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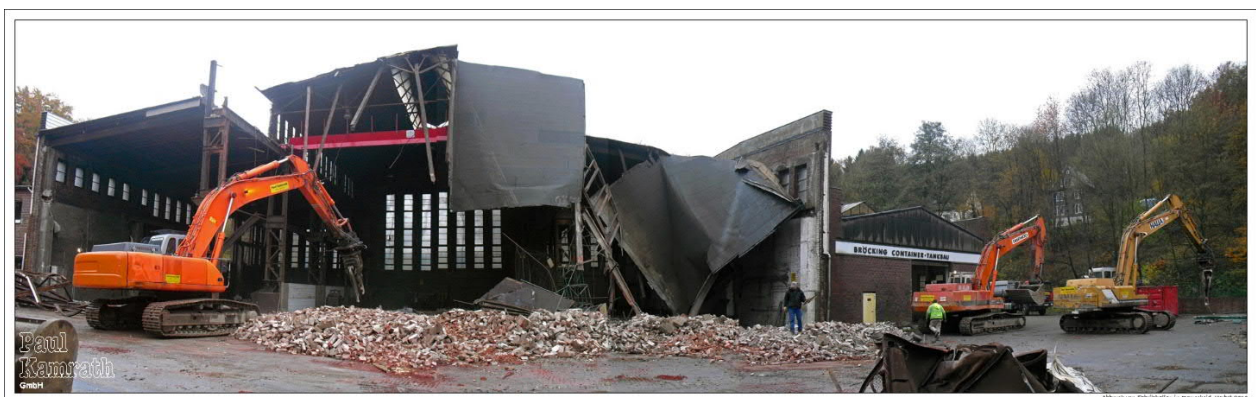
PROVISIONS FOR GREATER REUSE OF STEEL STRUCTURES

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Safe and efficient deconstruction

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Executive summary

This report (D2.1a) is part of the deliverable D2.1 of the PROGRESS project. It summarizes the research conducted under Tasks 2.1 and 2.2.

The objectives of these tasks are:

- To understand the challenges faced by contractors in deconstructing existing single-storey, steel-framed buildings, both in terms of safety and in terms of preserving the integrity of the recovered products for subsequent reuse.
- To provide advice on conducting pre-demolition audits of single-storey, steel-framed buildings, particularly with a view to enabling their deconstruction and reuse.

The deconstruction protocol for single storey steel buildings is presented in a separate report D2.1b.

Scope of this report

Other than the general introduction to demolition and deconstruction practice, the scope and focus of this report is existing single-storey, steel-framed buildings (SSB) constructed in Europe since around 1970. Older SSB buildings, while still potentially reusable, are not within scope. This is for consistency with other PROGRESS deliverables.

All main elements of steel-framed SSB are included, i.e. the primary and secondary structural elements and metal-based cladding systems and elements. However, greater focus is on the primary structural elements; these being the most likely elements to be suitable for deconstruction and reuse.

In terms of the structural forms considered, the scope is as defined in other PROGRESS deliverables, see for example Section 2.3 in deliverable D3.1. Structural forms include:

- Portal frames from hot-rolled and fabricated sections
- Truss or lattice structures from hot-rolled open or closed sections and cold-formed sections
- Braced box structures.

Secondary structural steel elements include hot-rolled and cold formed sections as purlins in roof structures and side-rails in wall structures.

Cladding elements include sandwich panels and built-up systems comprising two metal sheets separated by some form of spacer system and thermal insulation.

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1. Introduction to general demolition and deconstruction practice

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 or so 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. The boundary conditions of demolition sites, particularly in urban areas, are generally built-up areas constrained by infrastructure including roads and railways and frequently, underground transport and utilities. Consequently, uncontrolled demolition methods are often unsuitable and controlled methods, which are more conducive for deconstruction, are more common in these situations.

Another important issue is waste management, especially in highly populated areas of Europe. The volume of down-cycled concrete or masonry from demolition projects (by far the largest waste stream from demolition) is generally about twice as much as the local demand, e.g. as an alternative to natural gravel. In general, the need for crushed concrete or masonry depends on the local availability of aggregates. Thus, if natural gravel exists locally only in small quantities, willingness to use crushed concrete is higher and recycling (crushing) becomes more important as an alternative resource. In many situations, crushed concrete and masonry is of insufficient quality or is too contaminated to reuse as an aggregate in concrete and therefore is frequently used as low grade hardcore or as a piling mat.

Current demolition practice is influenced by the value of the materials and products that can be recovered. The highest recycling prices are achieved for metals such as steel, copper and aluminium. The typical end-of-life scenario for scrap metals is currently recycling by remelting. In this way, the value of the material is retained but the value of the product is not. In addition, the process of remelting metals requires significant energy which is not required if the product is retained and reused.

An alternative to demolition is to deconstruct the building with the objective of reclaiming construction products so that they can be reused in a subsequent application. Recognition that current practice of construction, using primary resources, and demolition is unsustainable is forcing the construction industry to consider how they can deliver a more circular economy by reusing components reclaimed from existing buildings and designing buildings which can be more easily deconstructed and reused in the future.

1.1 Definitions

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. Deliverable D1.1 defines the different types of reuse and their classification and these definitions are used in this report.

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.

More generally, and widening the definition of recycling to all generic construction materials, definitions of the type or level of recycling include:

‘True’ or **closed loop recycling** in which the recovered material is processed into a new product of the equivalent or higher utility or value.

Open loop recycling or ‘downcycling’ in which the recovered material is converted or processed into a new product or material of different, generally lower, utility or value. The common example from the demolition of buildings is crushing of concrete or masonry to produce aggregate.

Incineration with energy recovery in which the recovered (generally organic) materials are incinerated to reduce the volume of waste requiring disposal and beneficially using the energy recovered.

The above definitions are reflected in the EU waste hierarchy which has been a cornerstone of EU waste management policy for many years and reflects the hierarchy of most preferred waste management options with respect to both resource use and environmental impact.

Demolition, in the context of buildings, is the safe and efficient tearing down, destruction or dismantling of buildings. Historically, little thought was given to local environmental impact and/or separating waste-streams to facilitate recycling however, more recently, environmental and waste management requirements have influenced demolition practice so that new demolition techniques have been developed and adopted.

Deconstruction, in contrast to demolition, describes the process of dismantling a building (or parts) such that the condition of the recovered elements is preserved so that, in theory at least, these elements can be reused again.

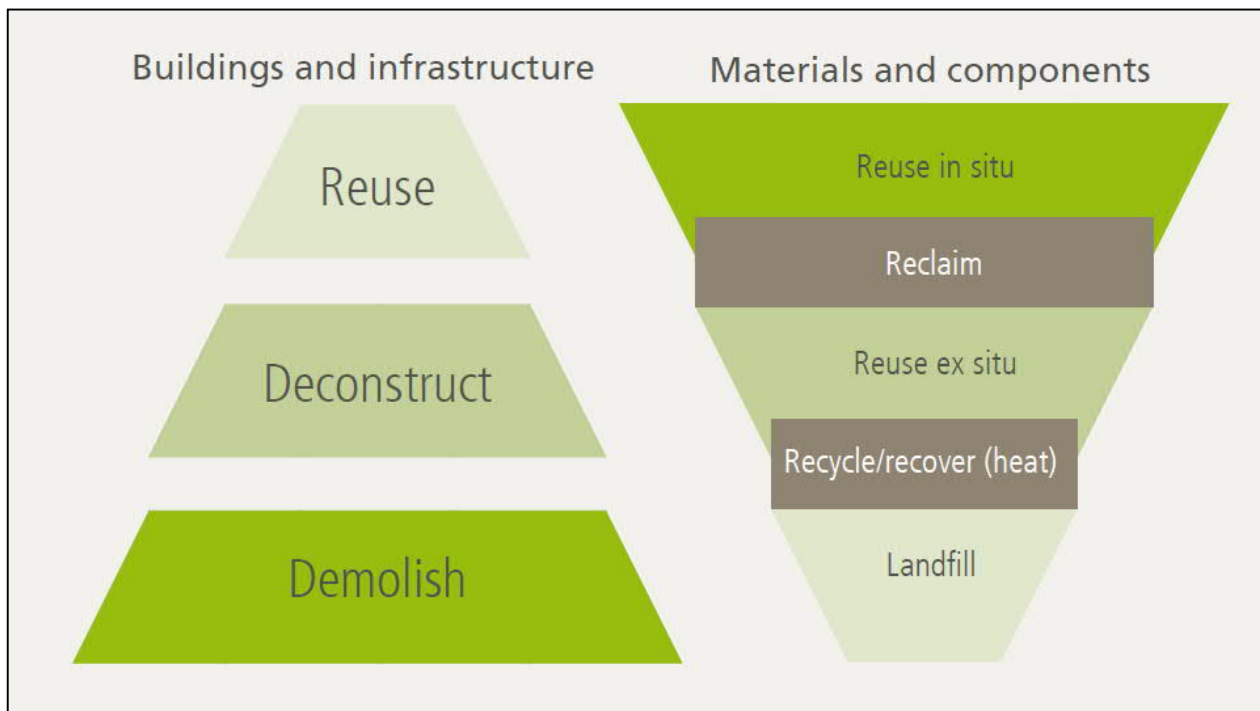


Figure 1.1 EU waste management hierarchy applied to buildings and materials



Figure 1.2 Modern demolition practice is generally a destructive technique without consideration of recovery of elements of the building for possible reuse

1.2 Demolition practice

The demolition industry has undergone major transformation within the last few decades. Traditionally, demolition was a labour intensive, low skill, low technology and poorly regulated activity, dealing mainly with the disassembly and demolition of simply constructed buildings. More recently, it has followed the trend of all major industries and mechanized the processes by replacing manual labour with machines. This is because of the increased complexity in building design, the financial pressures from clients, health and safety issues, regulatory and legal requirements and advances in plant design. The industry now employs fewer, but more highly skilled operators and very expensive specialized equipment. Traditionally, much of the demolition contractors' income was from the sale of salvaged and recycled materials. Today income is mostly generated from the contract fee; demolishing the building as quickly and as safely as possible. Nevertheless, substantial amounts of materials and components are recovered or reclaimed but is generally downcycled and therefore is not used to its fullest potential.

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 main issue is to identify the factors relevant to the choice of demolition methods in a particular case, and determine the influence that decision has on the eventual reclamation of materials. The demolition process relies on one of eight basic methods: pulling, impact, percussion, abrasion, heating (or freezing), expanding, exploding or bending. Table 1.1 and Table 1.2 summarise traditional and some innovative methods of demolition respectively.

Table 1.1 Traditional demolition methods [1]

Method	Tools/Equipment required	Application suitability	Preparation Procedure	Comments
By Hand	Portable tools including: crowbars or mattocks pneumatics drills power saws	Now reserved mainly for high and inaccessible areas, or architectural salvage	Demolition proceed in a top-down fashion, floors in buildings are removed prior to demolition to prevent premature collapse due to weight of debris collection	Oldest method Labour intensive and slow Expensive if labour costs are high Debris is easily segregated for salvage purposes Possible safety implications of working at height.
Pulling	Wire Rope Vehicle to provide pulling power	Brick or masonry structures	Remove all stabilising components e.g. pipework, beams and lintels Detach from adjacent buildings Set rope around section of brickwork and drag to collapse	Causes dust nuisance Time consuming if uncontrolled collapse occurs Destabilised for a period before demolition – safety implications.
Impact	Demolition ball between 0.5 and 2.0 ton suspended from a crawler crane	Fairly large, brick, masonry, concrete or r.c.	Remove floors as per hand Buildings > 30m high should be reduced by hand before using ball. Detach from adjacent	Widely used in European countries Produces noise, vibration and dust Can be set to drop weight vertically onto floors and foundations
	Pusher arm (extended arm and steel pad fitted to tracked vehicle)	Normally brickwork	Arm is positioned at top of wall and forward motion applied	Popular in late 1970s More controllable and versatile than demolition ball Restricted in terms of height of wall to be demolished
Percussion	Hammer: hydraulic or pneumatic: handheld or vehicle mounted	Concrete, brickwork, masonry and steel. Capable of partial demolition	Involves repeated impact	Pneumatic hammer is smaller and lighter, but noisier than hydraulic Both produce persistent noise
	Hydraulic breaker, four or five types available		Jaw-like attachments break or cut concrete and steel by holding and crushing into sections	Produces small size materials, no need for secondary crushing before use as recycled aggregate Reasonable cost

Table 1.2 Innovative demolition methods [1]

Method	Tools/Equipment required	Application suitability	Preparation Procedure	Comments
Expansion/ bursting: Static	Buster with wedges	Concrete or masonry	Mechanical wedges forced into pre-drilled holes and expanded by hydraulic pressure	Create noise and dust at drilling stages, otherwise nuisance free. Slow.
	Chemical expansive agent	Cannot be used for narrow structural members, r.c. or pre-stressed concrete	E.g. Injection of unslaked lime composite mixed with water into predrilled hole, hydration of mixture causes expansion which splits surrounding material	Good for working in close proximity to other buildings.
Dynamic	Explosives, high-pressure water, gas pressure		Apply to pre-drilled holes	
	CARDOX		Liquid carbon dioxide in metal tube inserted in pre-drilled hole, heated by electric filament, causes expansion	
Abrasive	Hammer drill, hand operated, or vehicle mounted	General	Reduces concrete to dust using rapidly rotating and hammering bit	Vehicle mounted hammer drill used for the destruction of mass concrete
	Diamond boring machine	Drilling concrete	Diamonds form abrasive interface	Quite slow and expensive
	Diamond disc cutter	Capable of cutting r.c.		
	Diamond wire saw	Cuts around circumference of concrete sections		Noisy, but produces little dust or vibration
	High-pressure water jet	Can be used to cut cement grout to release components	250-300 Mpa water jet forced through small nozzle can cut plain concrete. Addition of particles of steel allows it to cut through r.c.	Expensive in comparison to other methods. Uses large quantities of water

Heating	Thermic lance (metal tube, approx. 3m long containing aluminium alloy or iron alloy rods)	Reinforced concrete	Tip of lance heated to 1000C oxygen fed to tip produces flame 2500C, can melt reinforcing rods and concrete	Cutting of some materials can cause toxic fumes
	Fuel Oil Flame		Combustion of mixture of kerosene and oxygen gas produces flame to melt concrete	
	Argon-hydrogen/Argon-nitrogen plasma, and carbon dioxide laser beam		Development stage (Kasai 1998)	Specialist use only
	Heating and peeling using electrical conductors		Drill holes to reveal rebars, attach electrical conductors to induce current through the rebars, causes heating which dries out surrounding concrete so it peels	Little noise or dust after drilling stage. Could use microwaves to dry out concrete, omits use of drilling but expensive
Cryogenic		Reinforced concrete, steel framing	Quick-freezing steel in a restricted area makes it brittle	Time consuming, limited use and expensive
Bending	Jack-up.	R,c, horizontal members	Application of point force upwards against floor slab induces bending and shearing forces into slab designed for down loading only	Developed in Japan, rarely used.

Demolition practice is building and location specific and will be subject to local regulatory requirements. For example, the preferred demolition method for a low-rise building in a rural location is quite different from the demolition of a large multi-storey building in a city centre location. In general however, demolition procedures for all projects include:

- Site compound and security set-up
- Intrusive pre-demolition surveys (such as; asbestos survey for demolition, structural survey, hazardous materials surveys, etc)
- Isolation of utilities and removal of meters
- Disconnection of utilities
- Asbestos removal (in accordance with the Control of Asbestos Regulations)
- Soft strip (taking the structure back to construction materials including the removal of windows and door frames)

- Superstructure demolition with special measures as constraints demand, such as de-build or protection of adjacent structures
- Processing of superstructure arisings
- Slab and foundation demolition
- Processing of arisings
- Site finishes as required.

1.2.1 Demolition methods

There is a range of demolition methods that may be employed on a project. The most appropriate and cost-effective approach will depend mainly on the building type and location. In addition, the redevelopment programme and any local planning or other regulatory requirements may also influence the chosen demolition method.

Preferred demolition techniques have also evolved over time. In particular, the development of high-reach excavators with specialist attachments has strongly influenced demolition practice. See for example Table 1.3 which gives the breakdown by demolition technique in Germany in 2002.

Table 1.3 Breakdown of demolition techniques in Germany [2]

Main techniques (Usage quota in Germany, 2002)	
Deconstruction by excavators with shears etc.	82%
Exploding	4%
Deconstruction with wrecking balls	3%
Other machines	3%
Percussion, abrasion, heating etc.	3%
Robots	0.3%
Other	1.7%

In addition to the technological advances of demolition excavators, tightening legislation relating to health and safety has led to a greater uptake using excavators as the preferred and most cost effective demolition technique for most building types.

The following describes the principal demolition methods available.

Explosives

Explosives allow rapid and complete demolition where other methods may be dangerous or slow. This requires extensive use of the police to enforce exclusion zones as well as pre- and post-demolition structural inspections for a substantial radius (in the order of quarter or half a mile).

However, recent developments in high-reach machinery mean that buildings less than 22 storeys are generally demolished by machine.

Hand demolition

These methods may be used for small-scale projects, or when demolition has to be carried out in a more sensitive manner due to site constraints such as; proximity to uncapped mineshafts, overhead utilities, pedestrian access, adjacent structures, or structural instability.

It involves the progressive demolition of a structure by operatives using hand tools. In general, the order of demolition is the reverse of that of construction.

Machine demolition

This is by far the most frequently-used method and reduces the need for people to work at height, and significantly reduces manual handling.

Common techniques include:

- Swinging ball: Heavy steel ball suspended from a crane jib.
- Wire rope: Can be used for demolishing parts of a structure.
- Pushing arm: A machine fitted with a hydraulic pushing arm. This is operationally limited by height, so a building should be reduced by other methods first.

Other methods

Other methods that can be used include:

- Gas expansion burster: Used for 'bursting out' concrete in a prepared cavity.
- Hydraulic expansion burster: Similar to gas but uses wedges and pistons.
- Thermal reaction: Used together with wire pulling, this involves generating a thermal reaction which causes members to lose strength.
- Thermic lancing: Drilling or cutting silica materials by thermo-chemical action.
- Drilling and sawing: Used for cutting openings in reinforced concrete.

In addition to the demolition technique (above) the sequencing of the building demolition can also vary.

Top-down method

Top down (or floor-by-floor) demolition is essentially a method of demolition generally used for high rise buildings. The process involves the deconstruction of the property, floor by floor, from the top down to the bottom. This method is the safest method in which to undertake the demolition of high and medium rise buildings, it provides a strong level of control in terms of the structure of the building protecting those working in and around the demolition site.

Floor-by-floor deconstruction is a complex and technically challenging procedure that involves the highest degree of engineering investigation, structural testing and design throughout the planning and implementation stages.

The method of top down demolition generally involves a scaffold being erected around the building and then machinery being hoisted to the working level. The process is technically challenging and requires a good knowledge of the construction of a building and the engineering controls that need to be put into place.

Figure 1.3 shows an excavator being hoisted onto the multi-storey building undergoing top-down demolition. Tower cranes are generally installed to lift excavators and equipment to and from the working floors and to assist in clearing skips and lowering structural elements to the ground.

Structural deflection testing of the floors will best determine the size, type and number of excavators that can be safely employed. The choice of attachments used will also vary depending upon the nature and design of the structure along with environmental constraints.



Figure 1.3 Hoisting an excavator using a tower crane for top-down demolition of a large multi-storey building in London

Demolition from top to down means that demolition proceeds from the roof to the ground in a progressive manner. Particular sequences of demolition may vary depending on site conditions and the structural elements to be demolished. The demolition sequence is determined according to the building layout and construction, as well as the given site conditions. Generally, the following sequence is applied:

1. To ensure safety at later stages, all overhanging structures such as verandas, balconies, emergency stairs, etc. should be demolished prior to the main demolition. Roof installations (lifts, air conditioning units, etc.) should be removed to avoid them falling down during the demolition process.
2. Demolition of floor slabs begins at mid span, working towards the supporting beams.
3. Floor beams are demolished in the following order: (1) cantilevered beams, (2) secondary beams and (3) main beams.
4. Non-load bearing beams are first removed. Subsequently, load bearing beams are removed from the top down.
5. As soon as possible, the ground floor should be destroyed to avoid demolition waste lying on it. Due to the enormous load, this floor could otherwise collapse.

For relatively low rise buildings, top-down demolition may be undertaken using high-reach excavators using the appropriate crushing or shearing attachments. Figure 1.4 shows this demolition technique for a concrete-framed building.

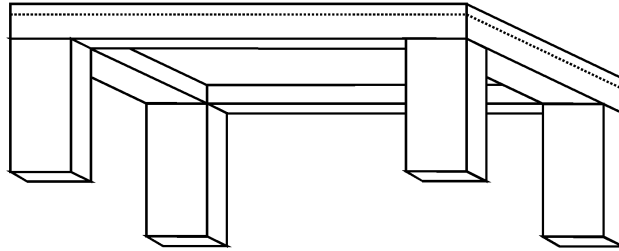


Figure 1.4 Typical top-down demolition of a concrete building using a high-reach excavator

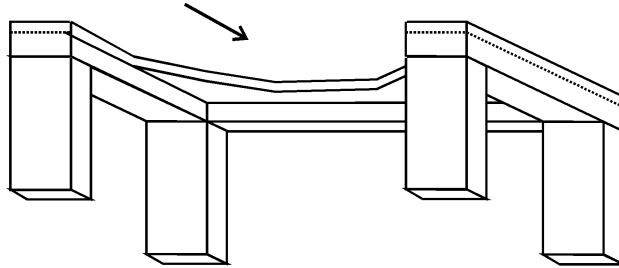
After demolition of all non-load bearing structural elements, the bearing columns are left. In the next step, the columns will be demolished beginning with the top level. After that, the demolition process repeats with the next floor.

Figure 1.4 shows the demolition of a building using the general top down sequence. Figure 1.7 also illustrates the technique.

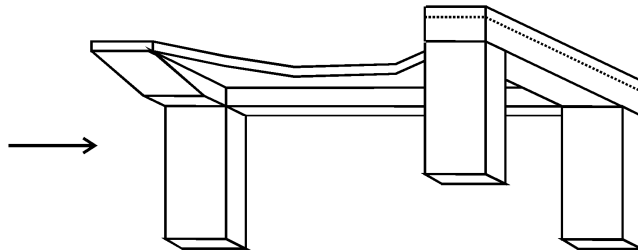
Typical structure of columns and slabs.



Remove the slab.



Remove the front columns.



Remove the rear columns and start with the neighbouring field again.

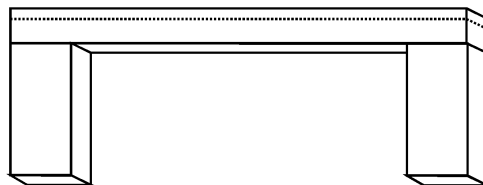


Figure 1.5 Typical top-down demolition sequence for a concrete building using an excavator with a concrete pulveriser attachment

In addition to using excavators, there are proprietary top-down demolition techniques such as self-descending DESPE system shown in Figure 1.6. This modular steel platform is supported on the existing columns on hydraulic supports and encloses three floors which are demolished before descending to the next three floors. This type of system avoids the use of scaffolding and although expensive for medium-rise buildings is fast compared to other techniques. It may also be preferred where implosion techniques are not suitable.



Figure 1.6 DESPE modular, top-down demolition system used to demolish an apartment building in Glasgow

Room-by-room method

The Room-by-Room method is generally applicable for relatively small, often residential, buildings constructed from masonry. These buildings do not follow a general raster of columns and beams. Once again, the demolition process is top-down. First, ceilings are removed. Then the floor beams and finally the walls are removed. With this technique, the demolition follows the structure of the building given by its different rooms. The building itself is divided in parts, where each room is treated as a separate object. This technique is shown in



Figure 1.7 Demolition of a large brick house using the Room-by-Room method

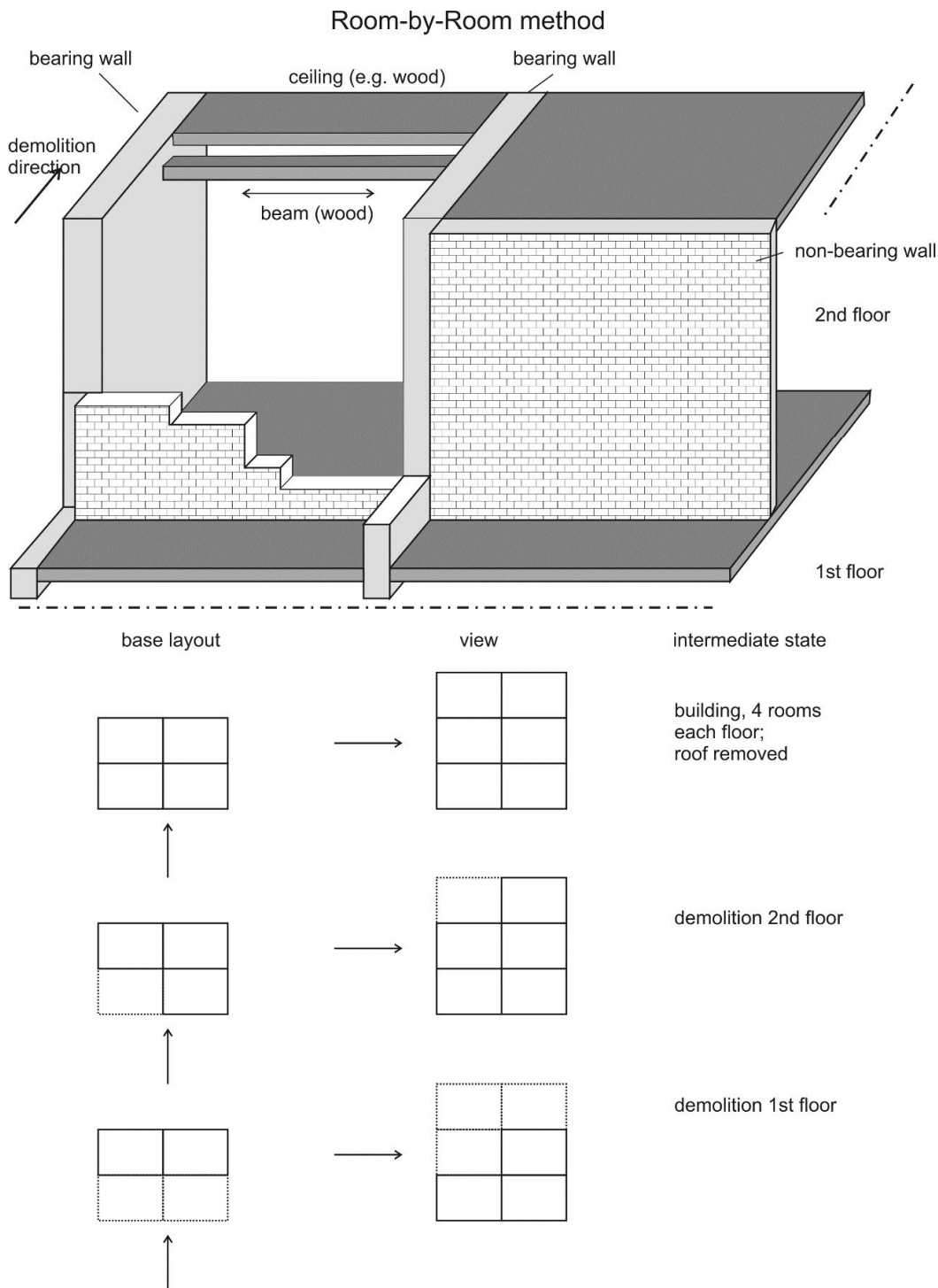


Figure 1.8 Demolition of general buildings using the Room-by-Room method. This method is a special variant of the top-down technique.

Demolition of masonry walls

A common risk during the demolition of masonry structures is the uncontrolled outward collapse of walls particularly at the corners of the building. While concrete structures do not allow displacement, masonry walls tend to deform during demolition. If too much deformation is applied to the wall, the

structure can crack and collapse. Thus, masonry walls need to have inserted a “demolition slot” that prevents displacement in two different directions see Figure 1.9.

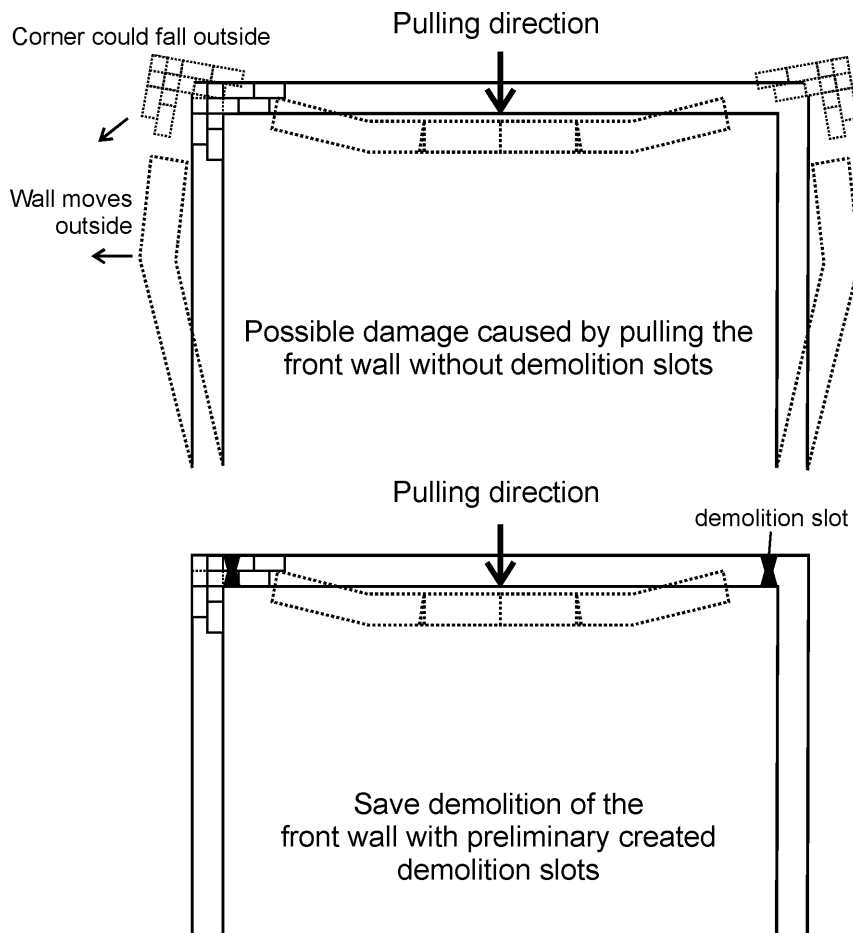


Figure 1.9 How to demolish front walls made of overlapping masonry structures and how to avoid the danger of corners falling. outwards.

1.2.2 High reach excavators

The use of excavators for demolition has grown significantly over recent decades. Driven by cost and health and safety legislation, excavators and particularly high-reach excavators have become the preferred and most cost-effective demolition technique for most building types.



Figure 1.10 Excavator being used to demolish a low-rise steel-structure

First introduced in 1970s, a high or ultra-high reach demolition machine is defined as a 360° bespoke excavator base equipped with a purpose-built, multi-boom or telescopic boom that has a working height of 15 metres or more. Most multi-boom or telescopic boom machines are capable of safe operation without the use of stabilising outriggers, although these may be fitted dependant on the manufacturer's specification.

This type of equipment is typically mounted on a tracked machine base that has undergone modifications including strengthening, widening and lengthening to allow it to work in a safe manner when the front end equipment is fully extended.

These machines must be fitted with a Falling Object Protective Structure (FOPS) and a Falling Object Guard Screen (FOGS) cab to conform to BS EN ISO 3449 & ISO 10262 to protect the operator see Figure 1.11. In many instances, the machines may also be equipped with additional protective equipment including laminated glass.



Figure 1.11 Falling object protection cage fitted to an excavator

Every excavator will utilise a variety of attachments to perform breaking, cutting, crushing and pulverising duties. These attachments include:

- Combi-cutter crusher
- Steel Shear
- Selecta grab
- Hydraulic Pulverisers
- Hydraulic Hammers.

Pulveriser attachments (Figure 1.12) are used to crush concrete structural elements.



Figure 1.12 High-reach excavator demolishing a concrete structure (left). Rotating pulveriser (right)

Of particular relevance to the demolition of steel structures are the steel shear attachments which are capable shearing large steel sections.



Figure 1.13 Steel shear attachment pulling-down and shearing a steel structure

New excavators are also being developed to further improve the efficiency and safety of demolition. These include the excavator shown in Figure 1.14 which has two booms in this example, with a grapple on one arm and a steel shear on the other. Such an excavator could support a steel section using the grapple while shearing it using the other arm.



Figure 1.14 Hitachi two-boom excavator with grapple and steel shear attachments

1.3 Deconstruction practice

Deconstruction with a view to reclaiming elements of the building for reuse is rarely done. Despite the environmental and the potential economic benefits, relative to demolition, there are two key barriers to deconstruction. These are:

1. The additional time (and associated cost) required relative to traditional demolition techniques. Demolition is generally part of the redevelopment of an existing site and redevelopment programmes frequently do not allow the additional time required to deconstruct existing buildings.
2. The health and safety implications of deconstruction in particular working at height.

1.3.1 Barriers to deconstruction and reuse of structural steelwork

Over recent years, demolition contractors have evolved from small and medium-sized firms using mainly manual labour, to large companies replacing manual labour with machinery (Kay and Essex, 2009 [3]; BCSA, 2016 [4]. Vukotic (2013) [5] identified three barriers to reusing steel from the perspective of the demolition contractor:

- Health and safety risks particularly linked to working at height
- Additional cost related to more lengthy, manual operations

- Programme (schedule and operational constraints).

These factors are noted by others. Addis and Schouten [6] describe the changes in the industry as favouring recycling over reuse (cost and programme). The study by J. Hurley et al. [1] identifies health and safety as a key driver for using machinery in place of high risk manual labour (health and safety). Allwood et al. [7] identify demolition safety, and the comparatively slow speed of mechanical deconstruction as being key barriers preventing reuse in practice in the UK (health and safety, programme). However, they suggest that health and safety concerns might be addressed if clients allowed more time for the demolition process (programme). J. Hurley et al. [1] suggest that new technologies could be developed to allow careful deconstruction at faster speeds, including machinery to automatically remove bolts in high risk zones (health and safety, programme).

Table 1.3 shows a theoretical comparison of different plant and man-hours required to demolish and deconstruction a steel SSB. The comparison is based on a 40m x 10m SSB with a height of 6m. The comparison was made by Paul Kamrath based on the German market.

Table 1.4 Theoretical comparison of equipment and manual labour required to demolish/deconstruct a medium size steel, SSB

Product/Activity	Quantity	Demolition		Deconstruction	
		Equipment	Hours	Equipment	Hours
Cladding	600m ²	excavator, grab-tool	10	manual, screwdriver	120
Roof: insulation	400m ²	excavator, grab tool	8	manual	80
Roof: steel sheet	400m ²	excavator, grab tool	16	manual, crane	80
Steel structure	8 sections	excavator, shear	32	manual, crane	64
Sorting waste	steel, styropor,...	excavator, manual	32	label, palletize	32
disposal, transport	160to	excavator, trucks	52	crane, trucks	96
		Total	150		472

As shown, in terms of man-hours, deconstruction requires around three times human resources than that required for demolition. This agrees with anecdotal information from the UK which suggests that deconstruction generally takes 3 to 6 times as long as demolition of the same building.

Demolition contractors are a key actor for the growth of the steel reuse market. They are specialised either to demolish or to deconstruct the building, with all necessary equipment. In practice, client development programmes generally dictate timescales which generally do not allow for longer deconstruction programmes. Therefore, a market for steel reuse will only be viable if demolition contractors can extract more value from the sale of recovered structural steel. In the UK, demolition contractors have noted that most steel reuse currently happens in the agricultural and temporary structures market, as these have no requirement for CE marking.

Demolition contractors operate under considerable time pressure, with little notice given before a building needs to be taken down. It is common practice to operate without any existing plans or building documentation, so identifying the potential value of reused steel can be difficult. Work carried out in densely populated urban settings may require more careful deconstruction (top-down demolition), rather than demolition, to avoid damage to nearby building or disruption to neighbouring properties. In these cases, it may be more viable to carefully deconstruct the building with a view to recover the steel elements. However, even in these projects, where an opportunity to reuse the steel

may exist, demolition contractors report that currently, the structural elements are typically sold as scrap for remelting.

Buildings are frequently left unoccupied for long periods of time before decommissioning, while planning permissions are obtained for new buildings. Demolition contractors will often price the demolition contract during this period, but are generally not able to perform detailed pre-demolition audits, or take down the building early. Pre-demolition audits, as recommended by the UK National Federation of Demolition Contractors, and would allow the assessment of the potential value of recovered steel, as well as provide time to find a suitable buyer. Pre-demolition audits also help to improve the health and safety and planning requirements for the demolition.

Demolition contractors rarely own large stockyards and therefore cannot hold large amounts of reclaimed steel, as they sell on the scrap steel quickly to scrap merchants. For reused steel to become common, the contractors would need to not only to find a suitable buyer for the reclaimed steel, but also to store the steel until the new construction begins. When the price of scrap steel is low, the small profit margins for remelting steel provide an incentive to find other markets to sell the steel, and the reuse of steel become more viable. Most demolition contractors believed that if there was an effective market for reused steel, and acceptable profits to be made, they would have no problem in switching to deconstruction of building and the reuse of structural steel.

The concerns about steel certification, expressed by other members of the supply chain, are a central issue for the demolition contractors: steel needs to be fully traceable or certified if it is to be sold for anything other than non-regulated, agricultural buildings. The contractors' interviews said that ideally every beam should be certified although the current costs of doing so are excessive. There was much scepticism about the potential of BIM to solve the certification problem in the future. A digital repository of all structural elements in a building, including their properties and history, was thought to be unlikely, given the difficulty of obtaining even paper plans of buildings being demolished today.

Demolition contractors, in the past, reclaimed a higher fraction of materials and structural steel from demolition jobs. However, recent changes in health and safety regulations has resulted in greater mechanisation in demolition practices, and the contractors expressed little appetite for returning to the labour-intensive practices of the 1960s and 70s.

1.4 Demolition and deconstruction safety and risks

Safety on demolition sites has been a major factor influencing current trends in demolition techniques, especially for steel and concrete structures. The track loader and crawler crane and drop ball have been replaced by excavators with long reach booms to distance the operator from the building being demolished. This trend of taking personnel out of potentially dangerous situations and providing machines for dismantling (for recycling) buildings is likely to increase and maybe extended to soft strip applications. Specialist tools and attachments to excavators and mini-excavators increase the scope of dismantling and deconstruction operations and can provide additional safety for operatives.

Most of the accidents that take place during dismantling and demolition of structures arise from premature collapse of the building or structure. Dismantling and demolition operations should be planned to the same detail as any other construction operation and Contractors should prepare a Method Statement detailing how the work will be carried out. The operations should have appropriate drawings and specifications detailing the structure and materials to be encountered.

All demolition, dismantling and structural alterations must be carefully planned and carried out in a way that prevents danger by practitioners with the relevant skills, knowledge and experience. Key issues are:

- Working at height and falls from height
- Injury from falling materials
- Uncontrolled collapse
- Risks from connected services
- Traffic management
- Hazardous materials
- Noise and vibration
- Fire
- Manual working
- Worker involvement.

All of the above are equally, potentially applicable to both demolition and deconstruction projects. The important difference is that modern demolition practice largely avoids manual working and, any operatives involved, are relatively remote from the building. In contrast, deconstruction is currently far more labour intensive and requires workers to operate both at height and close to and within the building during deconstruction. As a consequence, there are far greater risks to workers involved in deconstruction.

Although demolition and deconstruction projects both involve plant and equipment, modern demolition is largely based on mechanical means using powered mobile plants such as cranes, loaders, bulldozers and excavating equipment. Operators are generally well trained and are operate the plant relatively remote from the building.

In contrast, deconstruction, in addition to using some plant including mobile cranes, cherry pickers and scissor lifts involves a large proportion of manual operations meaning that operatives are working close to or within the building, often at height. Principal risks to operatives include

In addition to risks to operatives involved in the demolition, there are also risks to the public and neighbouring properties. These include:

Dust and air pollution: Concrete breaking, handling of debris and hauling processes are the main sources of dust from demolition. Dust mitigation measures complying with the Air Pollution Control (Construction Dust) Regulations of the specific country shall be adopted to minimize dust emissions. Burning of waste shall not be allowed. Diesel fumes generated by mechanical plant or equipment shall be subject to the control of the Air Pollution Control (Smoke) Regulations.

Noise and vibration: Noise pollution arising from the demolition works including, but not limited to, the use of specified powered mechanical equipment (SPME), powered mechanical equipment (PME), such as pneumatic breakers, excavators and generators, etc., scaffolding, erection of temporary works, loading and transportation of debris, etc. affects the workers, and the sensitive receivers in the vicinity of the demolition site. Silent type PME shall be used to reduce noise impact as much as practicable. Demolition activity shall not be performed within the restricted hours as established.

Hazardous Materials pollution: Of course, measures have to be taken to avoid the escape of hazardous materials in the environment as dust or suspensions. Thus, decontamination should be preliminary to the main deconstruction phase.

Further environmental risks are the discharge of wastewater from demolition sites, which require a valid discharge license, and possible traffic disturbances: Deconstruction needs to take place without essential interference to the traffic. Especially for the deconstruction of bridges or buildings close to main streets the increase in accident potential has to be addressed, which however is controlled due to adequate traffic control measures.

Control measures generally taken include:

- Careful assessment and planning of the work to eliminate hazards where possible, e.g. selecting a demolition method that keeps workers away from the immediate area, such as a long-reach machine or a crane and ball.
- Elimination or control of work at height.
- Structural surveys to assess the strength and stability of the structure and adjacent structures; propping and supporting may be necessary to prevent collapse.
- Assessing the strength and stability of floors to ensure that plant, machinery, and debris put on those floors do not exceed their tolerance.
- Disconnection of services (e.g. gas, electricity, water).
- Removal and disposal of any hazardous materials, such as asbestos, prior to demolition.
- Securing the site with fencing or hoardings to create a buffer zone and exclude unauthorized people.
- Damping down with water spray to reduce dust creation.

Falls from height

During demolition and dismantling, workers can be injured falling from edges, through openings, fragile surfaces and partially demolished floors.

Duty-holders have a responsibility to assess, eliminate and control the risks of falls from height.

Injury from falling materials

Workers and passers-by can be injured by the premature and uncontrolled collapse of structures, and by flying debris.

A safe system of work is one that keeps people as far as possible from the risks. This may include: establishing exclusion zones and hard-hat areas, clearly marked and with barriers or hoardings if necessary covered walkways using high-reach machines reinforcing machine cabs so that drivers are not injured training and supervising site workers

Uncontrolled collapse

The structural survey should consider:

- the age of the structure
- its previous use
- the type of construction
- nearby buildings or structures
- the weight of removed material or machinery on floors above ground level
- The method statement for the demolition should identify the sequence required to prevent accidental collapse of the structure. The requirement for any temporary Support must be carefully assessed. Measures include:
 - bracing
 - temporary restraints
 - anchorages

- false work.

Risks from connected services

Gas, electricity, water and telecommunications services need to be isolated or disconnected before demolition work begins. If this is not possible, pipes and cables must be labelled clearly, to make sure they are not disturbed.

Traffic management

Effective traffic management systems are essential on site, to avoid putting workers at risk of being hit by vehicles turning, slewing, or reversing. Where possible, vision aids and zero tail swing machines should be used.

Hazardous materials

Hazardous materials that should to be considered include dust, asbestos and respirable crystalline silica (RCS). There may also be material or contamination on site that has not been cleared, for example:

- acids from industrial processes
- paints
- flammable liquids
- unidentified drums
- microbiological hazards (especially in old hospital buildings).

Noise and vibration

Frequent exposure to loud noise can permanently damage a person's hearing. Noise can also create a safety risk if it makes it difficult for workers to communicate effectively or stops them hearing warning signals.

Vibrating hand tools used in demolition can cause hand-arm vibration syndrome (HAVS). Workers exposure to vibration must be managed and reduced as far as possible.

Fire

Fire is a risk where hot work (using any tools that generate spark, flame or heat) is being done. During structural alteration, the fire plan must be kept up to date as the escape routes and fire points may alter. There must be an effective way to raise the alarm.

Worker involvement

Everyone involved must to know what precautions are to be taken on site. Workplaces where employees are involved in taking decisions about health and safety are safer and healthier. Your employees are often the best people to understand the risks in their workplace.

Local restrictions and requirements in city centres

Although not particularly relevant to the scope of buildings studied within PROGRESS, demolition of buildings within densely populated city centres is highly regulated and controlled. By way of example, the City of London has a code of practice for deconstruction and construction sites which should be used by property developers during the planning process. Specific issues covered include:

- Noise – addressed by means of agreed working hours and methods, and noise limits
- Vibration – addressed by means of agreed working hours and methods, and vibration limits
- Vehicles movements and deliveries -
- Scaffolding and gantries

- Erection of fixed cranes and use of mobile cranes
- Air quality – addressed by means of an Air quality dust management plan (AQDMP) and monitoring
- Light pollution.

Specific details in the London Code of practice relating specifically to demolition include:

- The use of 'long arm' demolition equipment will not generally be sanctioned in the City, except where the work is within an enclosure or underground.
- Soft strip inside buildings before demolition (retaining walls and windows in the rest of the building where possible, to provide a screen against dust)
- Ensure water suppression is used during demolition operations
- Explosive blasting is not permitted, use appropriate manual or mechanical alternatives.

1.4.1 Hazardous materials and contamination

Hazardous C&D waste is defined as debris that has hazardous properties and that may prove to be harmful to human health or the environment. This comprises contaminated soil and dredging spoil, materials and substances that may include adhesives, sealants and mastic (flammable, toxic or irritant), tar (toxic, carcinogenic), asbestos-based materials in the form of respirable fibre (toxic, carcinogenic), wood treated with fungicides, pesticides, etc. (toxic, ecotoxic, flammable), coatings of halogenated flame retardants (ecotoxic, toxic, carcinogenic), equipment with PCBs (ecotoxic, carcinogenic), mercury lighting (toxic, ecotoxic), systems with CFCs, insulation containing CFCs65, containers for hazardous substances (solvents, paints, adhesives, etc.) and the packaging of likely contaminated waste.

These materials are usually found in demolition works, due mainly to the absence of past legislation regarding the use of certain hazardous materials such as asbestos and lead. Material re-use should not be neglected however, as these materials are not classified as waste and therefore not regulated, but in some cases these projects can also generate similar dangerous waste.

Decontamination is necessary so that hazardous particles will not contaminate the recyclable materials. Even if it is present in a very small proportion of the total waste materials, the possible presence of hazardous waste materials can reduce markets' confidence in the recycled waste materials drastically and therefore the perceived quality of the recycled products

In addition, proper decontamination needs to be done for a number of reasons other than reuse or recycling: to protect the environment; to protect the health of workers; to protect the health of people living in the surroundings of the site, and for safety reasons. Typical hazardous waste products from construction, renovation or demolition works are asbestos, tar, radioactive waste, PCBs, lead, electrical components containing mercury¹⁵, insulation materials containing hazardous substances etc.

Throughout the process, hazardous waste removal needs to comply with existing (national) level legislation. Depending on the Member State, the treatment of some of these waste types (e.g. asbestos) is regulated, whilst this is less so for others (e.g. PCB's and PAH's).

Annex III to the Waste Framework Directive [8] describes 15 properties (HP1 to HP15) of waste which renders it hazardous. Table 1.5 below provides an overview of the hazardous properties.

Table 1.5 Waste Framework Directive listing of hazardous properties

Hazardous Properties	
HP1	Explosive
HP2	Oxidising
HP3	Flammable
HP4	Irritant – skin irritation and eye damage
HP5	Specific Target Organ Toxicity (STOT)/Aspiration Toxicity
HP6	Acute Toxicity
HP7	Carcinogenic
HP8	Corrosive
HP9	Infectious
HP10	Toxic for reproduction
HP11	Mutagenic
HP12	Release of an acute toxic gas
HP13	Sensitising
HP14	Ecotoxic
HP15	Waste that can exhibit a hazardous property listed above, not directly displayed by the original waste

1.4.2 Hazardous coatings on existing structural steelwork

Specifically in relation to potentially hazardous coatings on existing structural steelwork, the BCF (British Coatings Federation) has provided the following guidelines for the UK.

History of the building, and information on its structural elements

If there is any data available on the building, and the nature of the steel structures that were used during its construction, then this should be acquired and fully reviewed. From a coatings perspective this is of particular use if there are details on the coating systems used (supplier tradenames, technologies etc.), how and when they were applied, and by whom, and any warranties that were provided at the time of construction. It would also be useful to understand if the steel structure was protected with an intumescent / reactive coating as part of the fire protection measures for the building. This information can assist with any decisions that need to be taken with regard to maintenance and refurbishment of the beams and columns before they may be used for any new construction. BCF Guidance Document G 021 September 2016 4

Assessment

The current state of the steelwork should be visually assessed, preferably by trained personnel.

Describing the state of the current coating system

If coatings are evident then the following should be recorded:

- Colour and state of the coating layer

If the coating layer(s) are damaged, then this should be carefully assessed by considering the:

- Integrity of the upper coating layer (topcoat)
- Integrity of any intermediate coating layers
- Integrity of the coating layer (primer) closest to the steel.

The evaluation of the condition of a surface coating is prescribed by the BS EN ISO 4628 [9] series of standards, which covers the following aspects:

- Part 1 - Introduction
- Part 2 - Assessment of the degree of blistering
- Part 3 - Assessment of the degree of rusting
- Part 4 - Assessment of the degree of cracking
- Part 5 - Assessment of the degree of flaking
- Part 6 & 7 - Assessment of the degree of chalking

Additional standards exist for the assessment of coating adhesion, including:

- BS EN ISO 2409 [10] – Cross cut test
- ISO 4624 [11] – Pull off adhesion test
- BCF Guidance Document G 021 September 2016 5

Lead in protective coatings

If the coating is a bright colour, especially red, yellow or green, and the steel originates from a building that was constructed over 40 years ago then there is a good possibility that the coating system is based on a lead pigment. Lead is a very hazardous material and care should be taken with regard to the treatment of lead painted surfaces (dust or fume creation should be avoided). There are specific methods available to confirm whether lead is present in the paint film. Please refer to the relevant BCF Guidance document HS 034 'Lead in Painted Surfaces' on this subject (www.coatings.org.uk). Although this guidance is intended for the architectural paint market and professional decorators, the information with regard to how to handle lead painted surfaces, and links to organisations who may be able to provide further advice, is still relevant.

Lead dust and lead paint fumes are extremely hazardous and therefore any cutting procedures that may lead to their creation should be avoided.

Refurbishment

Once the assessment is complete then the appropriate refurbishment activity may be established. We recommend that, if repair through new coating application is required, direct guidance from the chosen coating supplier is sought and followed, in order to develop a surface preparation regime and coating specification which is appropriate for the future environment and desired durability that the steel sections will be expected to withstand. This guidance should include comment on whatever warranties may be provided as a result of the refurbishment.

Use of relevant Standards

Definitions and the classification system for the corrosivity of an environment and durability together with guidance on developing coating specifications are provided in BS EN ISO 12944 [12]. The BCF's guidance document G020 'Classifying Corrosive & Fire Environments' may also prove useful in classifying the future environment for the steel structure. Also, the International Standard EN ISO 8504-1 may be used as guidance to assess and treat the steel substrate e.g. if it requires blasting.

It is possible that all existing coatings may need to be removed even though they are judged to be in a sound condition, if it cannot be clearly established that they will be suitable for a different service condition to their original use. It is essential that the quality and cleanliness of the final prepared surface is carefully controlled, as this has a fundamental influence on the performance of any subsequent coating layers that are applied to protect and / or decorate the structure. For additional guidance, EN ISO 8501-1 [13] is the reference standard used to specify the nature and quality of the surface to be coated. BCF Guidance Document G 021 September 2016 6.

If there is a significant degree of corrosion and rusting evident, and / or significant removal of the coating system right back to the substrate then there are two possible courses of action:

- Fully remove the coating system by standard techniques (usually abrasive blasting)
- Treat the affected areas with an anti-corrosive passivation coating, according to the manufacturers' instructions.

Advice may be sought from the UK Health and Safety Executive and from other organisations such as the British Constructional Steelworks Association and the Steel Construction Institute, with regard to the safest and most appropriate methods to use regarding removal of coatings:

www.hse.gov.uk/

www.steelconstruction.org/bcsa/

www.steel-sci.com

If there is only minor damage to the coating system, and only small areas of rust-spotting, then it may be possible to refurbish by applying a fresh primer coat directly onto the surface.

If there is an intention to apply an intumescent coating system as part of the refurbishment then please refer to the CEPE / EAPFP / EAIPC publication 'European Industry Best Practice Guide on the Application of Intumescent Coatings to Constructional Steel'. This provides comprehensive details with regard to substrate preparation and coating selection and application.

This publication is freely available at <http://www.coatings.org.uk/intumescent-coatings-statements-and-documents.aspx>

Any application of fresh coatings over the treated steelwork must be undertaken in accordance with the coating manufacturers' guidelines and advice.

1.5 Demolition of steel-framed buildings

As long as reuse is not intended and it is planned for the steel to be recycled after demolition, cutting the connections is the most common technique for demolishing steel structures. As a first step, any floors, which are generally concrete, are demolished. After this step, a structure built from steel beams and columns is left. If the cross-sectional size of the sections allows the sections to be sheared, then this is generally done using a shear attached to an excavator boom. See an example of a hydraulic cutting tool shearing sections in Figure 1.15.

The main intention is to pull down the structure and safely and quickly shear the steel sections into pieces of a manageable length for handling and transportation. There is no intention to preserve the shape or cross-section of the extracted beams or columns.



Figure 1.15 Excavator with hydraulic shear attachment to cut steel beams into manageable lengths

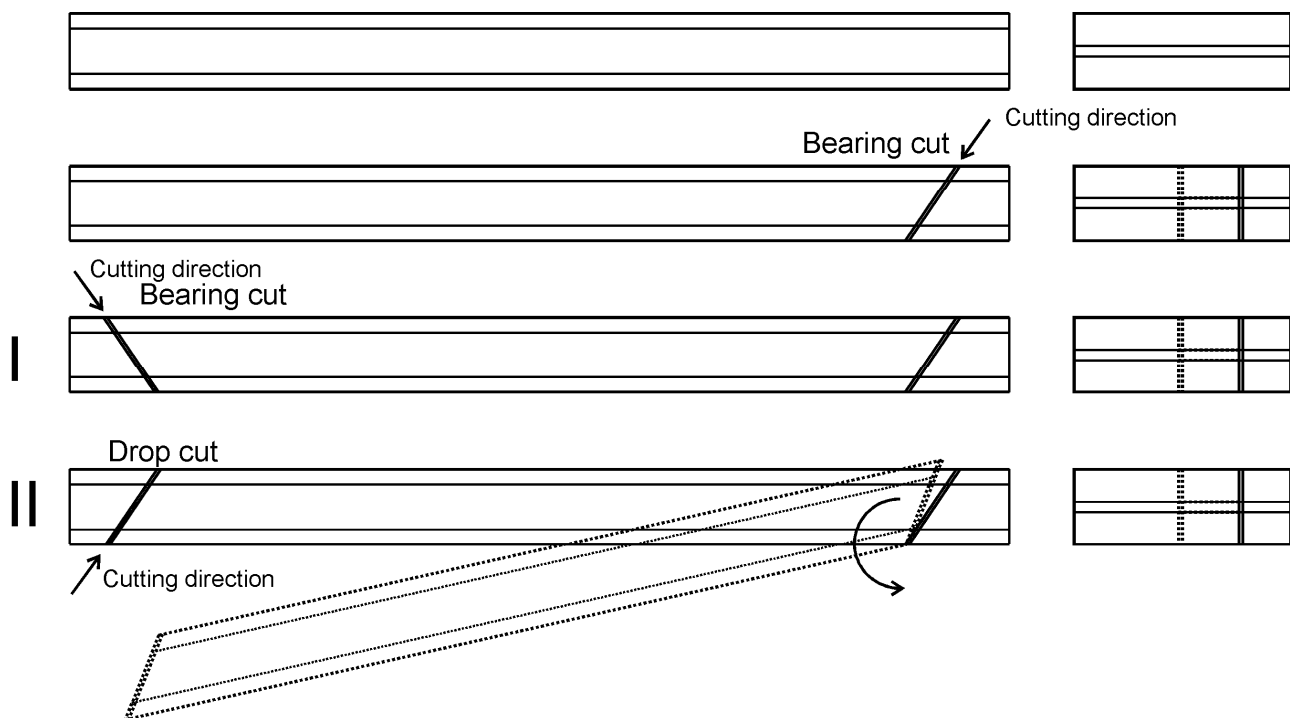


Figure 1.16: Technique for cutting beams manual by burning

The possibility to shear steel sections using excavators is limited by the size of the shear attached to the excavator boom. If shearing is not possible, beams are manually cut by burning. When steel beams are manually flame-cut, safety has to come first. The structure itself needs to be analysed due to the risk of failure of the whole structure. Then, for each beam, there is a risk of it falling down which has to be avoided by supporting the beam on a suitable crane or excavator. Even if 'dropping' the cut section is allowed, it is important to control the fall by using the correct cutting technique.

Generally, two different cuts are used: the "Bearing cut" and the "Drop cut". In general, manual cutting is done by a diagonal cut to prevent clamping. In case of a bearing cut the direction of the cut is made to the outside from the beam to be removed. The drop cut is done to the inner direction. If the beam is secured by chains, two bearing cuts are performed, and the beam is subsequently removed by the crane.

If dropping the beam is intended, first a bearing cut is applied and after that a drop cut so that the drop can be controlled see Figure 1.16.

Generally, for single-storey buildings, demolition is not done by removing the structural elements individually but instead the structure is generally torn down in whole sections, e.g. portal frames. It does not matter, whether the hall is made of sections in one direction only or by two-dimensional raster. Mainly, the goal is to create temporary hinges and rotate the structure using an excavator. At first, all connections square to the section need to be removed. In general, bearing cuts are performed to minimise instability (cut type "B" in Figure 1.17).

Afterwards the ground floor column connections are transformed to hinges. Depending on the alignment, parts of the beam are removed so, that the power of an excavator is sufficient to rotate the section and lay it to the ground. The further cutting of the section can safely be done while the steel is laying on the ground.

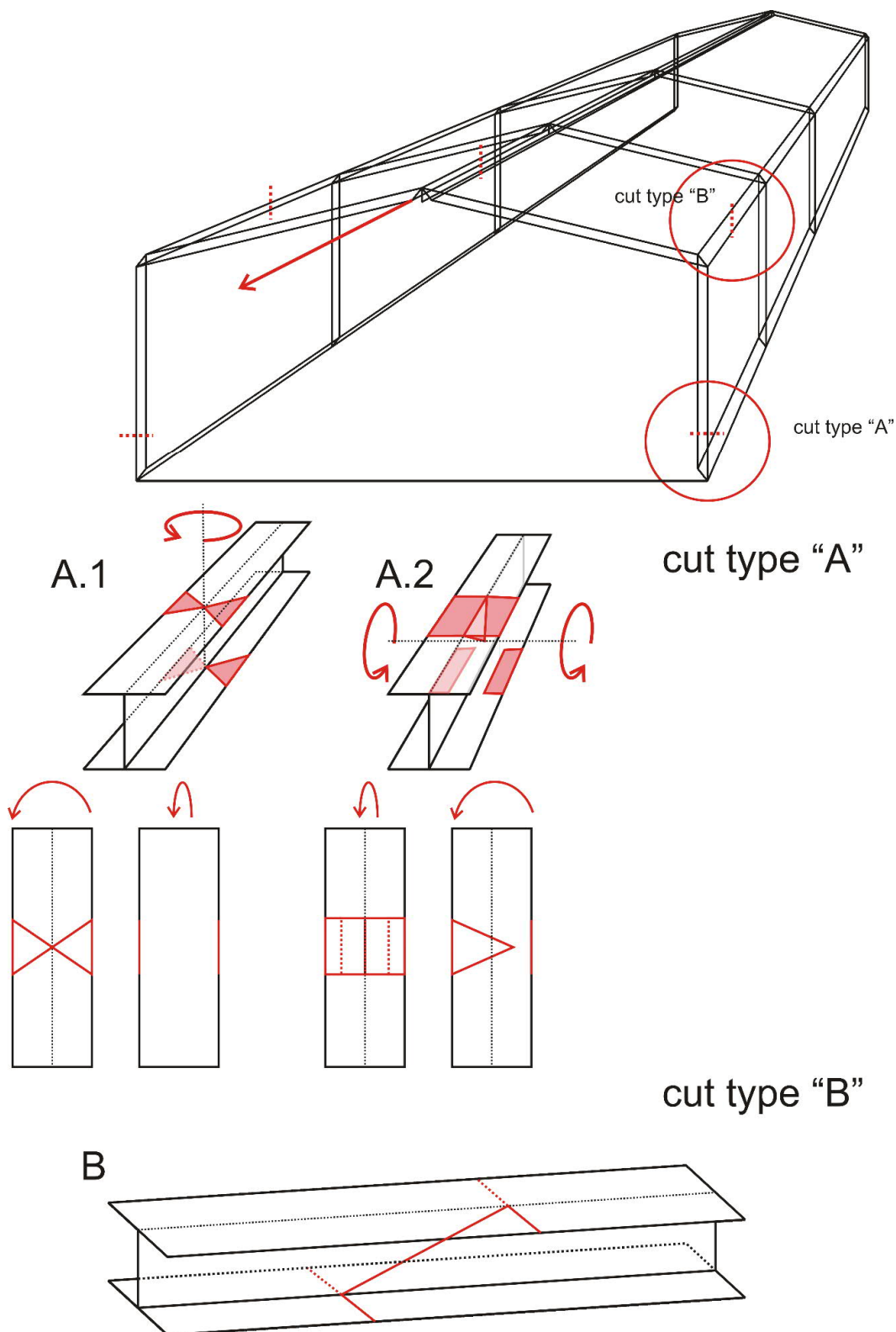


Figure 1.17 Technique for demolition of steel-framed single storey buildings

1.6 Demolition case studies

Paul Kamrath has documented case studies of demolition of steel-framed SSBs. These are reported here.

1.6.1 Demolition of a steel-framed single storey building

Located in Germany, this single-storey hall was built in the 1990s. The area covered by the hall was 407m². The height to eaves was 8m5m and the volume ca. 3,460m³.

The floor slab was reinforced concrete. All structural elements of the hall were constructed from steel. Thermal insulation in the walls comprised mineral wool between two metal sheets. The roof was insulated using styropor (polystyrene). The structural form is shown in Figure 1.18.

The hall was demolished to make way for a new building on the same site with no intention of reusing any of the structural elements. The demolition was planned in three steps:

the walls were opened to collect the mineral wool insulation (hazardous waste due to the fibres).

the steel structure and roof was pulled down using an excavator. When on the ground, the roof insulation was collected manually.

The concrete floor slab was broken out and crushed.

The wall insulation was transported to a hazardous waste landfill and the roof insulation transported to an incineration and energy recovery plant.



Figure 1.18 View inside the single-storey hall of 407m²



Figure 1.19 Partly demolished hall. At this stage all side walls were demolished and the insulation removed and structure was demolished using excavators

The total vehicle movement and weights of materials recovered from the building are shown in

Table 1.6 Weights of materials recovered from the building and number of vehicle movements

Waste stream	No. of vehicle journeys	Mass
Steel	17	80.38 t
Concrete	3	82.55 t
Cardboard	2	7.68 t
Insulation (mineral fiber)	2	1.12 t
Insulation (styropor)	2	2.6 t
Other	1	4.96 t
		179.29 t

The demolition of the building including the manual removal of the mineral wool insulation took in total 595 man-hours. The total cost was €33,351.

1.6.2 Deconstruction of steel roof trusses

Client: Gebr. Becker GmbH, Wuppertal, Germany
 Contractor: Paul Kamrath
 Demolition concept: Dr. Paul Kamrath
 Purpose of reuse: New building reusing with old structure

Original steelwork: ca. 1920
Implementation: 2018 - 2019



Figure 1.20 Deconstruction and reuse of steel roof structure

Description of the existing building

The single storey hall was part of an old fabrication plant located in Wuppertal, Germany. The production company has two fabrication sites. Due to growth over the years, this building was planned to be demolished and to be replaced by modern fabrication buildings on the same site.

There were two existing halls and an attached office building. While the office building and the greater part of the fabrication halls built in the 1950s were planned to be demolished, the oldest hall was planned to be kept for historical reasons. Unfortunately, modifications in the 1950s combined the bearing structure of the office building with the historical hall. Because fabrication first started in the 1920s hall, there was a deep interest, to keep as least the roof-structure and to integrate this in the new development as a remembrance to the origins of the company.

The demolition project was undertaken in three parts:

1. Demolition of the 1950s hall
2. Deconstruction and reclamation of the roof structure of the 1920s hall including the demolition of the remaining hall

3. Demolition of the office building.

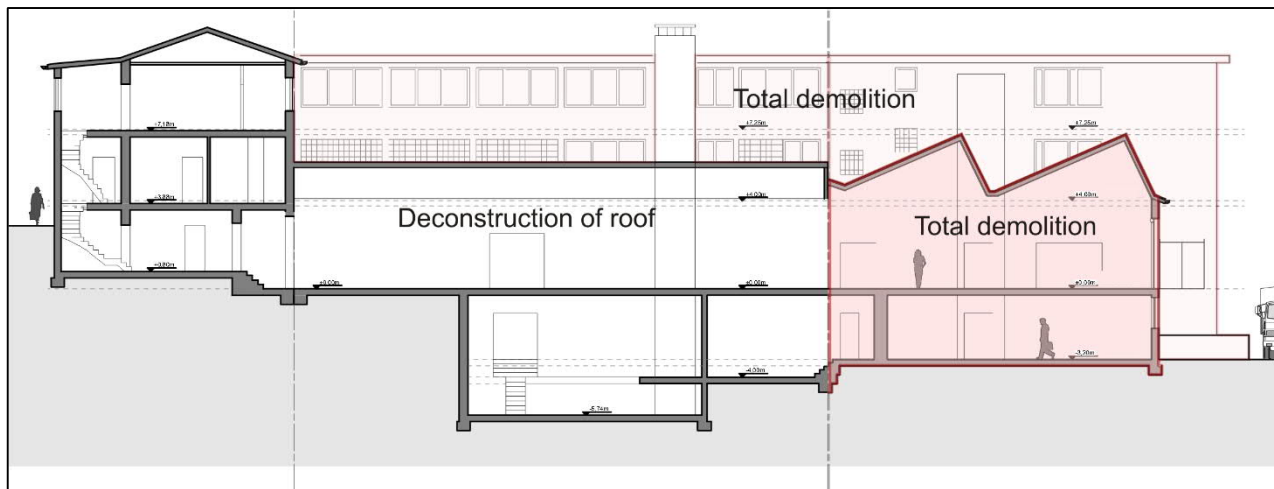


Figure 1.21 Cross section through the factory buildings

Deconstruction

The construction of the roof structure consists of steel-timbering. Up-on the bearing structure, the roof was build of wood with a regular sealing of old tar-based cardboard. Due to the filigree steal-structure preliminary cardboard and wood were deconstructed by man-power. Afterwards, all jointings of the girders to columns were dismantled. Only the horizontal links retained for stability reasons.

The links were dismantled just in time when the girders were removed.

To keep the steel timbering intact after the deconstruction it was evident, to build a construction to store the elements. This construction was fabricated of steel.





Figure 1.22 Images during the deconstruction project and the recovered roof trusses

Conclusions

The following key aspects of the project have been identified:

- Dismantling of structures for reuse issues is quite different from the regular demolition process. For regular demolition there is no need to keep anything intact. For demolition the boundary condition are safety of neighbouring buildings and a focus on raw materials, while the deconstruction focuses on the construction itself to be kept intact. Thus, there is an increase of manual labour instead of the use of excavators.
- In fact, both methods lead to the same rates of steel-reuse from the material view. If the costs are considered, the costs of deconstruction for reuse are much higher. Probably there are savings for the new building using the dismantled parts.
- Nevertheless, deconstruction for reuse is possible even for single-storey-halls originally built the early 20th century. For this case, it was helpful, that the new use for the girder-structure is at the same site. Especially if only parts of structures are identified for reuse, it is evident to find a suitable building to integrate the used parts later. This building needs to fit the geometrical dimensions.
- As long as the used structures are integrated on the same site, an additional benefit is the omission of any transports. Thus, there is a high saving of energy.

1.7 General recommendations for safe deconstruction of SSB

1.7.1 Introduction

The deconstruction process of a single-storey building can be divided into the following steps:

- Non-structural elements/equipment;
- Flashing elements;
- Cladding;
- Secondary structure;
- Primary structure;

1.7.2 Summary of deconstruction process

The suggested deconstruction protocol relies on the deconstruction of single bays, rather than the deconstruction of an entire building layer. The general process can be summarized in the following steps:

- Before any deconstruction procedure, all secondary elements or equipment must be removed/detached from the structure;
- Deconstruction of the building will start in one end of the building, where flashing and cladding elements are removed in the vicinity of the frame that will be first deconstructed;
- Based on the secondary steelwork detailing, it is likely that at least two roof cladding bays need to be removed to allow for the secondary steelwork deconstruction;
- For common south European countries, it is likely that rafters will not be able to resist their own self-weight without any intermediate flexural and lateral buckling restraint; rafters will need to be supported by a lifting crane while the secondary steelwork connected to the rafters is deconstructed;
- After removing secondary elements, with the rafters supported, the unbolting of the eaves connections takes place and the pair or individual rafters is deconstructed;
- The apex connection can be then easily deconstructed on the ground level;
- After removal of a pair of rafters, side rails and wall cladding can be removed for the bay without rafters;
- Columns must keep an out of plane restraint (say a pair of side rails, or eaves strut) before the column is supported by the lifting equipment; when the columns are supported, out of plane restraints can be removed;
- Individual columns can then be safely individually deconstructed;
- A similar procedure is repeated until the whole building is deconstructed;
- Salvaged members must be labelled before transportation from the site; it is recommended that the labelling sequence reflects the deconstruction sequence.

However, the deconstruction of the cladding layer may be performed prior to the deconstruction of secondary and primary structure layers under certain conditions.

In the next section, recommendations for the deconstruction of each building layer are provided.

1.7.3 Non-structural components

Non-structural elements such as HVAC units, solar panels, cranes, lightening, ceilings and other integrated systems must be removed before proceed with the deconstruction of the building.

1.7.4 Flashing elements

Flashing elements will be critical near building edges. They usually don't have a well-defined fixing system, so one may expect that a considerable amount of detachable or non-detachable fasteners will need to be removed. Careful deconstruction of these elements is required to avoid damaging the cladding system. Gutters will also need to be removed.

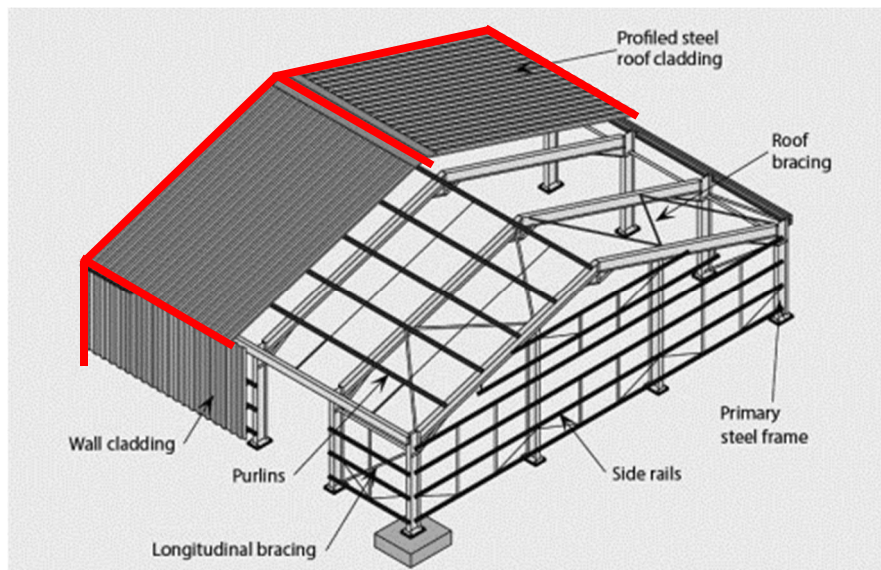


Figure 1.23 Critical flashing areas

Likely connecting systems that can be found between flashing system and claddings:

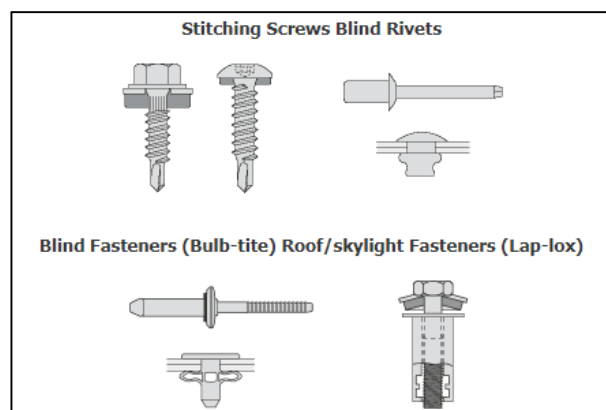


Figure 1.24 Usual flashing fixings

The usual UK method will be with self-drilling / self-tapping screws.

1.7.5 Cladding

Recommendations for cladding may be divide into two groups:

1. Short span cladding which are fixed to a secondary structure (usually made of cold formed steel sections); the short cladding can be sandwich panels or built-up solution with a double skin steel sheet with intermedium insulation layer; short span claddings will have a higher number of connections to be removed.



Figure 1.25 Short span cladding systems

2. Lon span cladding, which can be fixed directly to the primary structure or to a local secondary system; depending on the thickness of the primary structural element, a local secondary system (such as a cold formed element that facilitates the claddings fixation) may be required. Open section are often used, as it is more likely that the cladding/long span sheet fixation will not find hit a profile web while fixing with self-drilling screws.



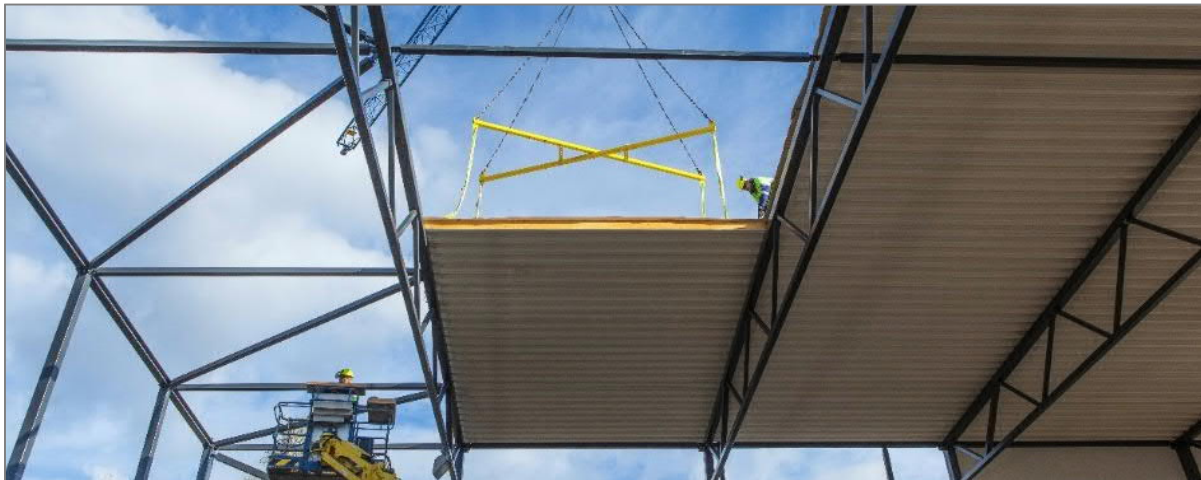


Figure 1.26 Long span cladding systems.

For the cases where no secondary steelwork exists (long span cladding systems), it is likely that a longitudinal roof bracing is present to ensure the rafter stability during erection (as shown in the figure above). For the cases where no bracing is present, an engineering judgement, or even some design calculations, is/are necessary to check if the rafter is stable without intermediate bracings. For Nordic countries, where snow loads are quite high, it is possible that no roof bracing is necessary for member stability during erection. For the UK market, as portal frames tend to be more slender due to the use of plastic global analysis, if no bracing is present, it is not recommended to remove the cladding entirely. For those cases, the rafter pair must be hanged by a lifting crane during the deconstruction of adjoining roof purlins.

Likely connecting systems that can be found between flashing system and claddings:

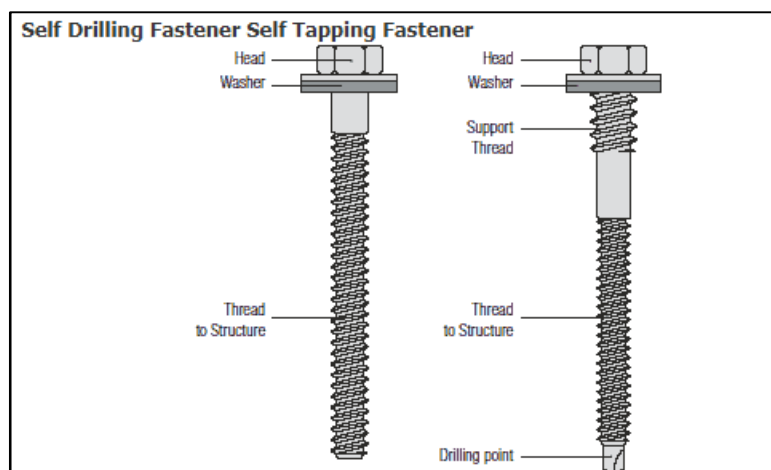


Figure 1.27 Usual cladding fixings.

This is one of the most delicate and probably expensive operations while deconstructing a single-story building. The position and number of the fasteners will be defined by the purlins position, meaning that clear alignments of fixings are expected over the purlins alignments. The high costs are related with the high number of connections that need to be removed.

Deconstruction needs to be performed by the exterior of the building. The removal of these fasteners are easy to perform in comparison with bolted primary structural connections.

Short span claddings are installed perpendicular to the secondary steelwork. Elements with up to 12m can be expected. Depending on the span, the cladding panel may have some internal divisions that need to be unscrewed.

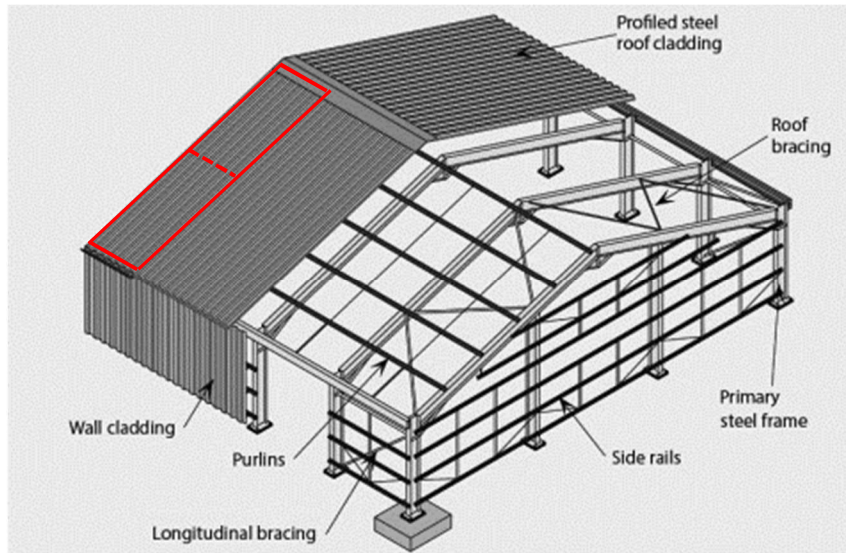


Figure 1.28 Example of cladding modules.

While removing façade cladding, it's 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. 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).

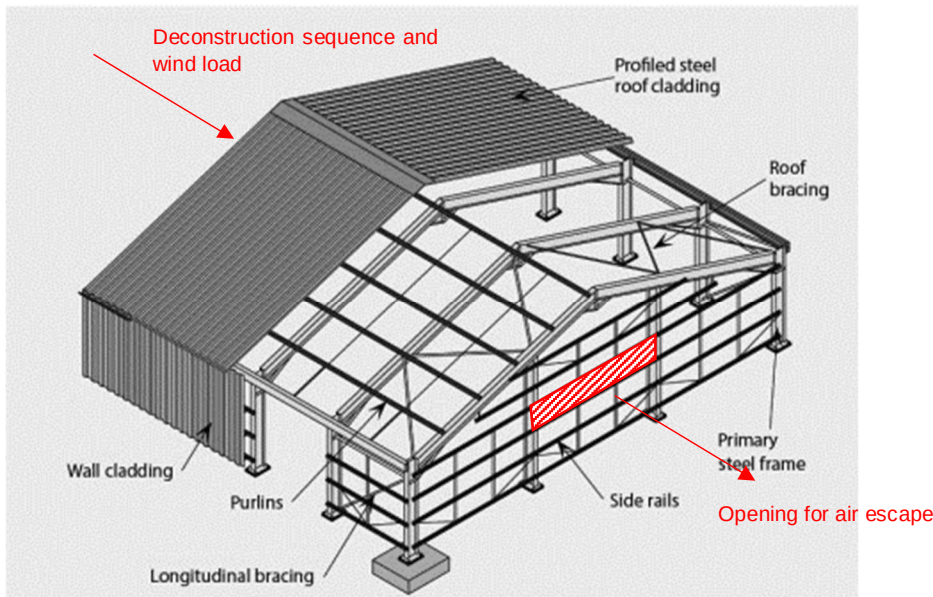


Figure 1.29 Illustration of detailing for air escape to control internal pressures.

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 below. 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.

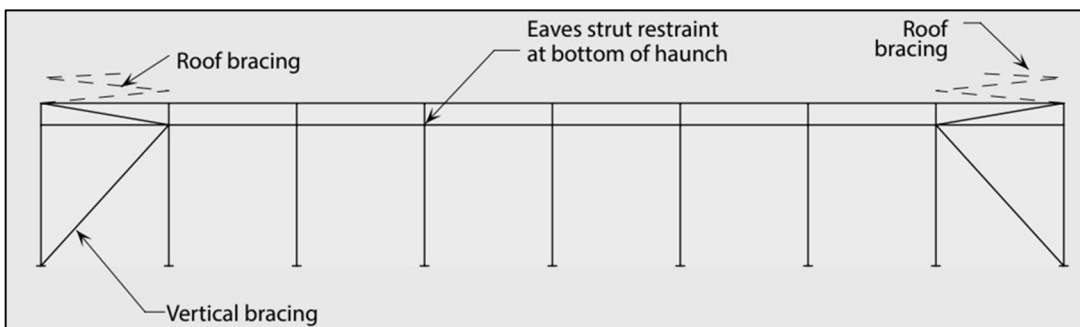


Figure 1.30 Vertical bracing and eaves struts.

Example of temporary bracing:



Figure 1.31 Examples of temporary bracings.

Suggestion for the system:

- Two tension only “X” bracings
- One strut element

It is suggested to have a temporary bracing element every 35m (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.

1.7.6 Secondary structure

Roof parapets and other secondary systems such as canopies above openings shall be removed before proceeding with the deconstruction of the primary structure.

Usually single-story buildings will rely on an independent bracing system for the out of plane stability. This system will comprise a set of longitudinal wall bracings and roof bracings.

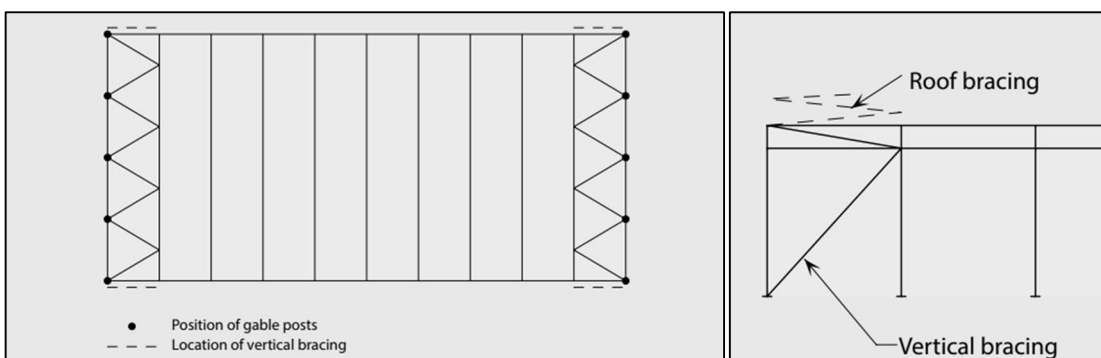


Figure 1.32 Conventional roof and wall bracings.

It is important to understand the structural purpose of the secondary steelwork for the building and individual elements stability. Secondary steelwork have often the important role of restraining out of plane flexural buckling and lateral torsional buckling of primary structural elements. This is particularly important for rafters, as they can be quite long and slender.

Particularly for south/central European countries where snow load is relatively low, rafters tend to be quite slender. As stated before, this will be even more critical in the UK, as plastic global analysis is usually implemented. For these cases, the secondary steelwork play an important role to restrain out of plane flexural buckling and lateral torsional buckling of the rafters. It is therefore necessary to make sure that before the removal of secondary steelwork, the rafter is hanged by a lifting equipment.



Figure 1.33 Rafters supported by mobile cranes during purlins installation/removal.

It is likely that at least two cladding bays need to be removed to deconstruct secondary steelwork. It is unlikely that for the most common secondary structural systems this procedure will not be satisfactory. For staggered double-bay solutions, staggered supports will be provided to the second rafter to be deconstructed to allow for the deconstruction of the first rafter (see image below).

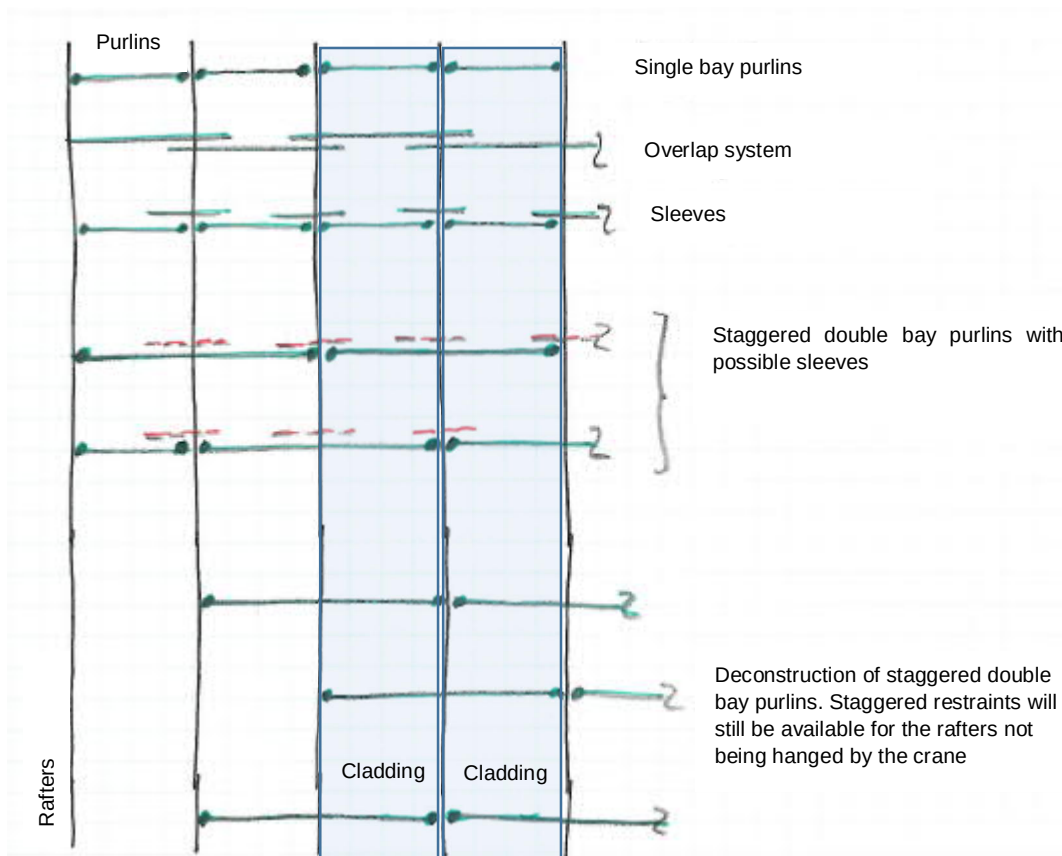


Figure 1.34 Usual secondary steelwork solutions

If no vertical /longitudinal bracing system is present, considering that a temporary bracing system is installed, it is recommended that secondary steelwork is kept on the façades until the roof structure is deconstructed. This is mandatory if no eaves strut is present. These recommendations are related to the cases where the cladding is entirely removed on one step. If cladding is removed for each individual bay, there is no concern of removing cladding and therefore the secondary structure for the individual bay.

It is expected that auxiliary secondary elements may be bolted to the primary structure (cleats, fly bracings, etc.). These elements don't need to be removed unless they have a considerable size. These elements can be kept attached to the primary structural elements.

1.7.7 Primary structure

It is important that bracing systems and their adjoining elements are kept as the last elements to be deconstructed. It is also important to ensure that the deconstruction sequence doesn't reproduce isolated sub-structures without longitudinal bracings. Every sub-structure must have a vertical /longitudinal bracing system.

For small frames, it may be more practical to handle an entire frame and perform the disassembling procedures of individual elements on the ground. On the other hand, for long spans or multi-bay frames, the deconstruction of pairs or individual rafters is more reasonable, due to the flexibility of the frame or simply by a limitation of handling and lifting equipment.

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 25m, 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.



Figure 1.35 Erection/deconstruction of individual long span rafters

While deconstructing rafters, it is necessary to assess the behaviour of base connections. Base connections are, in general, nominally pinned or fixed, which means that they have usually at least a nominally stiffness that can keep columns erected. Perfectly pinned base connections are quite rare and only used under architectural requirements.

It is recommended that some out of plane restraint is kept until the column is being hanged by the lifting equipment.



Figure 1.36 Isolated columns with out of plane restraint ready to be deconstructed

To allow for the deconstruction of frames or columns, it may be necessary to expose columns base connections by a careful local demolition process of the ground floor. This is an operation that can be performed in parallel with the deconstruction of cladding and steelwork.

With preloaded assemblies, disassembling may be difficult and may require a destructive process of the preloaded bolts. Bolts may need to be ground off.

1.8 3D modelling with photogrammetry using UAVS

The realization of a photogrammetric survey, with the subsequent creation of three-dimensional photo-realistic models, has involved researchers from various branches of the scientific world for years.

The introduction of Unmanned Aerial Vehicle (UAV) systems, coupled with modern processing techniques, allows taking aerial photographs with important advantages such as: The high execution speed of the survey, the remarkable detail of the images obtained and the lesser expense, economical and in term of time, compared to traditional techniques such as LIDAR. The ability to set flight plans, appropriately established at the preliminary stage as a function of the study object, and the growing availability of hardware and software systems to improve their automation, make drones a state-of-the-art tool for monitoring and control activities also involving areas of significant extension. Thus, the use of UAV systems are a possible choice for exploring demolition and deconstruction sites where this technique can be used to obtain the missing data, if the planning from decades ago is missing.

As a test site the nearer region of an SSH on the great market in Cologne was chosen as shown in Figure 1.37.



Figure 1.37: Aerial view of the area. The test object is an SSH on the right.

The aim is to create a usable 3D-model of the single storey hall which is to demolished.

The photogrammetric imaging with UAV platform cannot be without planning to capture a block of images with sufficient coverage (longitudinal and transverse) and a ground sample distance (GSD) dictated by the application type. The presence of an autopilot system (with GPS) is undoubtedly an essential requirement for capturing images that reflect the characteristics of a photogrammetric block. Shots are performed at positions previously established or, commonly, at regular intervals. Flight data are recorded for the next phase of processing and aerial triangulation.

Traditionally in the photogrammetric technique, the camera was calibrated or pre-calibrated. In fact, a self-calibration procedure would require the use of transverse strips, possibly at different dimensions. However, the evolution of software has enabled the use of pre-calibration cameras, since within the software itself there is a database with the characteristics of the most popular cameras in commerce. The images taken during the flight are then processed following the classic photogrammetric procedure.



Figure 1.38: Shadow of the UAV flying in survey phase

Usually, in flights executed through UAV, direct image orientation is not advisable, since the use of GPS, with only the code signal, makes the orientation data totally inadequate for this procedure. The bundle block adjustment is thus done by automatically identifying the homologous points and by defining a relative or absolute reference system (geo-reference), locating on the ground some points clearly visible inside the shots and determining their coordinates with a suitable topographic tool,

thus ensuring due precision. Image orientation can be derived from point clouds, derived orthophotos, polygonal, textured 3D models, or subject matter information, and extracting surface imaging (DSM) or soil (DTM) models with image matching techniques.

Monitoring of the area under investigation was carried out using the DJI MAVIC pro drone, a compact sized quad-copter equipped with a video camera capable of taking 10 Megapixel photos and video shooting possibilities Full HD 1920x1080p at 30 fps and 720p at 60 fps, Figures 1.38 and 1.39. The angle of the field of view, depending on the chosen image format, is 110° or 85°.

The creation of the 3D point cloud obtained from photogrammetric data was made through the PhotoScan software produced by Agisoft LLC, which allows the generation of dense clouds, meshes and textures.



Figure 1.39: Example of image shot by UAV

Agisoft PhotoScan is a low-cost commercial software that allows to get a high quality 3D model. The workflow is fully automated both for image orientation and for generating and reconstructing the model. The generated model can be exported to be managed and eventually processed with external software such as Meshlab. This has led to optimization of processing times, ensuring good performance of the machine / software complex. All processes can be performed with various levels of precision; furthermore, the different parameters can be set in order to improve the final result.

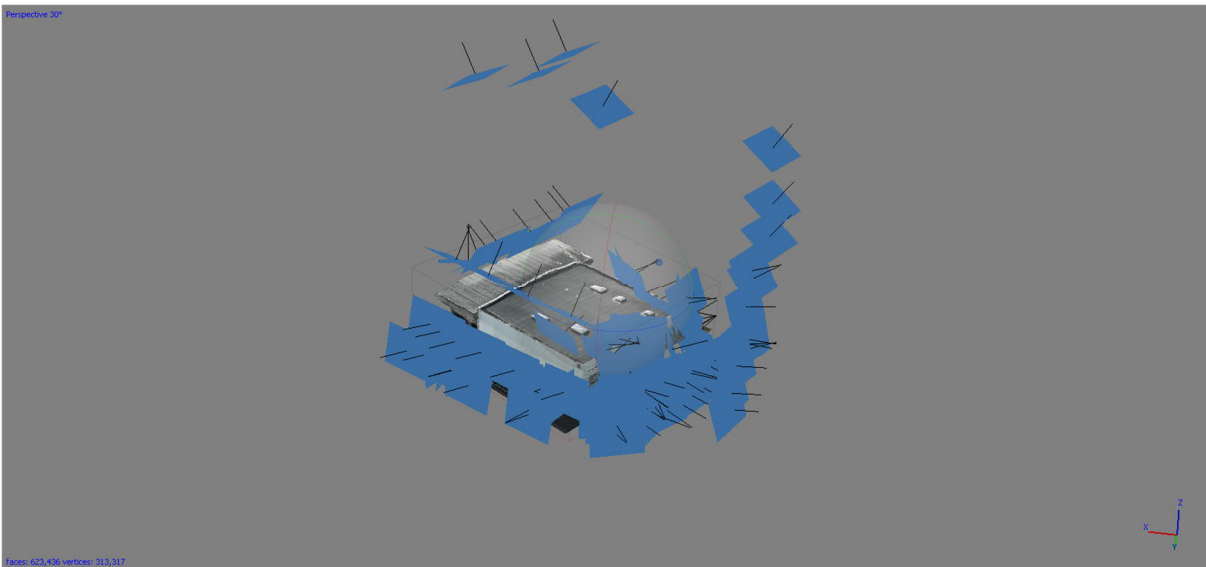


Figure 1.40: Object with camera positions

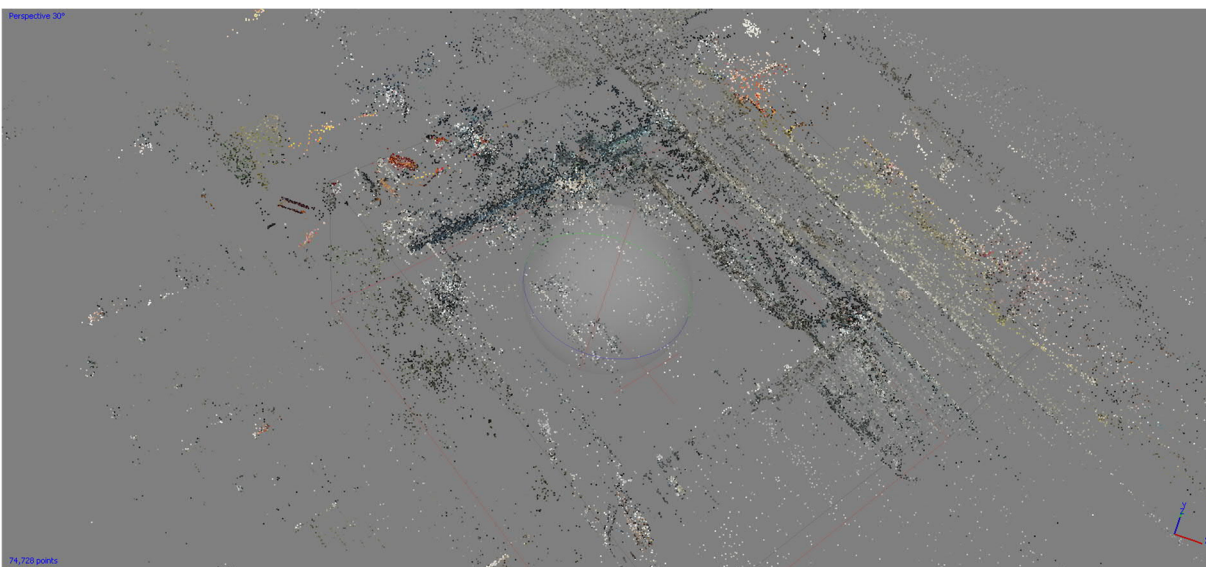


Figure 1.41: Sparse cloud of the area under examination

The images captured by the UAV attached digital camera have been saved in .jpeg format, file format supported by the software used in the test. For processing images, a general personal computer based on AMD Ryzen technology was used.

The processing phases were as follows:

1. *Align photos* (photo alignment) that consists in identifying the tie points through the use of operators of interest. The points chosen in the different pictures must have common features to be adequately superimposed. For good performance, the image quality must be high; there should be few shadow areas and adequate lighting. At this stage, the cloud of scattered points is obtained (Figure 1.40 and 1.41);

2. *Build dense clouds.* Through this phase, a dense cloud is constructed using dense image matching algorithms (Figures 1.42a and 1.42b). These are subdivided into algorithms that use a stereo pair to find matches (stereo matching) and those that instead identify them in multiple images (stereo multi-view);
3. *Build mesh,* which consists of generating a polygonal pattern based on the dense cloud created. The mesh is a subdivision of a solid in solid particles of polyhedra, Figure 7;
4. *Build texture,* it allows instead of getting the 3D representation of the work under investigation, Figure 1.43.

In total, during the entire flight session for DEM production, were performed 108 usable photographic shots. Based on the photographic shots the sparse point cloud computed 74.728 points which results in a dense point cloud of 4.560.940 points.

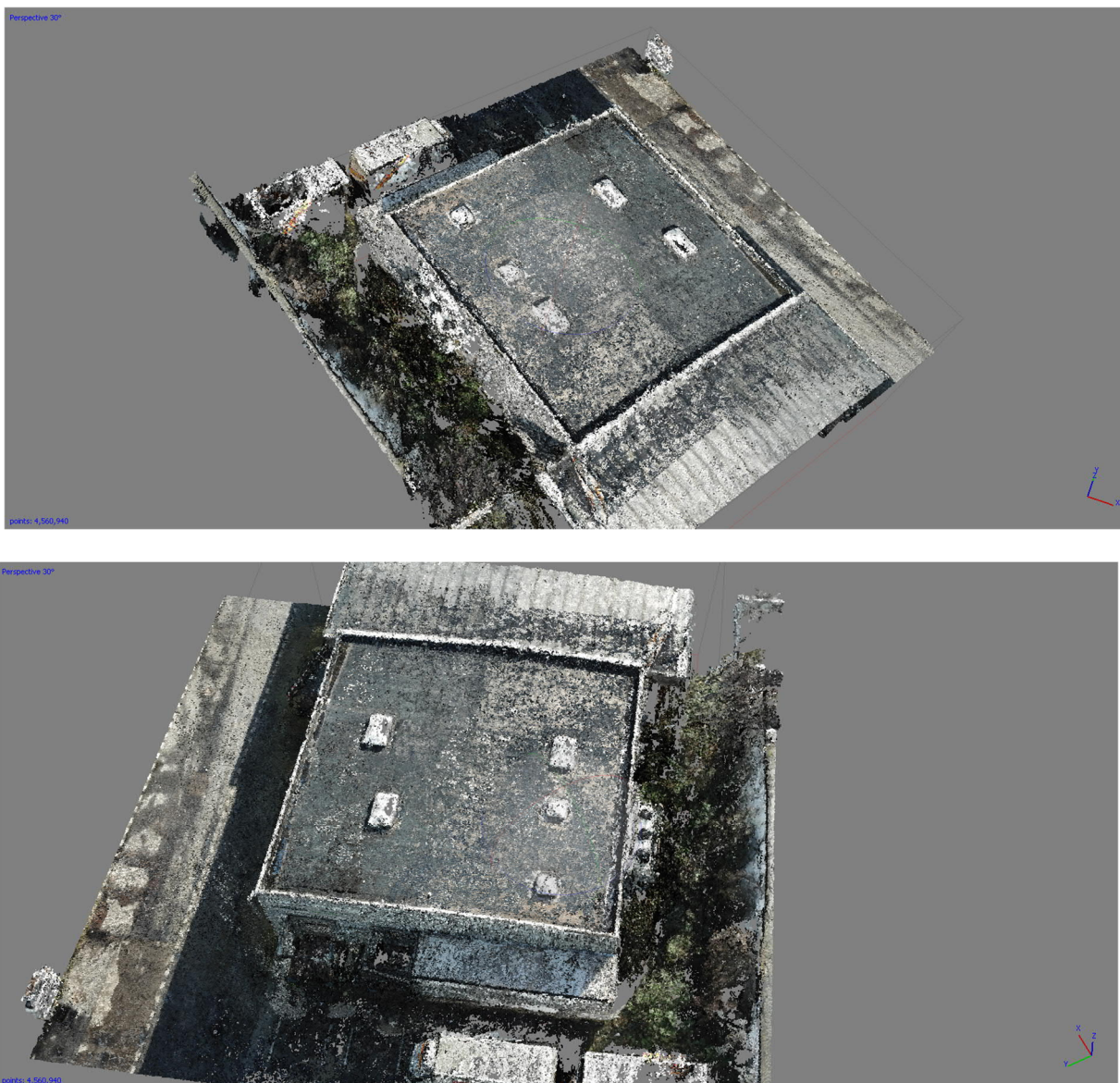


Figure 1.42a / b: Different angles of the dense cloud

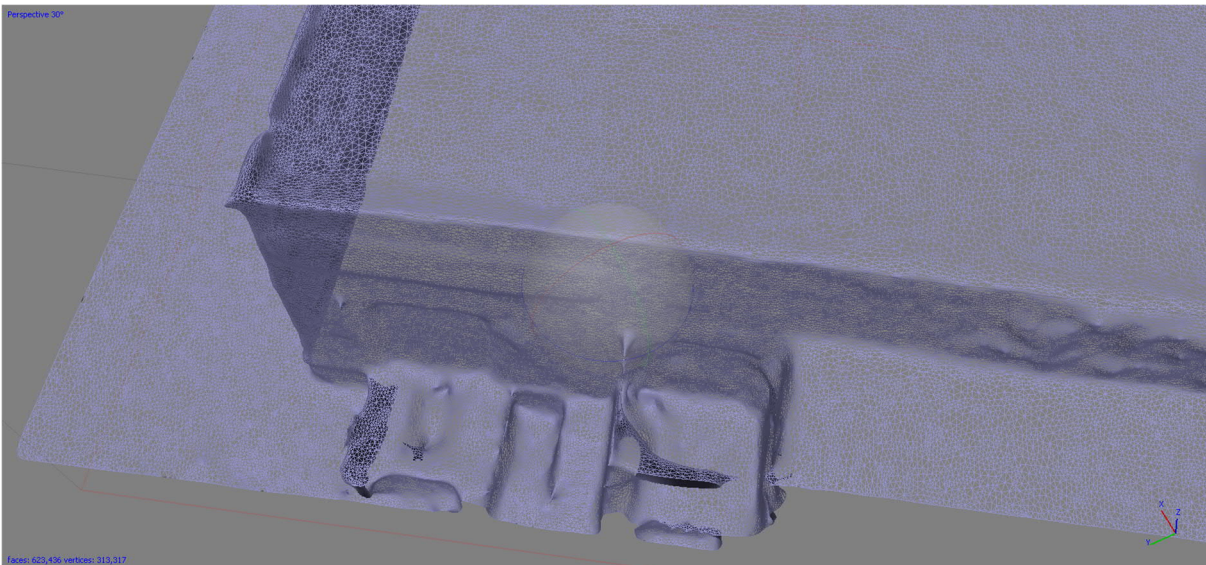


Figure 1.43: Mesh obtained



Figure 1.44: model

The computerized processing procedure from frames to model 3D (at each moment) is carried out according to a predetermined order in different phases (spatial modelling). The first phase is that of alignment of the images and of the construction of the sparse point cloud (cloud points basis). This step identifies the common points in both frames using the image matching algorithms. The points selected in the various photos must necessarily have some features in common for properly overlapping. The result is an overall view of all shooting points positioned along the three Cartesian axes (local reference system) and the points constituting the sparse points cloud. The construction of the denser point cloud (dense cloud points) represents the second stage of processing, in which starting from the cloud of sparse points we get a more detailed and dense cloud of points. The realization of the mesh allows obtaining a polygonal mesh of the sea surface, while the construction of the texture is the last step that allows to “coating” the polygonal mesh generated in the previous step using the color data of the uploaded images. The texture is, in fact, a set of points, lines, and shapes that give the overall impression of a compact surface, making it as realistic 3D model so far

obtained. The 3D model with texture obtained is subsequently scaled and geo-referenced using data collected on the structure supporting the camera site.

The temporal combination of the obtained models (space-time modeling) is made by appropriate algorithm implemented in own on MATLAB.

Constructing 3D-models with photogrammetry and structure-from-motion technology is cheaper than using LiDAR. LiDAR is an acronym for “light detection and ranging”. However, photogrammetry comes with some drawbacks [17]. Lidar uses its own light source and is therefore not affected by shadows or low light conditions. In the case of photogrammetry, if leaves on trees are blocking the ground it will be impossible to model it. LiDAR however has some capability to penetrate the foliage.

The use of terrestrial laser scanners has the ability to provide useful data for geometric modelling and determination (by comparison of the model realized in successive epochs) of deformations that are created. Laser technology, bypassing cases of simpler realization where the magnitude of deformations to be evaluated is of greater magnitude than measurement uncertainty, is useful and productive in most engineering applications that require measurements near-deformation, if not less than the uncertainty of scanned data.

Barrile t al. [14] analyzed the uncertainty of data derived for a region by UAV as well as LIDAR data. The used 10 georeferenced points on a chosen area and compared the accuracy obtained by the use of both techniques. The error by LIDAR data was between 2 and 4cm. The UAV data had a deviation of 8 cm with a maximum of 14cm. The results of the 3d model generated for the single storey hall showed a dispatching of similar values (Figure 1.45).

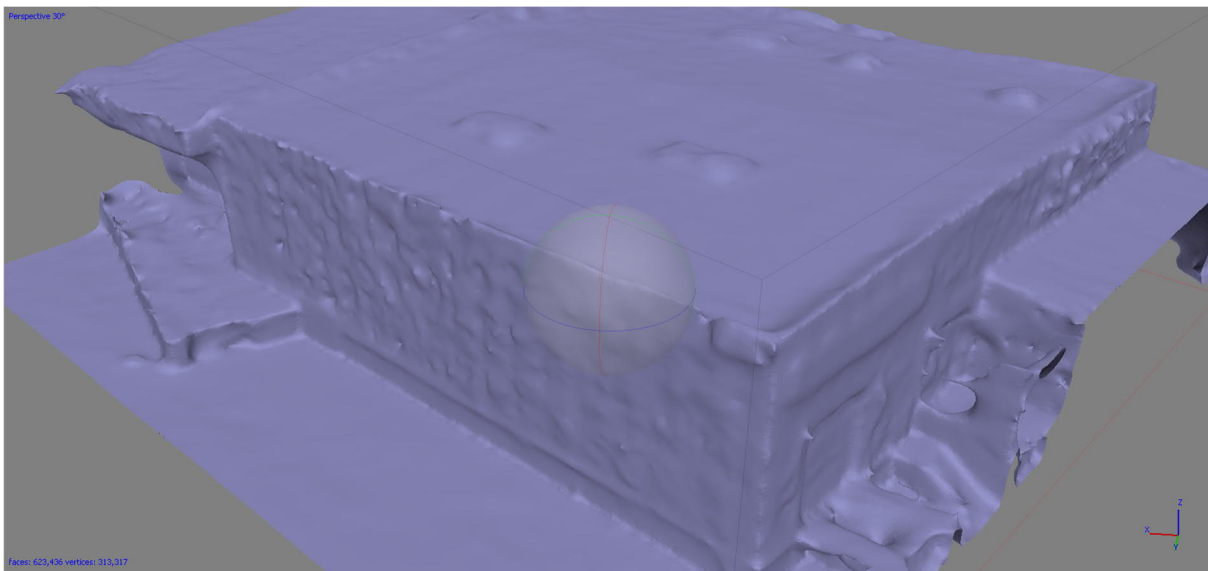


Figure 1.45: Deformations due to uncertainty of the computed 3D model by photogrammetry

In another case study conducted in Italy of the Ridracoli dam, a comparison between laser scanned data from a ground based LiDAR scanner and photogrammetric data acquired with a UAV was made. It showed that photogrammetry can rival LiDAR with possible improvements in the placement of ground control points [15]. The postprocessing of the data took a considerable amount of time and had to be partitioned into smaller pieces. Processing hardware and software as well as the size of the object to be mapped is essential.

A case study performed in Australia in 2012 of coastal erosion showed that a point cloud from UAV pictures were accurate at a sub decimeter level [16]. The present experiment showed that low cost systems based on UAV image processing and photogrammetric analysis with Structure from Motion algorithms are able to produce 3D models of areas and buildings such as SSH with a good level of accuracy. Data acquisition with remote pilot systems is faster, more flexible, and cost-effective than laser scanning and thus a usable technique in data acquisition during planning of demolition.

Moreover, it is good to note that weather conditions, in particular the presence of a strong wind, have not allowed the UAV to reach such a height that it can obtain the best data possible, limiting in fact the results achieved.

Quality and reliability are influenced, in particular, and especially for large items, by light conditions, number of images, and, of course, frame resolution. The use of a high-resolution camera with optics suitable for detection purposes could improve the results. Of great importance are the performance capabilities of computers, especially for larger objects, characterized by a large number of shots essential for proper reconstruction of the object acquired.

2. Basic principles of pre-deconstruction audits

Any demolition, renovation or construction project needs to be well planned and managed in order to reduce environmental and health impacts while providing important cost benefits. Therefore, the European Commission published the Guidelines for the Waste Audits 2017 [14]. The Guidelines provide information about the best practices for the assessment of construction and demolition waste (CDW) streams prior to demolition, deconstruction or renovation of building or infrastructure. The aim of the document is to facilitate and maximize recovery of materials and components for beneficial reuse and recycling without compromising the safety measures and practices outlined in the EU Construction & Demolition Waste Management Protocol [15]. The Guideline supports the targets of the Circular Economy Package presented by the European Commission in 2015 [18]. In this Circular Economy Package, CDW is identified as a key aspect and the preliminary assessment is an essential part of construction and demolition waste management. The following list summarizes the terms used in the Guidelines, the Protocol and this report.

Audit is the process initiated and organized by the building or infrastructure owner. It involves any initiatives that result in a documented work [14].

Pre-demolition audit is a preparatory activity with the purpose of collecting information about the qualities and quantities of the materials that will be released during the demolition, deconstruction or renovation works and giving general and site-specific recommendations regarding the demolition, deconstruction or renovation process [15]. Public authorities should decide upon the threshold for pre-demolition audits. Pre-demolition audits take full account of local markets for CDW, reused and recycled materials. A good pre-demolition audit must be carried out by a qualified expert (the auditor).

Waste audit is the specific part of pre-demolition audit. According to the EU Waste Audit Guideline [14] it results in a documented qualitative and quantitative assessment of possible waste streams prior to demolition, deconstruction or renovation of building or infrastructure. In addition to the inventory of hazardous and non-hazardous wastes, reusable materials and components (also called Demolition Bill of Quantities according to ICE [17]), the audit may include recommendations for specific management options for these materials and components, their value or environmental footprint. Waste audit is to be carried out before any renovation or demolition project, for any materials to be reused or recycled, as well as for hazardous waste.

Pre-deconstruction audit, the term used in this report, covers auditing of constructional steelwork and steel-based elements arising from deconstruction of single-storey buildings. It is aligned with European strategies for construction sector and waste management and follows the objectives of the Waste Framework Directive 2008/98/EC [8], which prioritize waste prevention and reuse over recycling and other recovery.

2.1 Auditing practices in EU

In the broad sense of the “audit” definition, the pre-demolition, pre-deconstruction or waste audit is performed in most of the Member States. In the case of hazardous waste (mainly asbestos and PCBs), most countries follow similar practices and legally enforce their identification prior to the relevant demolition, deconstruction or refurbishment works. For example, asbestos content must be analysed in all buildings built in Finland before 1995. An exception to this general rule is Italy, which has not established by law the execution of this type of inventories including hazardous wastes according to the study performed by European Commission’s Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG Growth) [19]. However, for non-hazardous materials, the type of works for which an audit or inventory is prepared vary greatly, due to the differences in national and regional regulations. Demolition contractors ordinarily perform their own waste inspection too, to set the price or to prepare more detailed demolition and waste management plan. These audits are based on the expertise and common practices of the contractor and rarely conform to any regulation. The contractors may have internal rules, templates, etc. for their audits and sometimes they make very detailed demolition and waste management plans based on this inspection.

The regulations and guidelines concerning waste audits in EU were identified in the study “Resource Efficient Use of Mixed Wastes” by BIO by Deloitte [20]. The map in Figure 2.1 shows the countries performing preliminary waste audits in Europe according to this study.



Figure 2.1 Countries performing waste audit in EU according to [20] (compulsory audits are green, limited audits are yellow, and countries without widely implemented auditing are red)

Comprehensive survey involving demolition contractors from eight EU countries was conducted by the European Demolition Association in 2016 [21] including topics concerning pre-demolition auditing. The survey showed that the knowledge about pre-demolition auditing requirements and practices can be very limited especially because of unclear or non-existing legislation and guidance. Figure 2.2 shows the percentage of respondents thinking that pre-demolition audits happen at least in a limited scope in their country. According to this survey, metals are the most frequent materials identified with the highest percentage of positive answers from the Netherlands and Belgium (over 84% respondents answered that metals are either often or always appearing in the pre-demolition audits).

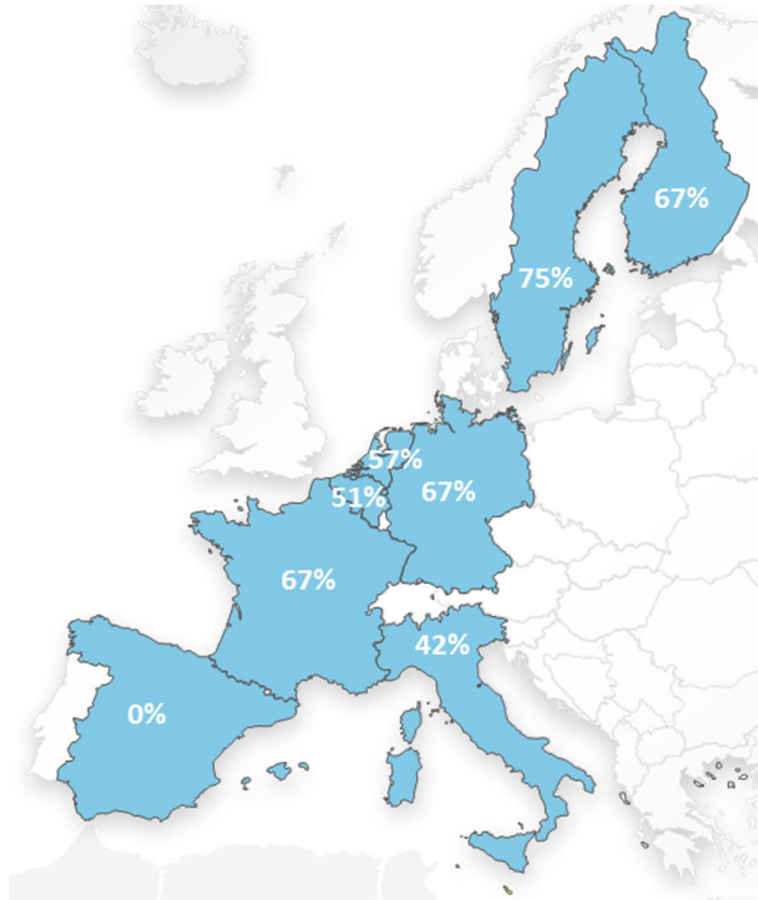


Figure 2.2 Percentage of respondents thinking that the audit is happening in their country according to the survey by the European Demolition Association [21]

According to the EU guideline [22], it is recommended that the decisions about the management of deconstructed components and materials follow the process described in Figure 2.3.

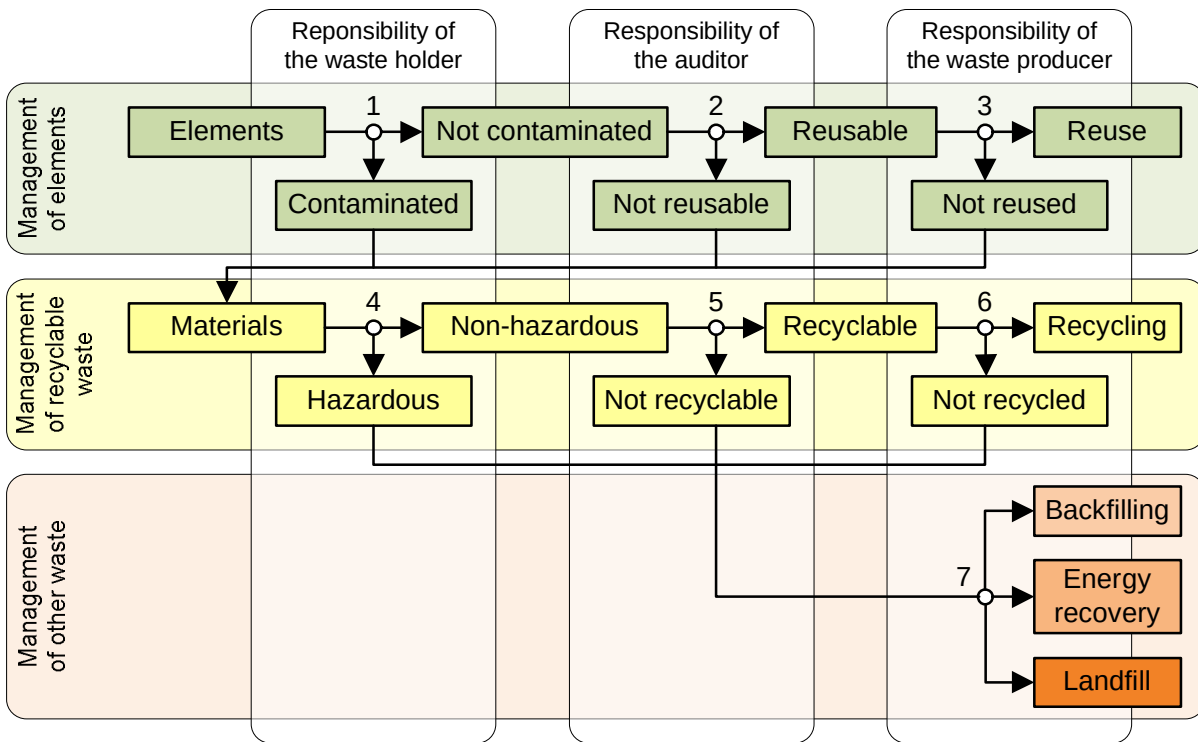


Figure 2.3. Decisions about the material and waste management adapted from [22]

The actors in the described process are:

Waste holder is the natural or legal person who is in possession of the waste at the time of waste declaration. In principle, he is the owner (developer) of the audited property, but the ownership of the waste can be transferred to the contractor. The waste holder is responsible for the accuracy of the data concerning quality and quantity of material streams and hazardous substances [22]. The waste holder shall have the knowledge about hazardousness and contamination of the building materials and components (decisions 1 and 4 in Figure 2.3). This information can be obtained from the auditor.

Auditor means the expert or the team of experts performing the audit. It can be represented by the owner (developer) of the property or technical consultant acting on behalf of the owner [22]. Apart from the identification of waste streams, the auditor is responsible for the expert assessment of reusability of deconstructed building components and recyclability of separated materials. The auditor shall have the experience and skills to decide about reusability of components (decision 1 in Figure 2.4) and recyclability of materials (decision 5 in Figure 2.3) and to recommend the most feasible material management options for the contractor/waste producer (decisions 3, 6 and 7 in Figure 2.3).

Waste producer means anyone whose activities produce waste. The waste producer is the waste holder or the contractor that executes the demolition, deconstruction or renovation work on behalf of the waste holder [22].

The aim of the audit according to the EU waste audit guideline is:

- to identify and localize hazardous substances in the building that will affect the deconstruction process and reusability of deconstructed components,
- to provide comprehensive inventory of the reusable building components,
- to provide additional information requested by the building owner or authorities such as recommended management (e.g. end-of-waste procedure), value, technical condition or environmental footprint of deconstructed materials and components.

According to the EU guideline, the audit consists of the steps described in Figure 2.4 (documentation research, field survey, condition evaluation and recommendations) and its results shall be recorded in a report.

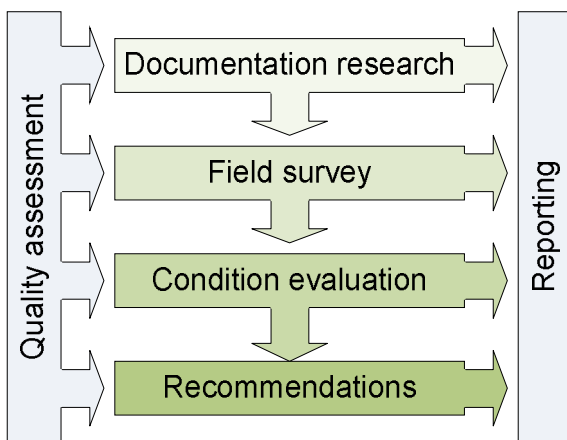


Figure 2.4. Waste/material audit process

The detailed procedure for field survey and testing is described in Deliverable D2.3 of the PROGRESS project [23] and the methods for condition evaluation (material assessment) of structural steelwork and its components are described in Deliverable 2.2 of the PROGRESS project [24].

2.2 Documentation research

A thorough study of available sources and building documentation should be conducted before or together with the site visit. The extent of the research is usually decided by the auditor, but the minimum requirement is to study technical drawings and material inventory from the original design documentation or any recent documentation of the building.

The aim of research of available documents is

- to provide the first estimate about the components, their geometry and material properties, and possible hazardous nature
- to provide indication of the age of the building or infrastructure, typical building practices and materials used in its location at the time of its construction, surrounding area and access to the site, location of nearest waste management facilities and salvage yards.

Typical sources of documentation are drawings and reports obtained from the building authorities and the owner of the building or infrastructure, memos of housing cooperative board meetings and documentation of the real-estate maintenance company. The information obtained from open public sources should be verified for instance by the data provided by building authorities or directly on site. All sources should be properly listed in the audit report.

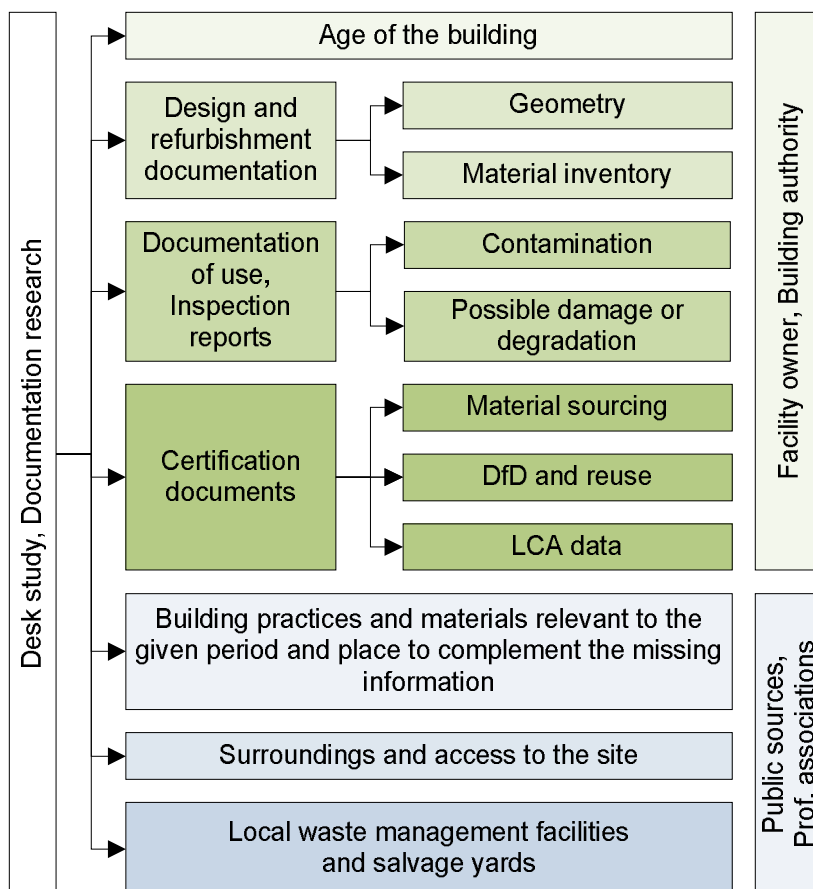


Figure 2.5. Documentation research

Design and refurbishment documentation

Architectural plans and technical drawings, whether or not accompanied by tender specifications or as-built documentation contain information that is useful for planning of the field survey and drawing up a material inventory. They serve for preliminary identification of construction date/period, dimensions, construction typology, composition, materials, location of machinery and installations, details of hidden or difficult to access spaces. The available design and refurbishment documentation needs to be studied

- to obtain the age of the building and its parts,
- to identify the basic materials, components and structural systems,
- to prepare the field survey and decide about examination methods during the survey.

Documentation of use and inspection reports

The aim of research of use and inspection reports is primarily to gather information on storage and use of hazardous products that might have caused contamination of other materials. It also verifies the findings obtained from the public sources and design documentation. The available documentation of use of the building, infrastructure or their parts needs to be studied to identify

- possible changes of the original building layout, materials or coatings,
- possible material deterioration and contamination,
- components damage,
- locations for sampling.

Certification documents

Any available CE marking and Declaration of Performance of harmonized construction products needs to be examined to understand the conformity of the reusable products with the current standards and to complement the knowledge about properties of the recyclable materials. This concerns products manufactured after 2000, when the first standards were harmonized.

It is recommended to study any other available material or building certification. For instance material certification (such as mill certificate), can provide additional information about the quality of the material used in the building construction or maintenance interventions, the certification of building sustainability can provide the information about the recyclability and reusability of materials (e.g. design for deconstruction and reuse, material sourcing and recycled content in materials, material connections and interfaces, and environmental footprint of materials).

Additional research

Any available guidance and literature provided by professional associations should be inspected to identify risk of presence of hazardous materials, and common building materials, construction systems and connection methods typical for the building age, type and location. Any available maps, charts and urban plans should be studied to find the most suitable access route for the material transport, machinery and temporary storage area for the recovered materials and components. Any available register of local waste management facilities and salvage yards should be accessed to find out the most viable waste management options and material dealers for the recovered building components.

2.3 Field survey

The field survey is the basic requirement of the audit, condition evaluation and recommendation for the management of released waste, materials and components. The aim of the field survey is

- to verify and update the information obtained in the documentation research,
- to identify and mark the reusable components,
- to determine the current condition of the building and its components,
- to obtain indications of hazard scenarios and exposure of the building materials and components,
- to collect material samples for the laboratory testing.

If the presence of hazardous materials is suspected, protocols to work with hazardous materials must be followed and worker protection measures applied during the field survey. During the field survey, the building is visually inspected and inventoried. If necessary, samples are taken for analysis. The work needs to be performed systematically and methodically. A recommended approach consists of four parts:

- site visit and general analysis of the building
- general survey to have an idea about type and location of deconstructed components and to prepare the necessary equipment for the next steps,
- detailed survey, measurements and on-site scanning to prepare the material inventory and waste declaration,
- sampling and analysis to obtain the quality, contamination and level of deterioration of materials.

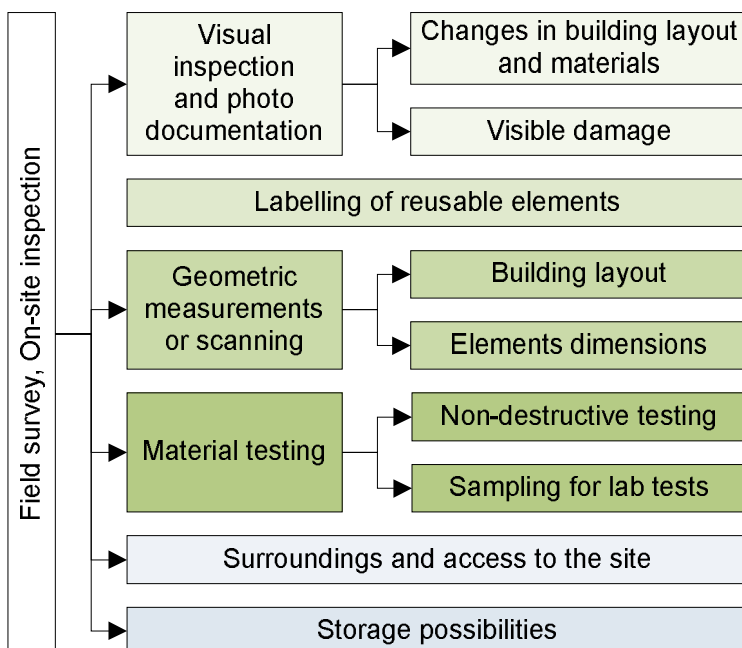


Figure 2.6. Field survey

Visual examination and photo documentation

During the visual inspection, the auditor should aim to:

- evaluate the consistency of the design documents and documents of the property owners with the actual situation,
- identify locations, different structure and technical systems and their materials
- make diagrams, notes, take pictures of the different parts and include them in the report.
- make sure to identify all the accessible components, their materials and coating (in covered areas, it is important to remove a small part of the covering to make sure that the materials underneath are those expected).

Labelling of reusable components

The components intended for reuse need to be visibly marked and their location noted in the building or infrastructure plan (such as paper or electronic drawing or BIM). The labels shall be unique (e.g. number, barcode or RFID tag) so the original location of each of the components will be known after the deconstruction.

Geometric measurements and on-site scanning

External dimensions and internal spaces can be verified by the adequate means; traditional measurements or advanced methods such as laser scanning, LIDAR or photogrammetry. Internal cavities, water leakage and materials in the core of composite building components and on the surface shall be identified by removing parts of the covering layers, or by the advanced non-destructive methods such as spectrometer, magnetometer, infrared camera, ultrasound, or ground penetration radar. The measurement methods and equipment shall be documented in the audit report.

Material testing

If the on-site measurements and scanning do not provide comprehensive information, the auditor may take samples of the materials for the further laboratory testing. The samples need to be visually inspected at the moment of collection and observations reported. The sampling and testing methods will be included in the report as well as the results and conclusions from the analysis.

Additional survey

The area surrounding the deconstruction site should be inspected with regards to

- neighbouring objects that can be affected by the recommended deconstruction and on-site management methods, especially noise and dust
- accessibility for the vehicles
- temporary storage possibilities for recovered materials and components

The description of the survey, sampling and measurement methods need to be included in the audit report.

2.4 Condition evaluation

The aim of condition evaluation of steel structures is to

- check the compliance of executed structure with the plans,
- examine defects, deteriorations (in particular as a result of corrosion and fatigue) and additional properties of components to fulfil the criteria for reuse according to the protocol presented in deliverable D2.2 of PROGRESS project [24],
- evaluate the level of contaminants in order to decide about the hazardous nature of the materials according to the recommendations from deliverable D1.3 of PROGRESS project [25],
- obtain any other properties required by the waste holder, for instance value calculated according to deliverable D5.2 of PROGRESS project [26] and environmental footprint calculated according to deliverable D5.1 of PROGRESS project [27],
- if the component becomes waste, clarify any uncertainties about material classification according to the List of Wastes [28], and provide properties of materials to fulfil the criteria for the recommended waste treatment.

If the information about the required material properties cannot be obtained directly on site, it should be provided by relevant experiments or mathematical models.

2.4.1 Recommendations

The aim of the “recommendations” part of the audit is to describe one or more feasible scenarios involving reuse of particular components or the whole structural assemblies. The degree of reusability can be calculated according to the methodology described in the Deliverable D1.2 of PROGRESS project [29].

The audit shall be completed with recommendations on how to perform on-site material management and interventions.

Additional recommendations can be provided for the off-site material management including the list of possible salvage markets and storage areas.

2.5 Reporting the material and components inventory

It is recommended to divide material and components inventory into three parts:

- Identification of hazardous substances
- Inventory of waste materials
- Inventory of reusable components

The declaration of hazardous substances should cover all identified hazardous and dangerous substances including those that are planned to remain in the reused components or structures. The reported information should include:

- Name of the identified substance,
- Quantity (e.g. kg, tonnes, cubic meters) or concentration (e.g. g per kg of coating),
- Description of the location within the component and building,
- Recommended treatment or decontamination

The inventory of waste should cover all hazardous and non-hazardous building materials that may become waste including those in the reusable components or structures. The reported information should include:

- Name of the material according to the European List of Wastes [28]
- Waste code according to the European List of Wastes [28]
- Quantity (e.g. kg, tonnes, cubic meters)
- Description of the location within the component and building
- Level of deterioration and other relevant technical condition
- Recommended waste management name and code according to the Waste Framework Directive [8] (can be several options),
- Optionally estimation of material value or disposal cost and of environmental footprint of the recommended waste management

The inventory of reusable components should cover all components intended for reuse (and visibly marked during the field survey). The reported information should include:

- Description (a) producer and type or (b) description of the component,
- Marking ID,
- Quantity: (a) tonnes, (b) cubic meters or (c) number of components,
- Description of the location within the building,
- Level of deterioration and other relevant technical condition,
- Recommended treatment, storage and distribution (can be several options),
- Optionally estimation of component value, treatment and storage cost, and of environmental footprint of the reuse process

3. Pre-deconstruction audit protocol for single-storey steel buildings

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 3.1). 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.

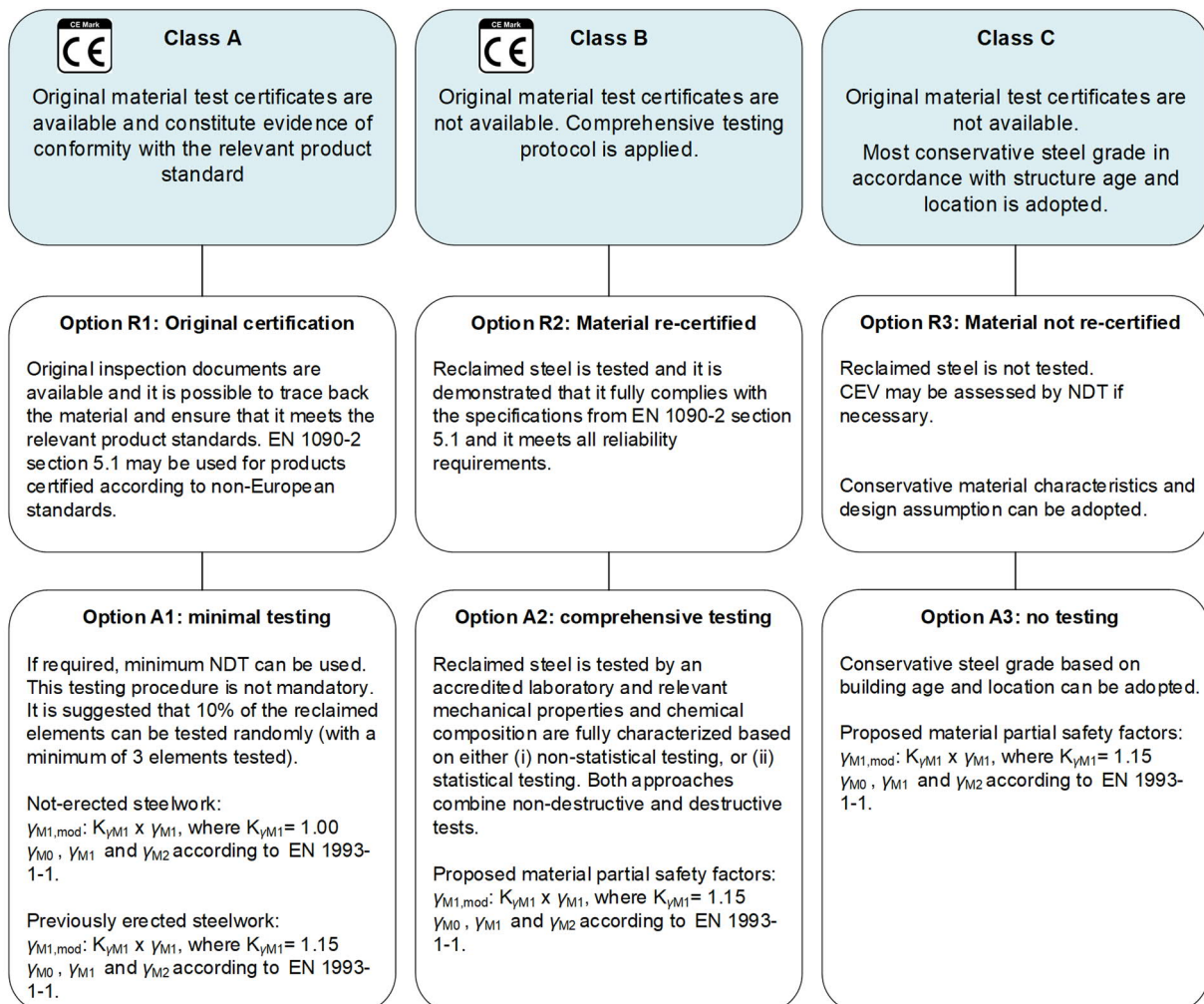


Figure 3.1. Summary of reclaimed steel classes

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 [18]. 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).

3.1 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-built 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 the building age and location. Geometric tolerances should be expected.

Table 3.1 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 3.2. 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.

3.2 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 [30]:

- 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 [30]:

- 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 3.3. 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.

3.3 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 3.4. 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.

3.4 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 3.5).

Table 3.5. 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_{YM0}	1.00	1.00	1.00
k_{YM1}	1.15 ³	1.15	1.15
k_{YM2}	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 $K_{YM1}=1$ 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 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.

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 3.6. *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 3.7 relates the recommended testing approach for yield strength, ultimate strength, elongation and chemical composition to Consequence class.

Table 3.7. *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 3.8* and *Table 3.9*.

Table 3.8. *Waste recovery and disposal operations relevant for the structural steel according to [8]*

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 3.9. *Waste recovery and disposal operations relevant for the other materials according to [8]*

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 incinerable 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 [30]:

- 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 120°C 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 3.8* and *Table 3.9* shall be used.

Table 3.10. 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;	

3.5 Reporting

All collected data are to 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 of 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 [32]

¹⁰ Minimum steel grade (e.g. S235) according to PROGRESS methodology [32]

¹¹ Testing protocol according to PROGRESS methodology [32]

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 [33]

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 substances¹⁴

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 waste¹⁹

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 [28]

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 [8]

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Annex A: Example of pre-deconstruction audit report

A General information

A1 Description of the building	
A1.1 Building description	Single-storey steel storage hall with welded-tapered frames, without envelope, fabricated by Mostárna Hustopeče (today's SIGNUM spol. s r.o.).
A1.2 Address, site number	Municipality of Jihava, Vysočina region, Czech Republic
A1.3 Year of steelwork fabrication	unknown (after 1980 due to known fabricator)
A1.4 Floor area	1080 m ²
A1.5 Main dimensions	span: 18 m, length 60 m, height: 7.2 m
A1.6 Envelope	n/a
A1.7 Crane (description, type, tonnage)	n/a
A1.8 Steelwork is already deconstructed	yes
A2 Purpose of the deconstruction (if A1.8 is yes) The current owner doesn't need the storage hall anymore	
A3 Description of the future use of deconstructed components (if known) Relocated reuse of 4 bays (frames F1 to F5 were selected by the owner – see the attached drawing), reusable purlins and rails will be selected after deconstruction.	
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) n/a	
A7 Building documentation and drawings	
A7.1 Design documentation	no
A7.2 Fabrication documentation	no
A7.3 Documentation of use and inspection reports	yes
A8 Certification	
A8.1 Mill certificates of delivered steel	no
A8.2 CE marking of delivered steel products or steelwork	no
A8.3 Other certification:	n/a

B Description of the audit and recommendations

B1 Description of the available documentation

No design documents or certificates are available. The structure was stamped by the manufacturer.

B2 Description of the on-site visits (dates, persons, equipment)

1st visit:

Date

Persons:

Equipment: Standard measuring equipment, laser scanner, camera

Distances, spans and cross-sections were measured during the visit. Since no design documentation was available, 25% of the primary structure and secondary structure was checked in more detail. Photo documentation was obtained at the measuring points.

After a visual inspection, it was concluded that the structure is not visibly damaged and its dimensions are within the acceptable tolerances. However, corrosion was observed on several places due to the removed envelope. Structure was not subjected to fatigue loading. It was observed that northern half of the structure (including frame F5 – see the attached drawing) is painted by intumescent paint. Further analysis was recommended.

2nd visit:

Date

Persons:

Equipment: Chemical sampling kit, protective clothes, HEPA vacuum cleaner

The second visit was requested by the owner in order to decide about reusability and recyclability of steel painted with intumescent paint. Samples of paint were taken from frame F5. The surface was cleaned afterwards.

B3 Description of the labelling system of reusable components

Frames were labelled F1 to F5 by paint, both on columns and rafters. Their location is identified in the attached drawing.

B4 Description of the on-site measurements (equipment, results)

Distances and cross-sections were measured on-site:

Spans: Outer:	Inner:	Distance between frames:
Heights: Eaves:	Ridge:	
Cross-sections:	Purlins:	Rails:
	Columns:	Rafters:

B5 Description of sampling (methods, sample sizes, locations, numbers)

Three samples of intumescent paint were extracted from frame F5.

B6 Evaluation tools and methods for off-site testing and condition evaluation

Samples of intumescent paint were sent for the chemical analysis to indicate most common hazardous substances.

B7 Results of the evaluation

Structural frames F1 to F5 can be reused as they fulfil the admissibility conditions. Secondary structure was not evaluated before the deconstruction.

High concentration of HBCD (Hexabromocyclododecane) of average 150 mg/kg was observed in all of the samples of intumescent paint. Since the same paint was used also for four other frames, it is assumed that they contain HBCD as well.

B8 Recommended reuse scenario(s) with optional evaluation of reusability (if not in A3).

Reuse scenario was defined by the owner. Reusability index was not evaluated.

B9 Recommended treatment of materials and components

All flaky intumescent paint shall be stabilised in-situ by the airless spray application of acrylic paint. Where steel members are to be cut, a 100 mm wide strip of paint about the cut line shall be completely removed (using a chemical paint stripper and scraper or vacuum-shrouded by dustless abrasive blast equipment). The removed waste shall be progressively placed into plastic bags and placed in the designated lead contaminated waste bin. The remaining paint shall be removed from all reused and recycled steel.

Deconstructed elements for reuse will be repainted and stored in a dry ventilated place. Remaining steel scrap will be collected and sent for recycling. Concrete will be separated and sent for recycling. Remaining mixed waste will be used for backfilling. Excavated soil will be used for landscaping.

C Inventory of reusable components

C1 General information

C1.1 Component	C1.2 Dimensions	C1.3 Quantity	C1.4 Location	C1.5 Year of fabrication	C1.6 Will be reused	C1.7 Reuse description
Frames F1 to F5	see the drawings	5	see the drawings	>1980	yes	see A3
Remaining frames	see the drawings	5	see the drawings	>1980	no	
Purlins (selected after deconstruction)	IPE 120	132 m	see the drawings	>1980	yes	see A3
Remaining purlins	IPE 120	528 m	see the drawings	>1980	no	

C2 Material information

C2.1 Component	C2.2 Steel manufacturer	C2.3 Component manufacturer	C2.4 Certified steel grade	C2.5 Recommended steel grade	C2.6 Recommended material testing
Frames	unknown	Mostárna Hustopeče	n/a	S235 without testing or higher according to C2.6	PROGRESS procedure, DT samples from not-reused frames, NDT for reused frames
Purlins	unknown	Mostárna Hustopeče	n/a	S235 without testing or higher according to C2.6	PROGRESS procedure, DT samples from not-reused purlins, NDT for reused purlins

C3 Recommended treatment

C3.1 Component	C3.2 Observed damage	C3.3 Recommended repairs	C3.4 Existing coating	C3.5 Recommended surface treatment
Frames with intumescent paint	n/a	n/a	Intumescent paint	repainting
Purlins	n/a	n/a	paint, corroded	repainting

D Inventory of waste and hazardous substances

D1 Hazardous substances

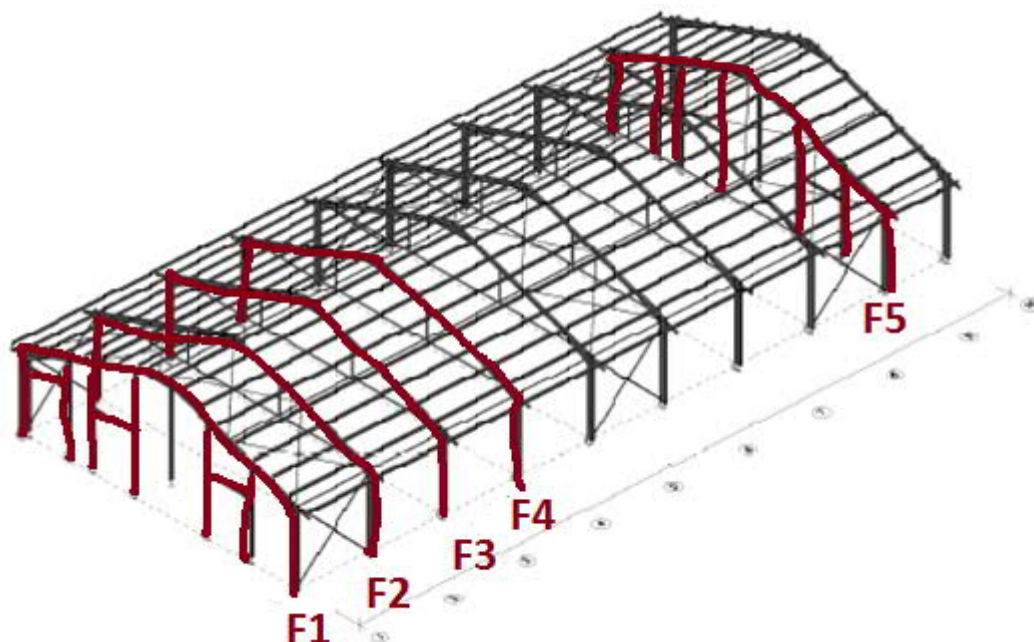
D1.1 Substance	D1.2 Present	D1.3 Quantity/concentration	D1.4 Location	D1.5 Recommended treatment
Asbestos	no	n/a	n/a	n/a
PCB	no	n/a	n/a	n/a
Creosote	no	n/a	n/a	n/a
Other: HBCD		150 mg/kg	Intumescent paint	Removal and safe disposal, see B9

D2 Inventory of waste¹⁹

D2.1 Material	D2.2 Code	D2.3 Hazardous	D2.3 Quantity	D2.4 Location	D2.5 Condition	D2.6 Recommended treatment
Iron and steel	170405	no	20.4 t	steelwork	painted, corroded	R4 (recycling of metals)
Concrete	170101	no	8 t	base slab	good for recycling	R5 (recycling of inorganic materials)
Mixed CDW	170703	no	4 t	base slab	n/a	D12 (permanent storage/backfilling)
Soil and stones	170504	no	9 t	excavation	n/a	D2 (land treatment)

E Drawings and photos

Frames to be reused



Photos

