to establish a value for the yield strength and the ultimate strength of the steel. A relationship exists between measured hardness and steel strength that is considered sufficiently accurate to define the material grade. The relationship between measured hardness and material strength depends on the type of hardness test performed.

Hardness testing should be completed on the flanges of reclaimed elements, at locations of lower stress in service. For simply supported beams, locations near the end of the element are recommended. Any surface treatment must be removed from the area to be tested.

The material hardness should be taken as the mean of three measurements in the same location.

Results from each member in a group should be assessed in accordance with EN 1990 to determine the representative value for the whole group. Once the hardness value for the group has been determined, the yield strength and ultimate strength should be calculated and compared with Table *E.10* to define the steel grade.

E.4 Assessment of hardness test results

The hardness of an individual member should be taken as the average of three measurements. If this average value for an individual member differs by more than 10% from the average value for the group of members, the inconsistent member should be removed from the group.

The characteristic value of hardness H_v of the entire group should be determined using Table D1 from EN 1990, assuming "V_x unknown" and calculated using the following expression:

$$H_v = m - k_n V_x$$

where:

H_v is the characteristic value of hardness for the group;

m is the sample mean value (mean hardness of the members within the group);

V_x is the standard deviation of the results;

k_n is taken from Table D1 of EN 1990 for "V_x unknown", presented as Table E.12.

Table E.12 Values of k_n for the 5% characteristic value (EN 1990 Table D1).

Number of members in the group (*n*)	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**20**	**30**	**∞**
V_x unknown	-	-	3.37	2.63	2.33	2.18	2.00	1.92	1.76	1.73	1.64

An ultrasonic hardness test can be used as testing method. Vickers hardness test according to EN ISO 6507 [50] is one of the available options.

E.5 Correlation between hardness and material strength

If the Vickers hardness is tested, the following relationship between hardness and strength can be used to estimate the material properties (rounded conservatively from reference [54]):

$f_y = 2.70\ H_v - 71$

$f_u = 2.50\ H_v + 100$

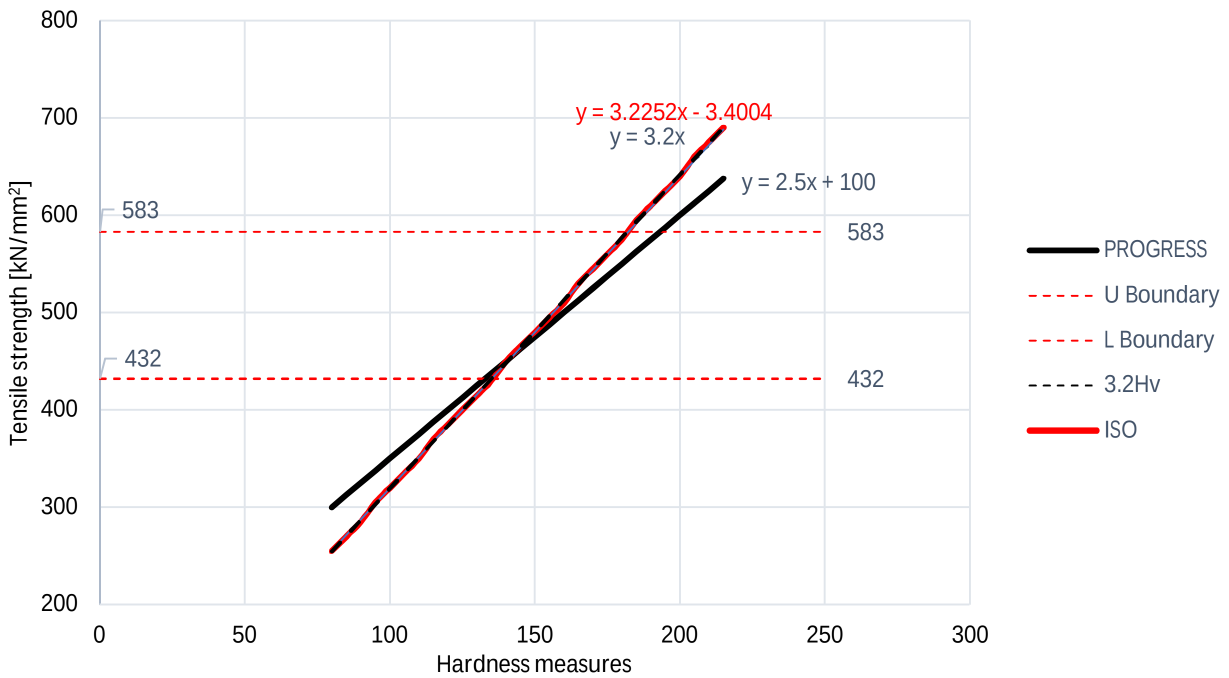
where:

H_v is the Vickers hardness value for the group;

f_y is the yield strength

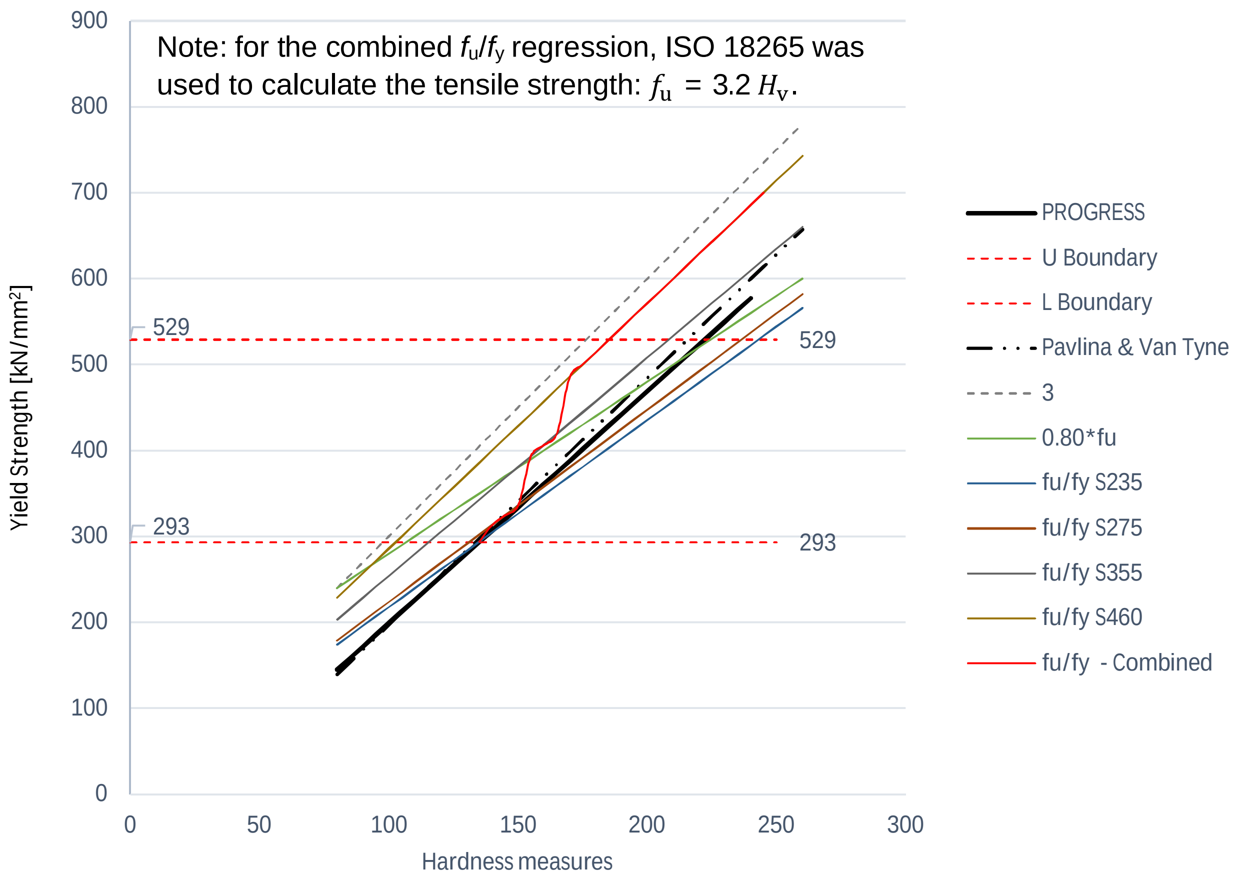
f_u is the ultimate strength

EN ISO 18265 [66] can also be used to estimate ultimate strength based on hardness values. The rule from ISO 18265 can be approximately represented by: $f_u = 3.2\ H_v$. This method tends to be less conservative that the one proposed above for the range of tensile strengths to be tested.



Annexes Figure 2. Comparison between correlation for tensile strength and hardness measures.

There is no standard method to calculate the yield strength from hardness measures. However, some references can be found in literature. As a rule of thumb, a ratio of 3 between yield strength and hardness measures can be found. Others report that keeping a ratio of 0.8 between yield and tensile strength is reasonable. Reference [67] proposes a linear regression as follows: $f_y = 2.876\ H_v - 90.7$. Bearing in mind the data from section E.2, the mean relationships between tensile and yield strength can be used as benchmarks to assess the proposed method. A combined regression is presented in Figure 3 below where data from S235, S275, S355 and S460 is used. It can be shown that the proposed method is reasonable in comparison with literature and steel data from section E.2.



Annexes Figure 3. Comparison between correlation for yield strength and hardness measures.

Correction factors need to be applied according to EN ISO 6507-1 [50] for curved surfaces.

E.6 Calculation example

In this example, 20 steel members have been identified as a group. Each member was subject to a non-destructive hardness test. Three measurements were taken from each member and the mean result calculated. The mean of the 20 results was calculated as 169.5. The standard deviation was calculated as 5.06.

As 20 members have been tested, n = 20 and k_n = 1.76 (from Table E.12)

For the group, H_v = 169.5 – 1.76 × 5.06 = 160.6

If H_v = 160.6, then:

f_y = 2.7 × 160.6 – 71 = 362 N/mm^2

and:

f_u = 2.5 × 160.6 + 100 = 502 N/mm^2

According to Table *E.10* the steel is identified as S275, as the yield strength is greater than 313 kN/mm^2 and the ultimate strength is greater than 452 kN/mm^2.

E.7 Destructive tensile tests: non-statistical and statistical testing regimes

E.7.1 General guidance for destructive testing

The location of samples for destructive tests should be selected according to the recommendations of the product standard. Appendix A of EN 10025-1 provides guidance for hot rolled members and plates. Annex C of EN 10219-1 provides guidance for hollow sections.

Destructive tensile tests are used to determine the following properties of the steel:

- Yield strength,
- Tensile strength,
- Yield to ultimate ratio,
- Elongation at failure.

The tensile destructive tests shall be performed according to EN ISO 6892-1 [56]. As a reference, test sample locations may be defined according to ISO 377 [55]. Guidance from the relevant product standard may be also followed, for examples, EN10025 or EN10219.

The declared yield strength, tensile strength and elongation should be based on the results of the destructive tests, not on the non-destructive tests. The declared yield strength and tensile strength should be the strengths given in the appropriate product Standard for the determined steel grade, which is identified using results of the destructive tests, not on the non-destructive tests.

As a remark, it should be noticed that if a reclaimed element does not comply with a certain product standard, such as EN 10025-2, the element can still be used as long as the relevant material properties are declared, as requested by EN1090-2 section 5.1. As an example, if the elongation at failure measured by a destructive test does not comply with the minimum values from EN10025-2 for a specific steel grade, but if the measured elongation is such that the minimum values from EN 1993-1-1 for elastic global analysis are fulfilled, the reclaimed steel can still be reused.

E.7.2 Non-statistical testing

In addition to the 100% non-destructive testing of every member, a single destructive test (taken from any member in the group) is required to confirm the assessment described in Section E.3. A single test has no statistical value, and is therefore described as 'non-statistical'.

Non-statistical destructive testing (*i.e.* one single destructive test from a group) is recommended for steel to be used in Consequence class 1 or Consequence class 2 structures.

E.7.3 Statistical testing

If reclaimed steel is to be used in Consequence class 3 structures, a greater degree of reliability is required. In addition to the 100% non-destructive testing of every member, the mechanical properties of the steel members should be determined by increasing the number of destructive tests, and completing an assessment in accordance with EN 1990.

A minimum of three destructive tests are required, taken from members within a group. Increasing the number of tests will improve the precision of the calculated values and will generally result in higher values.

The characteristic value of yield strength and ultimate strength of the entire group should be determined using Table D1 from EN 1990, assuming “V_x known” and calculated using the following expression:

$$X_d = m - k_n V_x$$

where:

X_d is the characteristic value of interest (yield strength, or ultimate strength);

m is the sample mean value;

V_x is the standard deviation;

k_n is taken from Table D1 of EN 1990 for “V_x known”, presented as Table E.13.

Table E.13 Values of k_n for the 5% characteristic value (EN 1990 Table D1)

Number of tests	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**10**	**20**	**30**	**∞**
V_x known	-	-	1.89	1.83	1.80	1.77	1.74	1.72	1.68	1.67	1.64

The use of “V_x known” is justified because the coefficient of variation for both yield strength and ultimate strength is known (and proposed for publication in the revised version of EN 1993-1-1).

If statistical testing is completed, the calculated values from the destructive tests should be used to determine the steel grade from Table C.1.

Annex F Testing: impact toughness - adequacy assessment

F.1 Destructive tests

Unless destructive tests are conducted, it should be assumed that the steel is subgrade JR. There may be economic benefits in completing destructive tests to demonstrate that reclaimed steel is of a tougher sub-grade, particularly on thicker sections.

If required, destructive tests should be used to establish the steel sub-grade of members within a group, based on the testing of one representative member. In accordance with EN 10025-1, six samples are required for testing purposes, taken from locations identified in Annex A of EN 10025-1.

For every 20 tonnes in a batch, one set of tests (six samples) from one single member should be used to determine the Charpy value for all members in that batch. The Charpy test should be performed according to EN ISO 148-1 [57].

Annex G Testing: chemical composition - adequacy assessment

G.1 Introduction

The chemical composition of reclaimed steel should be determined so that the Carbon Equivalent Value (CEV) can be calculated using the expression in EN 10025-1 section 7.2.3 or EN 10219-1 section 6.6.1.

The chemical composition should be assessed using non-destructive and destructive techniques. The CEV for the group should be taken as the maximum CEV from any test, including both the non-destructive test results and the destructive test results.

The chemical composition of each individual member should be tested and recorded. If the measured carbon or manganese content for an individual member differs by more than 10% from the average value for the group, the inconsistent member should be removed from the group.

The anticipated chemical composition of a specific steel can be found in Section 6.6.1 of the relevant part of EN 10025 and EN 10219.

G.2 Non-destructive tests to determine chemical composition

Optical emission spectroscopy can be used to determine the chemical composition of a steel member. Although this technique is considered to be a non-destructive test method, a small burr is left on the surface of the steel.

The chemical composition may be assessed according to BS ISO 19272 [96].

G.3 Destructive tests to determine chemical composition

The chemical composition of the steel can be determined by analysing swarf from a drilled cavity. The member should be drilled in a low stress location.

For Consequence class 1 and Consequence class 2 structures, destructive tests on one representative member should be used to establish the chemical composition for all members in the group.

For Consequence class 3 structures, where a minimum of three destructive tests are recommended (see *Table 7.4*), no statistical analysis should be undertaken.

The chemical composition may be assessed according to EN ISO 14284 [58].

Annex H Inspection: geometric tolerances - adequacy assessment

H.1 General guidance

Geometric properties and tolerances can be verified by adequate methods such as laser scanning, LIDAR or photogrammetry. LIDAR (Light Detection and Ranging technique) is a surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target. LIDAR is sometimes called 3D laser scanning, a special combination of a 3D scanning and laser scanning.

H.2 Cross section dimensions

The cross-sectional dimensions (depth, breadth, flange thickness, web thickness, wall thickness etc.) must be measured for all members. A declaration of the measured dimensions must be provided by the stockholder.

If the section dimensions fall outside the permitted deviations according to the product standard (see *Table 2.2*), the measured dimensions should be used to determine the cross-sectional properties.

H.3 Bow imperfections (lack of straightness)

The straightness of every member, in both axes, should be measured and compared with the permitted deviations in EN 1090-2. Members falling outside the permitted deviations should be straightened as part of the fabrication process. See also section 4.9.2.

Annex I Withdrawn product standards

The product standards presented in the next sections may be of interest for re-certifying the reclaimed steel based on building age and location. This is also intended to map existing documentation with current product standards such as EN 10025.

I.1 European overview

Table I.14 Withdrawn European product standards.

Designation according EN 10025-2:2004		Equivalent former designations in: According EN 10025:1990 +A1:1993		According EN 10025:1990	Germany according to DIN 17 100	France according to NF A 35-501	United Kingdom according to BS 4360	Spain according to UNE 36-080	Italy according to UNI 7070	Belgium according to NBN A 21-101	Sweden according to SS 14 followed by number steel grade	Portugal according to NP 1729	Austria according to M 3116	Norway according to number steel grade
S185	1.0035	S185	1.0035	Fe 310-0	St 33	A 33		A 310-0	Fe 320	A 320	13 00-00	Fe 310-0	St 320	
		S235JR	1.0037	Fe 360 B	St 37-2	E 24-2			Fe 360 B	AE 235-B	13 11-00	Fe 360-B		NS 12 120
		S235JRG1	1.0036	Fe 360 BFU	USt 37-2			AE 235 B-FU					USt 360 B	NS 12 122
S235JR	1.0038	S235JRG2	1.0038	Fe 360 BFN	RSt 37-2		40 B	AE 235 B-FN			13 12-00		RSt 360 B	NS 12 123
S235J0	1.0114	S235J0	1.0114	Fe 360 C	St 37-3 U	E 24-3	40 C	AE 235 C	Fe 360 C	AE 235-C		Fe 360-C	St 360 C	NS 12 124
													St 360 CE	
a	a	S235J2G3	1.0116	Fe 360 D1	St 37-3 N	E 24-4	40 D	AE 235 D	Fe 360 D	AE 235-D		Fe 360-D	St 360 D	NS 12 124
S235J2	1.0117	S235J2G4	1.0117	Fe 360 D2	--									
S275JR	1.0044	S275JR	1.0044	Fe 430 B	St 44-2	E 28-2	43 B	AE 275 B	Fe 430 B	AE 255-B	14 12-00	Fe 430-B	St 430 B	NS 12 142
S275J0	1.0143	S275J0	1.0143	Fe 430 C	St 44-3 U	E 28-3	43 C	AE 275 C	Fe 430 C	AE 255-C		Fe 430-C	St 430 C	NS 12 143
													St 430 CE	
a	a	S275J2G3	1.0144	Fe 430 D1	St 44-3 N	E 28-4	43 D	AE 275 D	Fe 430 D	AE 255-D	14 14-00	Fe 430-D	St 430 D	NS 12 143
S275J2	1.0145	S275J2G4	1.0145	Fe 430 D2	--						14 14-01			
S355JR	1.0045	S355JR	1.0045	Fe 510 B	--	E 36-2	50 B	AE 355 B	Fe 510 B	AE 355-B		Fe 510-B		
S355J0	1.0553	S355J0	1.0553	Fe 510 C	St 52-3 U	E 36-3	50 C	AE 355 C	Fe 510 C	AE 355-C		Fe 510-C	St 510 C	NS 12 153
a	a	S355J2G3	1.0570	Fe 510 D1	St 52-3 N		50 D	AE 355 D	Fe 510 D	AE 355-D		Fe 510-D	St 510 D	NS 12 153
S355J2	1.0577	S355J2G4	1.0577	Fe 510 D2	--									
a	a	S355K2G3	1.0595	Fe 510 DD1	--	E 36-4	50 DD			AE 355-DD		Fe 510-DD		
S355K2	1.0596	S355K2G4	1.0596	Fe 510 DD2	--									
S450J0	1.0590						55C							
E295	1.0050	E295	1.0050	Fe 490-2	St 50-2	A 50-2		A 490	Fe 490	A 490-2	15 50-00 15 50-01	Fe 490-2	St 490	
E335	1.0060	E335	1.0060	Fe 590-2	St 60-2	A 60-2		A 590	Fe 590	A 590-2	16 50 00 16 50-01	Fe 590-2	St 590	
E360	1.0070	E360	1.0070	Fe 690-2	St 70-2	A 70-2		A 690	Fe 690	A 690-2	16 55 00 16 55-01	Fe 690-2	St 690	

[a] When a product is delivered in the N condition +N shall be added to the designation (see 4.2.2).

I.2 UK overview

Table I.15 Historical British Standards covering the specification of UK structural steel.

BS	Date	Title
BS15	1906, 1912, 1930, 1936	Standard Specification for Structural Steel for Bridges and General Building Construction
CF(15)7376	1941	War Emergency revision to BS15
BS15	1948	Structural steel
BS15	1961	Mild Steel for General Structural Purposes
BS546	1934	High Tensile Structural Steel for Bridges and General Building Construction
968	1941	(War emergency standard) High Tensile (Fusion Welding Quality) Structural Steel for Bridges and General Building Purposes
968	1962	High Tensile (Fusion Welding Quality) Structural Steel for Bridges or General Building Purposes
BS 4360	1968, 1972, 1979	Weldable Structural Steels
1	1901	First attempt to standardise steel sections
4	1904	Structural steel sections
449	1932, 1959	Use of structural steel in buildings
CP 113	1948	The structural use of steel in buildings
4360	1968	Weldable structural steels (superseded 15 and 968)

From 1903, when British Standard 4 was first issued, all the tables in the various historical handbooks, refer to British Standard Sections, though at various times since 1903 some steel sections have been imported and used which do not conform to British Standards. The most notable of these are Broad Flange Beams rolled on the continent of Europe.

In 1972 British Standard 4848 Part 4 (Metric Equal and Unequal angles) was issued. These metric sizes replace the imperial sizes in British Standard 4. Details of metric angles and their properties are contained in the Constrado publication "Structural Steelwork Handbook - Metric Angles to BS4848 Part 4 1972" published in 1973.

The second major development was the issue of British Standard 4 Part 1 in 1980. This updated previous issues of BS4 to correct minor inaccuracies and to cover the properties of Universal Beams, which (as at 1980) all have parallel flanges. Again, all the details given in BS4 Part 1 1980 are included in the BCSA/Constrado publication "Structural Steelwork Handbook - Sections to BS4 Part 1".

For steel design, 5950, which succeeded 449 in 1985, uses partial safety factors to cover variations in material quality, structural performance and applied loads. A material factor (γ_m) of 1.0 has been adopted for structural steel. As far as loading is concerned, the make-up of the partial load factor is as described in Section 4.6.3 of BS5959. The structural performance factor, γ_{f3}, takes account of rolling tolerances on the steel, together with inaccuracies of design, fabrication and erection.

Where welding is to be undertaken on an existing structure, as part of repair or strengthening, it is necessary to check that the original material is of a suitable composition and condition. 5135, now withdrawn, contains a useful formula for establishing the weldability of steel in terms of a ‘carbon equivalent’ value taking account of other elements present including manganese. It will often be worthwhile to seek specialist advice on weldability and welding techniques, particularly for older steel which may contain higher levels of sulphur and phosphorus than is permitted in more recent steel specifications.

Annex J Assessment and design of old metallic materials

J.1 General considerations

The focus of this protocol is “modern” steelwork, produced and erected after 1970. However, in this annex provisions for assessing and design with older materials are provided. This section is also intended to justify the consistency of the proposed testing protocol. For instance, questions may arise about why when using non-statistical testing, the elongation is justified by one representative destructive test. However, it is clear that there is no actual concern in the minimum requirements to design according to Eurocode 3 based on available data for old materials presented in this section.

Often the evidence from visual inspection and dating will, with experience, be conclusive in identifying cast, wrought iron or steel. However, testing procedures from previous annexes are recommended to confirm the material provenance.

J.2 Overview of old materials characteristics and main period of use

As a reference, a summary of the material characteristics based on the period of use can be found below. This may be a way forward for structural metallic materials erected before 1970.

Table J.16 Characteristic values of old structural steel and iron – adapted from [32]

Material	**Period of use 1)**	f_{yk} 2) **[N/mm²]**	f_{uk} 2) **[N/mm²]**	**G [N/mm²]**	E_k 2) **[N/mm²]**	ε_{uk} 2) **[%]**	**v**	ρ **[kg/m³]**	α_T $[10^{-6}/°C]$	f_y/f_u
Cast iron 3)	Before 1900	70-200 4)	120-600	29000	78000	<0.8	0.26 5)	7250	10	1.71
Wrought iron	1850-1900	220	320	77000	200000	15	0.30	7800	10	1.45
Mild rimmed iron	1890-1900	220	320	77000	200000	25	0.30	7800	10	1.45
	1900-1940	235	335	81000	210000	25	0.30	7800	10	1.42
Mild steel	1925-1969	235	360	81000	210000	25	0.30	7850	10	1.53
Connections:										
Welds	1900-1924	-	300	-	-	-	-	-	-	-
	1925-1969	-	360	-	-	-	-	-	-	-
	From 1970	-	+360 6)	-	-	-	-	-	-	-
Rivets: wrought iron	1850-1900	-	320	-	-	18	-	-	-	-
Rivets: Mild rimmed iron	1890-1940	-	320	-	-	28	-	-	-	-
Rivets: Mild steel	From 1925	-	350	-	-	30	-	-	-	-

1) Main phase of manufacture; 2) Parallel to the direction of rolling; characteristic value; elongation at failure; 3) Cast iron with lamellar graphite in accordance with EN 1561 [126]; 4) Conventional value of 0.1% ultimate strain, since cast iron has no yield range; 5) Average value for different type of cast iron; 6) At least equal to the base material.

It is unlikely that steels with a characteristic yield strength lower than 235 N/mm^2 are found before 1970. Further guidance about old materials may be found in: SCI P138 – "Appraisal of existing Iron and Steel Structures" and BCSA - "Historical structural steelwork handbook".

For design with old materials, SIA 269/3 [32] may be used as a reference.

J.3 Visual characteristics of cast and wrought iron, and steel

Table J.17 Visual characteristics of cast and wrought iron, and steel – 1/2 [59]

Visual characteristic	Grey cast iron	Wrought iron	Steel
Surface texture (uncorroded)	'Gritting' or pitted from mould Possible 'blowholes' Possible straight lines or 'steps' from junction of half moulds (e.g. diametrically opposite along axis of hollow circular column)	Smooth	Smooth Possible millscale
Surface texture (corroded)	Uniformly rough; 'powdery' rather than 'flaky'	Possible 'delamination', with rust layers flaking off like puff pastry (flat sections) or triangular wedges (rods) - see Figure 6.3	Possible 'delamination' as for wrought iron, usually on flat sections only
Fracture surface	Crystalline, bright (new) or grey (old)	Fibrous (crystalline if fatigue failure)	Slightly fibrous or striated (crystalline if fatigue failure)
Element cross-sectional profile	Typically 'chunky' with relatively thick sections, often ornate or complex profile (fluted or plain hollow circular or cruciform columns, |,I,⊥ or polygonal beam sections)	'Crisp' profile, typically ●,|,I,L,T, or Z section or compound riveted section; joists and channels usually thicker than steel members	Thin 'crisp' profile, typically ●,|,I,U,L, or T section, solid or hollow circular or rectangular columns, or compound riveted or welded section
Corners of element	External corners sharp, typically 90°; re-entrant corners rounded	Outer flange corners sharp, often less than 90°; 'toe' and 'root' corners rounded	As wrought iron, except for recent I-sections (sharp 90° external corners)
Flange section	Rectangular, or polygonal in beams with typically larger tension flange and small or absent compression flange (see Figure 3.2) Flange width or thickness may vary along element (largest at midspan)	Usually tapered flanges on I-sections, thickest at web; equal flange sizes Constant flange section along element	As wrought iron, except for recent I-sections (which have parallel flanges) Constant flange section along element

Table J.18 Visual characteristics of cast and wrought iron, and steel – 2/2 [59]

Visual characteristic	Grey cast iron	Wrought iron	Steel
Element elevational profile	Usually varies along length; beams often have 'fish-belly or 'hump-backed' web profile and integral web stiffeners; columns often have ornate Classical heads with spigots and extended ledges or 'tables' supporting beams, baseplates and intermediate stiffeners; other elements often ornate and complex Beams and columns may have intermittent openings in web	Constant along length unless compound beam(s) or plate girder when web profile may vary (plate girders only) and flange plates increase in number and size towards midspan Openings in web usually stiffened (if original) by L or T framing on all sides	As wrought iron; recent plate girders may have web and flange plates of various thicknesses and depths butt-welded together As wrought-iron, also castellated and cellular beams in recent construction
Section size	Large beams (over say 10 m) often cast in sections, bolted together at flanged junctions	I-sections up to 20 inches (508 mm) deep, occasionally slightly more; deeper sections invariably built-up riveted plate girders; columns built-up from I-section, angles, and plates; small tees and channels	I-sections up to 3 feet (914 mm) deep; solid circular columns up to 1 foot (305 mm) diameter; hollow tubular columns up to around 18 inches (457 mm) side length
Connection methods	Typically bolts (often square-headed); beams often tied together at column heads by wrought iron 'shrink rings' fitted around cast-on beam lugs	Rivets for all built-up sections; bolts (often square-headed); flats, bars and rods sometimes hammer-welded together in older structures; cotters and wedges for tie-rods	Rivets (up to 1950s); bolts in clearance holes (earlier square, later hexagonal heads); welding (20th century); close tolerance bolts (since First World War); high strength friction grip bolts (since 1950s)
Identification on element	Maker's name and location often cast onto element (e.g. on web of beam, in plaque at foot of column); occasionally load capacity also indicated	Rarely, at intervals on rolled sections; cast iron plaque sometimes attached to major elements (bridges, roof structures)	Often, at intervals on rolled sections; BS 15 used to require that "every piece of steel shall bear the maker's name or trade mark" (excepting bars and small pieces) while BS 548 (high tensile steel) required this plus "the letters H.T." (to distinguish it from mild steel).

J.4 UK overview of old materials characteristics and main period of use

Table J.19 shows the main periods of structural use of iron and steel in the UK. With this data, it can be pointed out that the reclaimed metallic elements from the construction industry in the XX century are likely to be mild steel or modern steel. In a transition period between 1880 and 1900, composite elements made of wrought iron and mild steel were common.

Table J.20 Main periods of the structural use of cast and wrought iron, and steel in the UK [59]

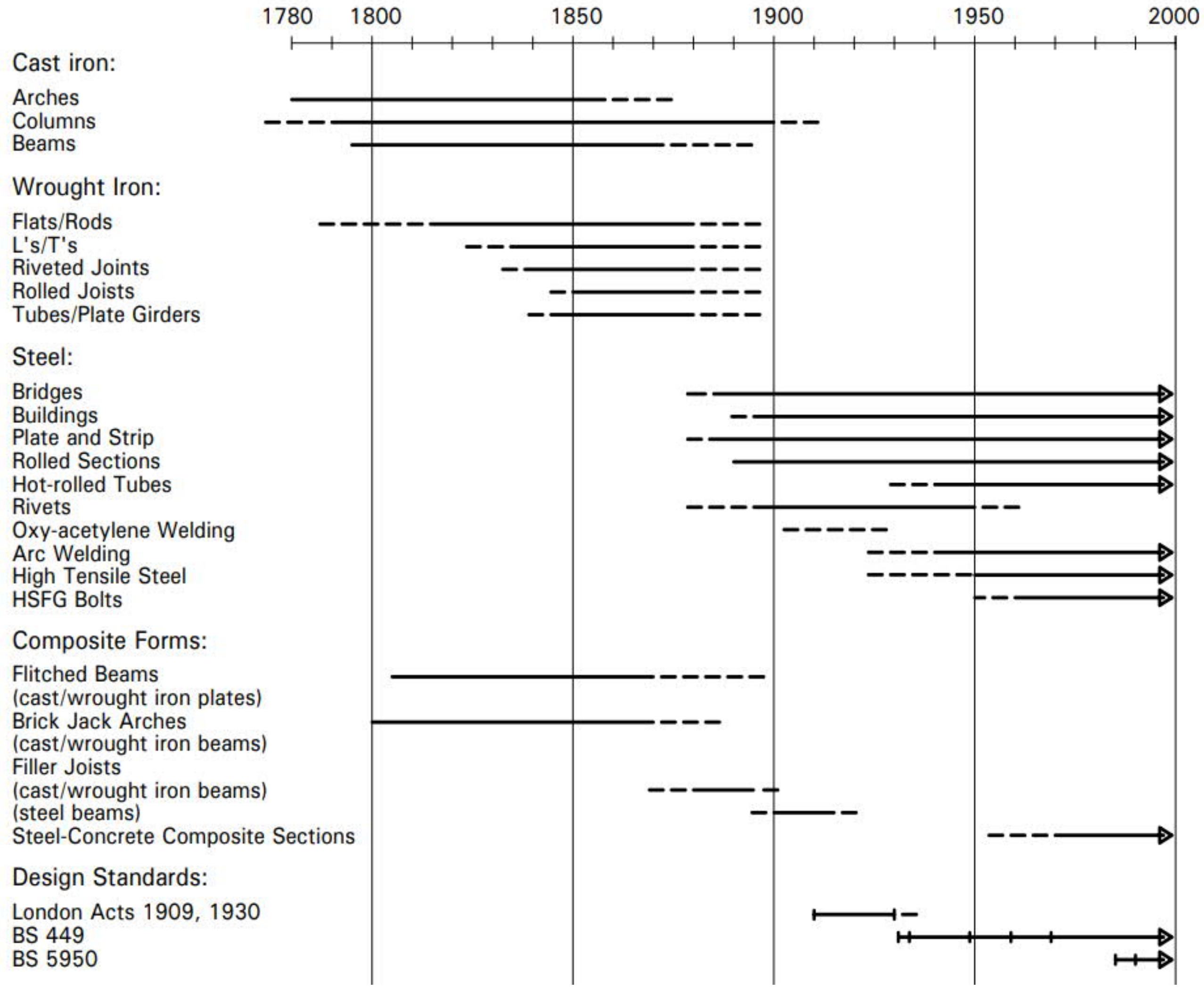


Table J.21 Typical properties of structural grey cast iron [59]

Property (values in N/mm² unless noted)	Typical values (or range of values)	Notes
Ultimate tensile strength: Lowest Mean Highest	 65-100 123 150-280	Results from various authorities[22] and various section sizes; typical strain at failure 0.5-0.75%[37]
Flexural tensile strength (modulus of rupture): Rectangular bars not exceeding 1 inch (25.4 mm) wide Rectangular bars 3 inches (76.2 mm) wide Round bars 1 inch (25.4mm diameter) Round bars 2 inches (50.8 mm) diameter I-beams of various section sizes Bridge beams	 315 208 355 309 116-232 116-134	 Typical values from Ref. 22 " " " " " " " " " " " " " " " " Ref. 21
Ultimate compressive strength	587-772	Ref. 22; squat specimens
Ultimate shear strength	Not less than UTS	Ref. 22
Young's modulus (kN/mm²) Tension Compression	 66-94 84-91	Cast iron is neither isotropic nor linear-elastic, and these are secant modulus values from Ref. 22; modulus falls with increasing stress
Modern grade 150 grey cast iron	69-103	Ref. 37

Ref. 21 – [117]

Ref. 22 – [118]

Ref 37 – [119]

Table J.22 Tensile strengths of modern grey cast iron (from 1452:1990) [59]

Grade and minimum tensile strength of separately cast sample (N/mm²)	Casting section thickness (mm)	Expected tensile strength of sample from casting (N/mm²)	Expected tensile strength of cast-on sample (N/mm²)
100	2.5-10	120	*
	10-20	90	*
150	2.5-10	155	*
	10-20	130	*
	20-40	110	120
	40-80	95	110
	80-150	80	100
	150-300	*	90
180	2.5-10	185	*
	10-20	160	*
	20-40	135	150
	40-80	115	135
	80-50	100	125
	150-300	*	100
200	2.5-10	205	*
	10-20	180	*
	20-40	155	170
	40-80	130	150
	80-150	115	140
	150-300	*	130

* Not quoted

Table J.23 Typical properties of structural wrought iron (UK) [59]

Property (values in N/mm^2 unless noted)	**Typical value (or range of values)**	**Notes**
Ultimate tensile strength (and flexural tensile strength)	278-593	Ref.22; values are for tension parallel to direction of working i.e. parallel to slag strands - UTS normal to this direction is about two-thirds to three-quarters of these values; UTS is increased by cold-working, with substantial reduction in ductility
	309-386	BS 51:1939[40], now withdrawn
Ultimate compressive strength	247-309	Ref.22
Ultimate shear strength	At least two-thirds of UTS	Ref.22
Young's modulus (kN/mm^2)	154-220	Ref.22
Elastic limit	154-408	Ref.22; higher values are achieved by cold-working, with a substantial reduction in ductility
Elongation at failure (%)	7-21	Ref.22; other sources give ranges of 4-36%(sic) depending on degree of working
Poisson's ratio	0.25	Ref.22

Ref. 22 – [118]

Table J.24 Typical properties of structural steel before 1906 (UK) [59]

Property (values in N/mm² unless noted)	Typical value (or range of values)
Ultimate tensile and compressive strength	386-494
Ultimate shear strength	Three-quarters of UTS
Young's modulus (kN/mm²)	200-205
Elastic limit	278-309
Elongation at failure (%)	18-20
Poisson's ratio	0.26-0.34

Table J.25 Properties of structural steel prescribed by British Standards since 1906 until 1968 (UK)

Property (values in N/mm² unless noted)	Typical value (or range of values)	Notes
Ultimate tensile strength:		
BS 15: 1906	432-494	BS 15 covered mild steel
BS 15: 1912-1941	432-509	
BS 15: 1948-1961		
Rivet bar	386-463	
Other	432-509	
BS 548: 1934-1942		BS 548 covered high tensile
Rivet bar	463-540	steel
Other	571-664	
BS 968: 1941	As BS 548: 1934	BS 968 covered weldable high
BS 968: 1943	509-633	tensile steel
BS 968: 1962	494-602	
Yield strength:		
BS 15: 1948-1961	225-235	
BS 15: 1961-1968	230-250	No change in UTS.
BS 548: 1934-1942	293-355	No requirements for rivet bar;
BS 968: 1941	As BS 548: 1934	values depended on steel
BS 968: 1943	293-324	thickness, being lower for thicker
BS 968: 1962	340-355	sections
Elongation at failure (%):		
BS 15: 1906-1941		
Rivet bar	25 (min.)	
Other	20 (min.)	
BS 15: 1948-1961		
Rivet bar	26-30	Cold bend test
Other	16-24	
BS 548: 1934-1942		
Rivet bar	22-27	
Other	14-18	
BS 968: 1941-1943		
Plates	14-18	
Sections and bars	14-22	
BS 968: 1962		
Standard test pieces	15-23	

Annex K Evaluation procedure for reuse of sandwich panels

General	Here is given rules for evaluation of potential for reusing sandwich panels, dismounted after being in use for a considerable amount of years. The reason for dismounting the panels should be a change of the use of the building, not a failure in the panels. For the evaluation of safety aspects for reuse, the rules in EN 1990 (safety factors) and rules in harmonized product standard EN 14509 [133] for type testing essential properties are used. Type testing is used in EN 14509 as name for the testing where the declared values for all essential characteristics are done and following rules in EN 14509. A basic requirement for a limited amount of testing is that the name of manufacturer is known and a copy of original declared values (values given by the manufacturer) is known. This might limit the use of reduced testing program for panels older than 25 years, because of the lack of common known rules, unless they have been produced under national type approvals with an existing type testing and third-party control. For other cases a full testing program following rules in EN 14509 is recommended.
Main evaluation criterion	The evaluation of potential to reuse sandwich panels are: -Architectural or aesthetical based -Performance based; evaluation of essential properties as in EN 14509
Aesthetical aspects	For this purpose, color change of the surface or damages in surface is visually observed
Mechanical strength and safety	The mechanical panel properties to be declared and to be determined based on Type Testing are according to EN 14509: -wrinkling strength, -shear strength and shear module, -creep coefficient (for permanent loads only) -compression strength and compression module; -tensile strength and tensile module, -durability properties -tolerances For further processing the reference level of mechanical properties are the values declared by the manufacturer at the time of delivery of the panels. This reference level is further called as zero level. The evaluation of the possible degradation of the panel mechanical properties is first evaluated by comparing the level of cross panel tensile strength to the zero level. If considerable degradation (over 10 % lower characteristic value compared to the declared value) is noticed, the panel shear strength and compression strength is tested. The characteristic value of the panel shear strength, determined on panels sampled from the panels

	dismounted is the value used for design when reusing the panels. The other properties used by design are -The mean value of the shear module measured from the panels to be reused. -For wrinkling strength and compression strength and module the originally declared values are reduced with the ratio of the characteristic shear strength to the originally declared shear strength. This procedure is evaluated to be conservative as the experience is that the ageing is affecting mostly cross panel tensile strength and panel shear strength. Results from testing dismounted panels at the end of 90'ies indicate that the ageing rate of wrinkling strength is approximatively the half of the ageing in shear strength. The level of material safety factors is suggested to be the same as determined based on original type tests. In principle a lower level could be possible as the expected life time of the panels to be reused is lower than when originally installed. As there is little knowledge on this behavior today, the original material safety values are suggested to be used. It is suggested to test samples taken from dismounted panels for testing cross panel tensile strength as specified in EN 14509 chapter A.1. The number of samples should be at least 3, preferable 10. The density of the samples is measured from samples taken close to the samples for tensile strength.
Tensile strength and density	The characteristic value of tensile strength is compared to originally declared value. If there is degradation in the level of less than 10 %, the panels can be reused using the originally declared properties for all mechanical strength properties. If the degradation is more than 10 % a set of samples for testing shear strength and module and compression strength and module should be taken. At least 3 samples each should be taken, preferably 5 for shear and 10 for compression tests.
Shear strength	The shear strength and shear module are tested for the samples taken from the dismounted panels. If the degradation in tensile strength is not more than 10%, one shear test is performed. The test result shall be at least the same as the declared value. The full scale of tests is performed if the cross panel tensile strength has degradation more than 10 % compared to original declared tensile strength. The characteristic value is calculated for the shear strength. This value is used for the design of the panels to be reused.
Compression strength	The compression strength is tested for the samples taken from the dismounted panels. The tests are performed if the cross panel tensile strength has degradation more than 10 % compared to original declared tensile strength. The characteristic value is calculated for the compression strength. This value is used for the design of the panels to be reused.

Bending moment/Wrinkling strength	For the bending moment or wrinkling strength, the originally declared value can be used if the tensile strength has degradation less than 10 %. If the degradation is higher either the wrinkling strength is reduced with the same ratio as the shear strength is in comparison to the originally declared shear strength, or the wrinkling strength is tested for panels sampled from the dismounted panels. The characteristic value of test results is then used in design when reusing the panels.
Material safety factors	The material safety values determined by the original type testing is used. Alternatively, the safety values determined form the tests on dismounted panels can be used calculated as given in EN 14509 chapter A.16.
Durability properties	Need of repeating testing of durability is actual only if there is degradation of tensile strength more than 10 %. In that case only the short-term durability testing (14 days, see EN 14509 Annex B, clause B.2.4, for all other core types than mineral wool and 7 days for mineral wool core, see EN 14509 Annex B, clause B.3.4) shall be done. For panels with core of mineral wool the degradation shall be less than 15 % and for all other types less than 17 %.
Tolerances	The tolerances are visually inspected and if deviation noticed checked that the panels are fit for reuse
Thermal behavior	PU panels: If there is reduction in closed cells ratio (see ISO 4590) for PU is decreased wit 10%, the thermal conductivity shall be retested and a new design value shall be determined (EN 14509, clause A.10).
Fire safety	Only panels with core materials with fire retardants hall be retested for the small flame behavior. This is to check that the effect of fire retardants is still active. Otherwise a reclassification might be needed. The panels are fit for use where fulfilling the requirements in the project for reuse.

<table>
<tr><td colspan="2">Summary on evaluation procedure for reuse of sandwich panels.
For more information on testing see EN 14509.
Mechanical strength
Testing cross panel tensile strength 3 samples a minimum (EN 14509, A.1): Calculate characteristic result for tensile strength
Testing one sample for shear strength (EN 14509, A.3 or A.4)</td></tr>
<tr><td rowspan="2">Evaluation:
Tensile strength ≥ 0,9* Declared value of Tensile strength and
Shear strength ≥ Declared value of Shear strength</td><td>If YES; No further testing. All declared values for mechanical strength can be used</td></tr>
<tr><td>If NO; New declared values to be determined with a test program according to EN 14509 for
-Tensile strength
-Compression strength
-Shear strength
The wrinkling strength is reduced with same amount that shear strength is reduced.</td></tr>
<tr><td colspan="2">Durability</td></tr>
<tr><td rowspan="2">Tensile strength ≥ 0,9* Declared value of Tensile strength</td><td>If YES; No further testing; panels are fit for use</td></tr>
<tr><td>If NO;
<u>Miwo panels</u>:
The 7 days testing (see EN 14509 clause B.3.4) is to be done. The reduction in tensile strength after ageing shall not exceed 15 % of the mean value of the tensile strength in ambient temperature
<u>For all other panel type</u> the procedure in EN 14509 Annex B.2 is followed so that the panels are tested 14 days in the temperature as described in B.2.4. The reduction in tensile strength after ageing shall not exceed 17% of the mean value of the tensile strength in ambient temperature</td></tr>
<tr><td rowspan="2">Tolerances; damages evaluated by visual inspection</td><td>If no serious damages or faults found; Panel can be reused</td></tr>
<tr><td>If serious damages are found causing weakness in strength, in insulation behavior or tightness of joints then those panels are rejected</td></tr>
<tr><td>Moisture content</td><td>If no notable wetness of core material found the panels can be reused</td></tr>
<tr><td colspan="2">Thermal behavior</td></tr>
<tr><td>For PU panels:
Closed cell ratio ≥ 0,9* closed cell ratio by type testing and change in density less than 10 %</td><td>If YES; no further testing; original thermal conductivity value can be used
If NO; new test for determining thermal conductivity is to be done following rules in EN 14509 chapter A.10.</td></tr>
</table>

Fire safety	Small flame tests (see EN 14509 clause C.1.2) to be done with core material including fire retardants. The classification is checked and if needed reclassified. The panels are fit for use where fulfilling the requirements in the project for reuse.

Annex L Evaluation procedure for the reuse of light gauge steelwork

L.1 General considerations

The success rate of reclaiming secondary light gauge steelwork is likely to be much lower in comparison with primary hot rolled steelwork. This is due to the fact that cladding is usually fixed with a considerable number of connectors. However, in this section, recommendation for sampling and testing procedures for light gauge elements are proposed.

L.2 CE marking of reclaimed light gauge cold formed elements

L.2.1 CE marking

The re-certification of non-constituent light gauge cold formed elements is allowed by clause 5.1 of EN1090-4 [108]. It is stated that *"If constituent products that are not covered by the standards listed in Clause 5.3 are to be used their properties shall be specified".* The following properties were identified as required for an appropriate product recertification:

1. Yield strength or 0,2 %-proof strength ($R_{eH}/R_{p0,2}$);
2. Tensile strength (R_m);
3. Elongation after fracture A80 mm in %;
4. Bend radius to thickness ratio, if relevant;
5. Adhesion of metallic coating;
6. Tolerances on dimensions and shape, including minimal thickness;

In addition, if the steel is to be welded, its weldability shall be declared as follows:

7. A maximum limit for the carbon equivalent of the steel, or;
8. A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated.

L.2.2 CE Marking of reclaimed steel

There will be no difference in the fabrication processes, procedures, standards or tolerances for either new steel or reclaimed steel. It is therefore appropriate that re-fabricated, reclaimed structural steelwork can be CE Marked in accordance with EN 1090.

In addition to careful control of the fabrication process, material properties must be declared according to EN 1090-4 clause 5.1. When using reclaimed steel, this is the stockholder's responsibility.

L.2.3 Declaration of properties

The purpose of declaring material properties is so that the material used in construction meets the appropriate standard and that properties required by design are confirmed, *e.g.* the required material strength assumed in the member verifications has actually been provided.

The requirements of EN 1090-4 and the testing regime for reclaimed steelwork are discussed in Section L.2.4.

L.2.4 Material properties to be declared for reclaimed cold formed steelwork

The test regime for cold formed steelwork is intended to allow the necessary material properties according to EN 1090-4 clause 5.1 to be declared, based on dimensional survey, by non-destructive tests, by destructive tests or by making conservative assumptions. A summary of the necessary material properties and how they are to be assessed is presented in Table L.26.

Table L.26 Proposed material properties to be declared – based on EN 1090-4

Item	**Property**	**To be declared**	**Procedure**
1	Yield strength or 0,2 %-proof strength (R_{eH}/$R_{p0,2}$)	Yes	Determined by destructive tests.
2	Tensile strength (R_m)	Yes	Determined by destructive tests.
3	Elongation after fracture A80 mm in %;	Yes	Determined by destructive tests.
4	Tolerances on dimensions and shape, including minimal thickness	Yes	Based on dimensional survey.
5	Bend radius to thickness ratio, if relevant	If required	If required, determined by destructive tests.
6	Metallic coating composition, designation and layer mass and thickness	Yes	If required, determined by non-destructive or destructive tests and visual inspection
7	Adhesion of metallic coating	Yes	Based on visual inspection
In addition, if the steel is to be welded, its weldability shall be declared as follows:			
Item	Property	To be declared	Procedure
8	A maximum limit for the carbon equivalent of the steel, or;	If required (usually not required as welding procedures are often not used)	Maximum to be declared from manufacturer's test certificates.
9	A declaration of its chemical composition in sufficient detail for its carbon equivalent to be calculated		Determined by non-destructive and destructive tests.

Section L.2.5 provides a commentary on each material property that must be declared.

L.2.5 Commentary on the required properties

Yield strength & Tensile strength

The same conclusions from section 2.5.1 of this document are applicable.

It is not expected that cold formed light gauge elements erected before 1970 suitable for reuse can be found.

According to EN 10346 [109], the tensile tests shall be performed without coating, in the test direction given in Tables 7 to 11 and section 7.2.5.2 of the same standard.

Elongation after fracture

The same conclusions from section 2.5.2 of this document are applicable.

According to EN 10346, the tensile tests shall be performed without coating, in the test direction given in Tables 7 to 11 and section 7.2.5.2 of the same standard.

Geometric tolerances and limitations

The geometric tolerances on dimensional shape shall comply with EN 10143 [110].

EN 1993-1-3 [116] specifies minimum thicknesses for cold formed elements.

The following limits must be respected:

- For sheeting and members: $0.45mm \leq t_{\mathrm{cor}} \leq 1.5mm$
- Connections: $0.45mm \leq t_{\mathrm{cor}} \leq 4mm$

Where t_{cor} is the plate thickness without any coating material.

According to EN 1993-1-3 section (2), if thicker or thinner materials are used, the load bearing resistance need to be determined by a design assisted by testing.

According to EN 1090-4, the following minimum thicknesses shall apply:

Profile steel sheets:

Decking: $t_{\mathrm{N}} \geq 0.75\ mm$

Roof coverings: $t_{\mathrm{N}} \geq 0.50\ mm$

Floors: $t_{\mathrm{N}} \geq 0.75mm$

Walls and wall claddings:

Outer skin: $t_{\mathrm{N}} \geq 0.50\ mm$

Single skin or inner skin: $t_{\mathrm{N}} \geq 0.50\ mm$

Liner trays: $t_{\mathrm{N}} \geq 0.75mm$

Structural members:

Purlin: $t_{\mathrm{N}} \geq 0.88\ mm$

Spacer profiles in roofs and walls: $t_{\mathrm{N}} \geq 0.75\ mm$

Edge stiffening profiles: $t_{\mathrm{N}} \geq 1.00\ mm$

Edge trims: $t_{\mathrm{N}} \geq 0.75\ mm$

Restraint members: $t_{\mathrm{N}} \geq 0.88\ mm$

t_{N} is the nominal thickness of the element (with the coating system).

In addition to the referred requirements, EN1090-2 and EN1090-4 tolerances must be respected.

Bend radius to thickness ratio

As the reclaimed steelwork is already bent, there is no need to specify this property. A visual inspection to assess possible cracks and the adhesion of metallic coating nearby the bend region shall be undertaken for each reclaimed element.

Metallic coating composition, designation and layer mass

The composition of the metallic coating needs to be specified according to EN 10346. Section 3 from EN 10346 specifies the key chemical components for each coating type. All members must be tested by non-destructive test procedures.

Coating type	**Description EN 10346 section 3**	**Characteristics EN 10346 section 3**	**Appearance EN10346 section 7.4**
Z	application of a zinc coating by immersing the prepared strip in a molten bath of zinc	The zinc content is at least 99%.	**Normal spangle (N):** The finish is obtained when the zinc coating is left to solidify normally. Either no spangle or zinc crystals of different sizes and brightness appear depending on the galvanizing conditions. The quality of the coating is not affected by this. If a pronounced spangle is desired, this shall be indicated specially at the time of enquiry and order. **Minimized spangle (M):** The finish is obtained by influencing the solidification process in a specific way. The surface will have reduced spangles, in some cases, not visible to the unaided eye. The finish may be ordered if the normal spangle does not satisfy the surface appearance requirements.
ZF	application of a zinc-iron coating by immersing the prepared strip in a molten bath of zinc and a subsequent annealing	The zinc content of the bath is at least 99%. The annealing produces an iron-zinc coating with an iron content of normally 8 % to 12 %.	The regular zinc-iron alloy coating results from heat treatment in which iron diffuses through the zinc. The surface has a uniform matt grey appearance.
ZA	application of a zinc-aluminium coating by immersing the prepared strip in a molten bath of zinc-aluminium	The composition of the bath is approximately 5% aluminium, small amounts of mischmetal and the balance zinc.	The coating finish has a metallic lustre that is the result of unrestricted growth of the zinc-aluminium crystals during normal solidification. Crystals of different sizes and brightness may appear depending on the manufacturing conditions. The quality of the coating is not affected by this.
ZM	application of a zinc-magnesium coating by immersing the prepared strip in a molten bath of zinc-aluminium-magnesium	The composition of the bath is sum of aluminium and magnesium from 1,5 % to 8 %, containing minimum of 0,2 % magnesium and the balance zinc.	Due to the normal solidification of the coating, the surface has a uniform metallic appearance and may be slightly matt to bright. It may also show variations in appearance and a tendency to darkening.
AZ	application of an aluminium-zinc coating by immersing the prepared strip in a molten bath of aluminium-zinc-silicon	The composition of the bath is 55% of aluminium, 1,6% of silicon and the balance zinc.	The products are supplied with a normal spangle. Normal spangle is a coating finish, having a metallic lustre, which is the result of unrestricted growth of the aluminium-zinc crystals during normal solidification. If a pronounced spangle is desired, this shall be indicated specially at the time of enquiry and order.
AS	application of an aluminium-silicon coating by immersing the prepared strip in a molten bath of aluminium-silicon	The composition of the bath is 8 % to 11 % silicon and the balance aluminium.	Deviating from other hot-dip coated products, a relatively pronounced (Al-Fe-Si) alloy layer is formed over the base material during hot-dip coating. This shall be taken into account for further processing. If a maximum value for the mass of this layer is required, this shall be especially agreed upon at the time of enquiry and order. The test method is described in Annex C of EN 10346.

For the coating layer weight assessment, section 7.3 from EN 10346 must be considered. The single spot minimum coating mass value may be used to assess the actual coating designation according to EN 10346 section 7.3.

For coating thickness assessment, recommendation from EN10346 section 7 shall be applied.

EN 13523-1 [111], Coil coated metals — Test methods — Part 1: Film thickness.

Adhesion of metallic coating

For many purposes, the adhesion test has the objective of detecting any adhesion less than "perfect". For such a test, one uses any means available to attempt to separate the coating from the substrate. This may be prying, hammering, bending, beating, heating, sawing, grinding, pulling, scribing, chiselling, or a combination of such methods. If the coating peels, flakes, or lifts from the substrate, the adhesion is less than perfect.

Existing steelwork was already bent. Therefore, visual inspection for assess this. There shall be no cracks at the bended areas visible by the naked eye (EN1090-4 section 6.1).

Relevant standards for bending tests:

EN 13523-6 [112], Coil coated metals — Test methods — Part 6: Adhesion after indentation (cupping test) EN 13523-7 [113], Coil coated metals — Test methods — Part 7: Resistance to cracking on bending

EN 10346 section 7.10 specifies that adhesion of the coating shall be testing by using "an appropriate method", referring that the selection of the method is "left to the discretion of the manufacturer".

Chemical composition

Chemical composition is important to establish the durability and particularly the weldability of the reclaimed structural steel. The stockholder must provide a declaration of chemical composition, based on non-destructive and destructive tests. The chemical composition declaration must provide measures of certain chemical elements according to the relevant Standard. For cold forming products, EN 10346 may be used, where in table 2 of the same standard the chemical composition for steels for construction is presented. Table 6 of EN 10346 presents permissible deviations of the product analysis are provided.

The intent of this declaration is to enable the carbon equivalent value (CEV) to be calculated, which is a key measure of weldability.

L.3 Design recommendations

The design recommendations from section 4 shall be considered.

For Class C reclaimed steelwork, as a wide range of steel grades are likely to be available, it is not recommended to assumed a yield and tensile strengths of more than 120 MPa and 260 MPa respectively. See EN 10346 section 7 and EN 1993-1-3 section 3 for more detail.

L.4 Assessment of reclaimed steelwork

Recommendation specified in section 5 are also applicable for cold formed light gauge elements.

L.5 Responsibilities of the holder of stock

Recommendation specified in section 6 are also applicable for cold formed light gauge elements.

The additional material properties described in section L.2.4 shall be specified. Annex C recommendation shall be adapted to cover the required properties for light gauge cold formed elements.

L.6 Test programme – comprehensive testing

The recommendations for comprehensive testing procedure (testing protocol) require 100% non-destructive testing of the reclaimed structural members in combination with non-statistical or statistical destructive testing.

The non-destructive testing of all reclaimed members establishes that a group of members (see Section 6.1) can be represented by destructive test results from one or more representative members from the group. Purlins and side rails and other type of elements shall be treated separately for each type of profile cross-section (as individual groups) with a maximum of 4 tonnes.

Non-statistical testing is not recommended for reclaimed cold formed steel elements.

Statistical testing requires destructive testing to assess material characteristics in accordance with EN 1990. Statistical testing exceeds the requirements for 'new' steel specified in the product Standard.

The table below relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition (if needed) according to the building Consequence Class.

Table L.27 – Testing approach related to Consequence class for cold formed light gauge steel

Consequence class	NDT	Minimum number of DT	Acceptance approach
CC1	All members to be subject to non-destructive tests to establish yield strength, ultimate strength (and CEV if required; usually not required as welding procedures are often not used with cold formed elements).	3	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)
CC2		5	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)
CC3		7	Statistical for yield strength, ultimate strength and elongation (maximum value of CEV)

The use of hardness test to assess the likely steel grade for light gauge cold formed elements is possible according to ISO 6507-1 [50]. Appropriate considerations for the test force according to Annex A of ISO 6507-1 must be considered. To undertake hardness measure, coating system need to be removed. The testing area needs to be repaired by a zinc-rich spray.

Samples for destructive tests shall be collected from the profile webs, as far away as possible of any bent part. The coupons here can be simple strips of 250x20mm collected from different elements.

L.7 Fabrication issues

Light gauge cold formed elements are likely to be welding free. However, the disassembly process may cause damage to the steelwork. Problems with existing coating systems are not expected. However, the steelwork aging certainly reduced the coating mass (which will be affected by building/steelwork exposure environment). This means that coating mass for the subsequent life cycles are reduced, reducing the durability of the coating system. It is expected that the testing protocol will define the remaining/available coating mass for the reclaimed cold-formed steelwork.

L.8 Reliability assessment for light gauge cold formed elements

There is no available comprehensive data from tests to use as a reference to perform the reliability assessment of cold formed reclaimed steelwork. From the product standard, the data in table L.30 can be obtained for the characteristic values of yield and tensile strengths for the different steel grades according to EN 10346. The proposed minimum values for yield and tensile strength to be used for the reliability assessment are presented in table L.28.

Table L.28 Steel grade according to EN 10346.

Steel grade	f_y [N/mm^2]	f_u [N/mm^2]	f_u/f_y	Elongation %
220	220	300	1.36	20
250	250	330	1.32	19
280	280	360	1.29	18
320	320	390	1.22	17
350	350	420	1.20	16
390	390	460	1.18	16
420	420	480	1.14	15
450	450	510	1.13	14

Data from 46 tensile tests was collected from several resources. Mean values and coefficient of variation were calculated for each steel grade. The results used to produce table L.30 were derived from the values presented in table L.29. As buckling curves don't depend of the yield strength for cold formed elements, average values for mean strength (yield and tensile) and coefficient of variation are proposed for all steel grades up to S450.

Table L.29 Tensile test data

Steel Grade	f_{yk}				f_{uk}			
	Mean	Ratio	Sdev	COV	Mean	Ratio	Sdev	COV
S280	295.975	1.057	6.012	0.020	392.451	1.090	16.341	0.042
S320	328.667	1.027	4.163	0.013	431.667	1.107	8.505	0.020
S350	406.427	1.161	26.332	0.065	471.315	1.122	27.846	0.059
S450	470.208	1.045	21.436	0.046	560.961	1.100	47.804	0.085
Average	**375.319**	**1.073**	**14.486**	**0.036**	**464.098**	**1.105**	**25.124**	**0.051**

Table L.30 Proposed values for the reliability assessment of cold formed elements to EN 10346.

Steel grade	Yield Strength						Tensile Strength				
	f_y [N/mm^2]	Mean X characteristic value	COV	Min [N/mm^2]	Mean [N/mm^2]	f_u [N/mm^2]	Mean X characteristic value	COV	Min [N/mm^2]	Mean [N/mm^2]	f_u/ f_y mean
220	220	1.100	0.04	226	242	300	1.10	0.05	303	330	1.364
250	250	1.100	0.04	257	275	330	1.10	0.05	333	363	1.320
280	280	1.100	0.04	288	308	360	1.10	0.05	364	396	1.286
320	320	1.100	0.04	329	352	390	1.10	0.05	394	429	1.219
350	350	1.100	0.04	360	385	420	1.10	0.05	424	462	1.200
390	390	1.100	0.04	401	429	460	1.10	0.05	465	506	1.179
420	420	1.100	0.04	432	462	480	1.10	0.05	485	528	1.143
450	450	1.100	0.04	463	495	510	1.10	0.05	515	561	1.133