Life cycle assessment (LCA) and life cycle cost (LCC) on the reuse of reclaimed steel. Case studies

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Objective

The aim is to present the **environmental impact** and **life cycle cost** of a single-storey steel building (SSSB) made of reclaimed steel.

The SSB is designed as:
- a new construction using new steel components;
- a new construction using different amounts of reused steel components.

Reuse scenarios of PROGRESS project

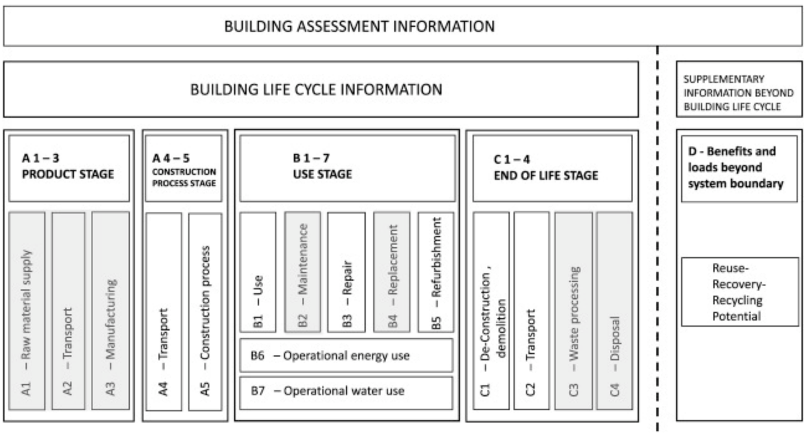
	In-situ	Same site		Different site	
		Same configuration	Different configuration	Same configuration	Different configuration
Entire primary structure	**A**	**B**	**C**	**D**	**E**
Elements of the primary structure	**N/A**	**N/A**	**F**	**N/A**	**G**
Individual elements	**N/A**	**N/A**	**H**	**N/A**	**I**

Type of product:

- The entire primary structure;
- Elements of the primary structure, e.g. trusses or 2D portal frames;
- Individual structural elements, e.g. the column or rafter.

Location:

- Reuse in-situ, i.e. the primary structure is retained and not deconstructed;
- Reuse on the same site, i.e. the primary structure is deconstructed and re-erected either in the same configuration and/or same or different location;
- Reuse on a different site.



Modules of the building life cycle

EN 15804: *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products*

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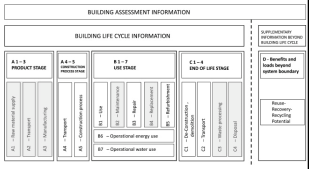
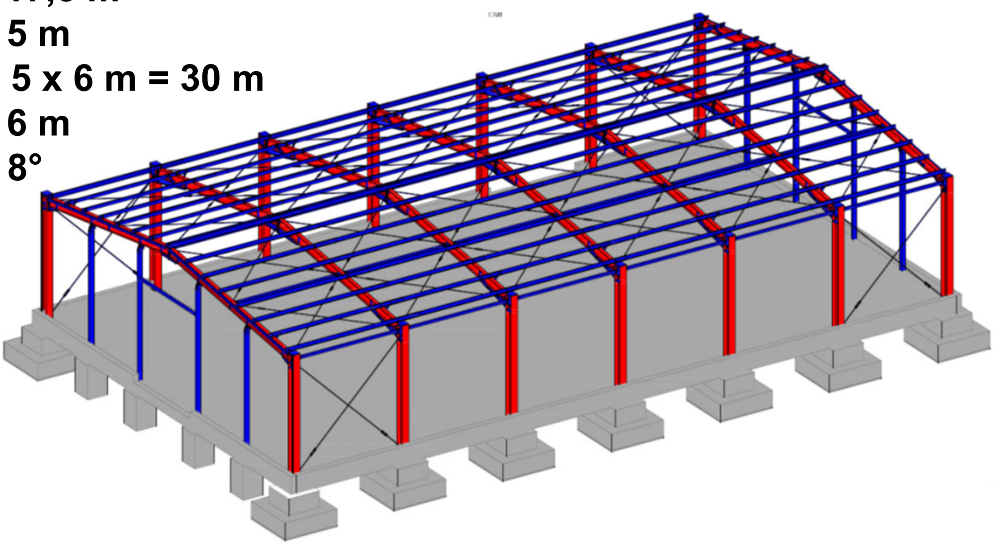


Building life cycle stage	Product stage	Construction process stage		Use stage	End of life stage			
Case	A3	A4	A5	B1-B7	C1	C2	C3	C4
A								
B								
C								
D								
E								
F								
G								
H								
I								

Active modules of a building life cycle in case of reused building scenarios A-I

Case study

SSSB L = 17,5 m
T = 5 m
B = 5 x 6 m = 30 m
h = 6 m
α = 8°



CASE 1: Design considering the reuse of the **portal frames** of an existing steel structure. The portal frames are originated in Germany and will be reassembled in Romania. All other components represent new steel.

CASE 2: Design considering reclaim steel elements. Existing profiles for **columns and beams** were identified in Germany, coming from the deconstruction of other buildings, and are transported to Romania. All other components used in fabrication represent new steel.

CASE 3: Design considering reclaim steel elements. The same as CASE 2, including **also end plates for beams and columns**, coming from the deconstruction of other buildings. All other components used in fabrication represent new steel.

CASE 4: Design considering the **full reuse of an existing primary steel structure**, covering the overall dimensions and site conditions. The structure is originated in Germany and will be reassembled in Romania.

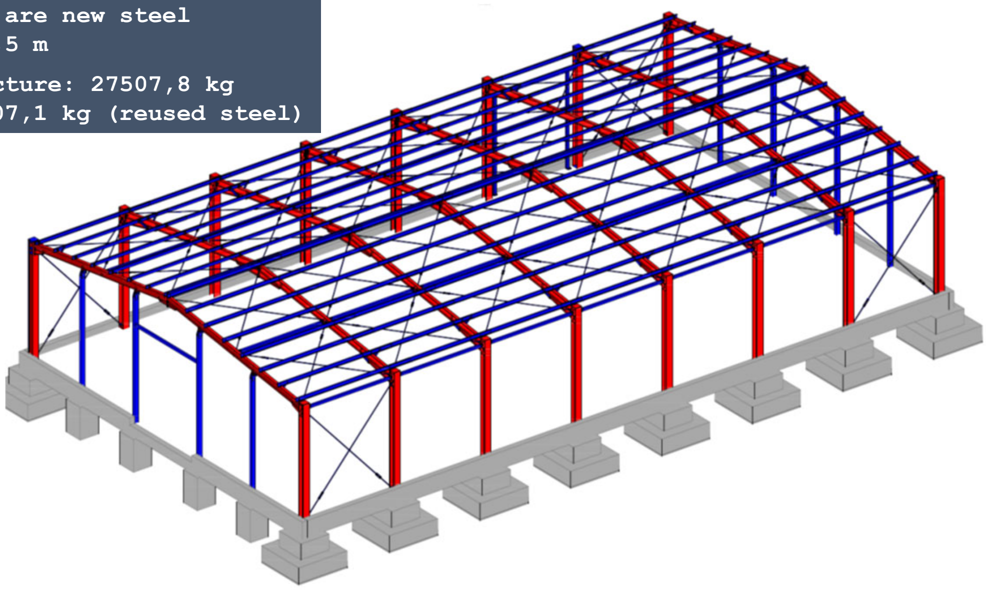
CASE 0: Structure is designed as a new structure with new steel - optimal design.

CASE 0+: Structure is designed as a new structure with new steel. This case considers design for deconstruction.

CASE 1: Design considering the reuse of the existing portal frames – S355

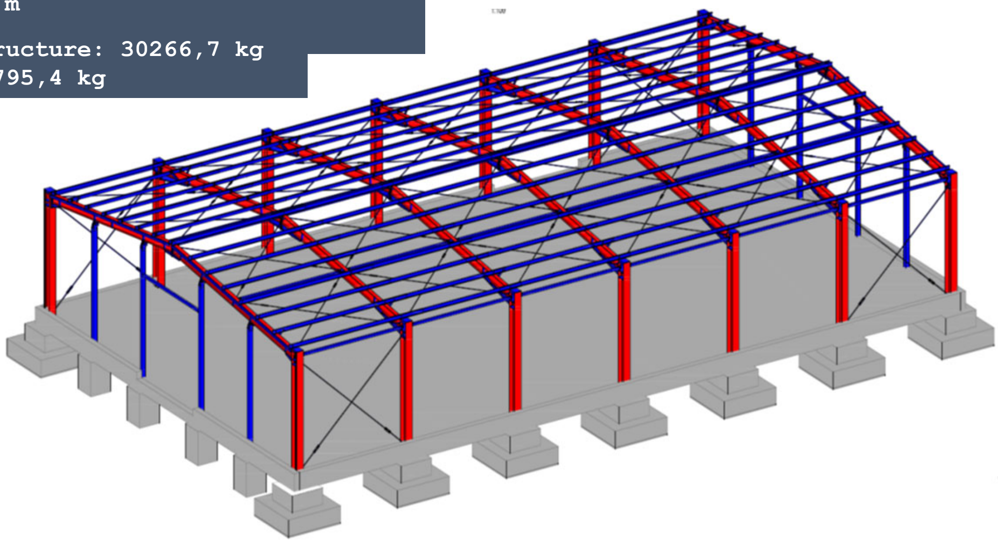
Roof and wall bracing system and longitudinal beams are new steel
T = 4,5 m ; B = 31,5 m

Total primary structure: 27507,8 kg
Portal frames: 17907,1 kg (reused steel)



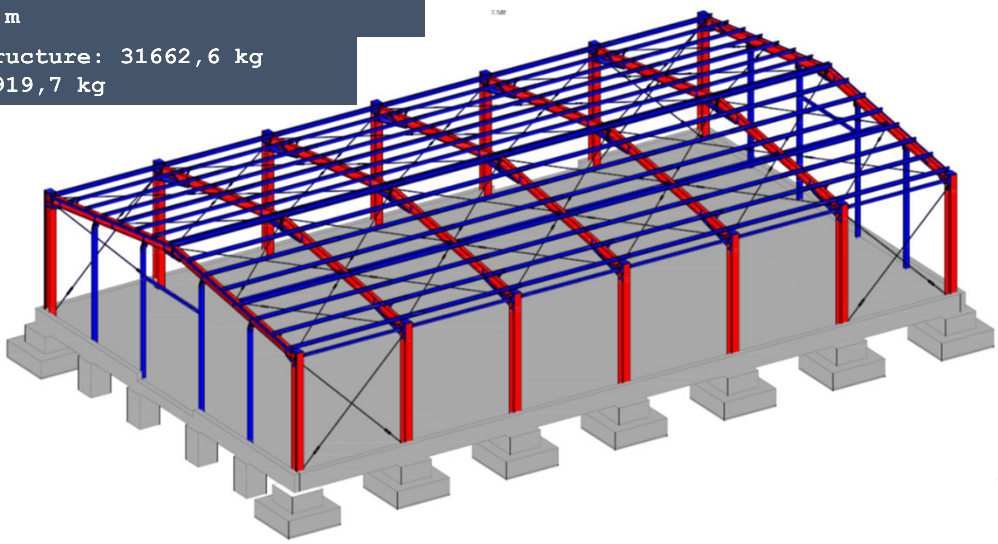
CASE 2: Design considering reclaimed elements
Profiles HEA400 for columns and IPE 360 for beams – S275
All other elements are new steel
T = 5 m ; B = 30 m

Total primary structure: 30266,7 kg
Reused steel: 16795,4 kg



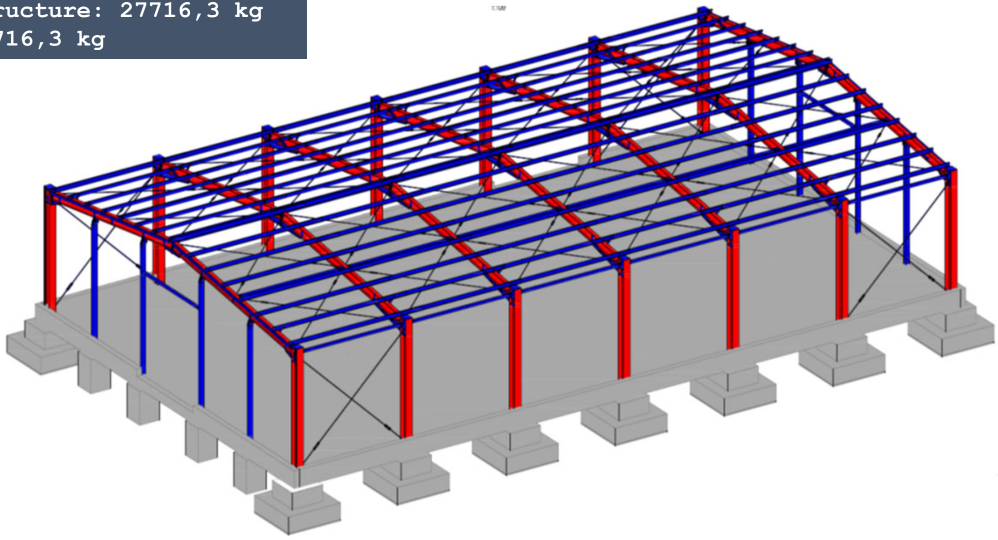
CASE 3: Design considering reclaimed elements
Profiles HEA400 for columns and IPE 360 for beams – S275
End plates for beams and columns – S275
All other elements are new steel
T = 5 m ; B = 30 m

Total primary structure: 31662,6 kg
Reused steel: 19919,7 kg

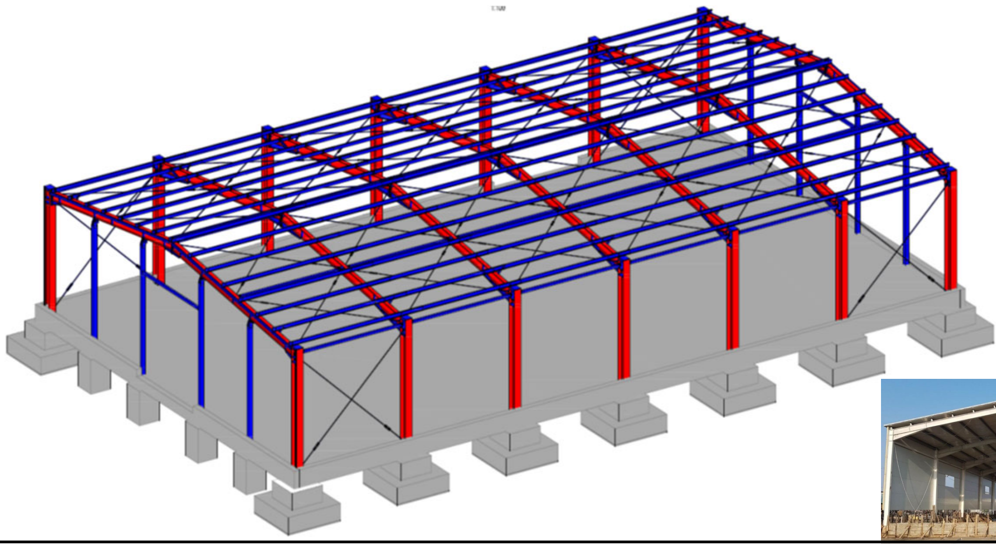


CASE 4: Design considering the full reuse of an existing primary steel structure
T = 5 m ; B = 30 m

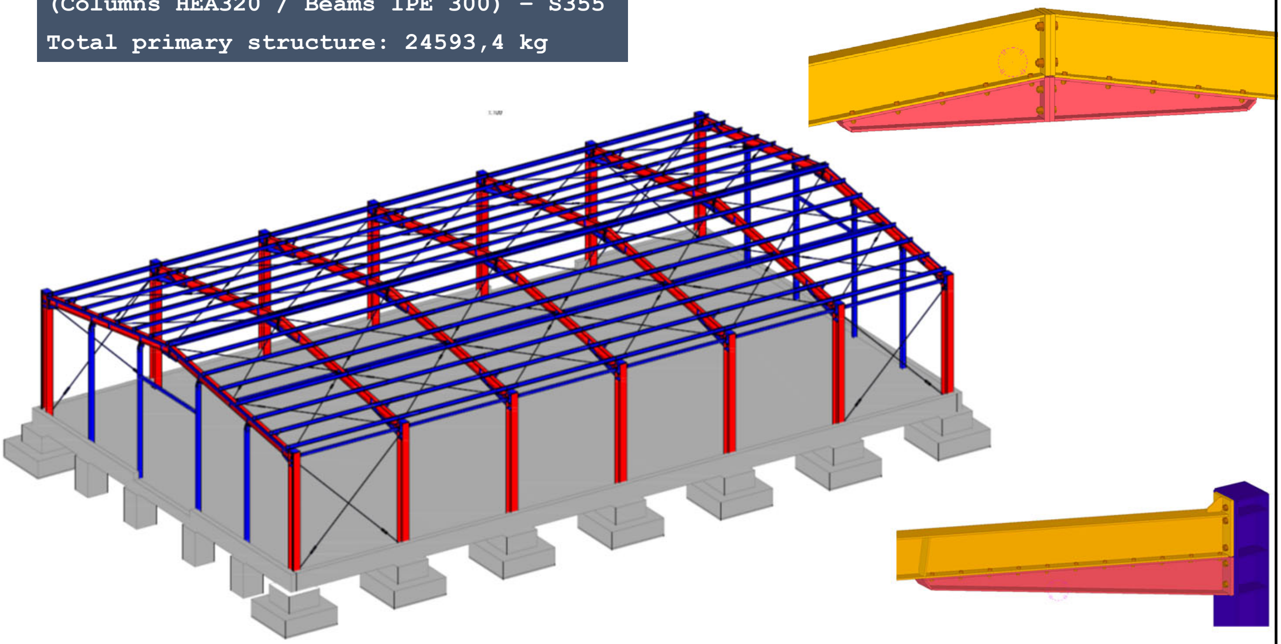
Total primary structure: 27716,3 kg
Reused steel: 27716,3 kg



CASE 0: New design / new steel (real design)
(Columns HEA320 / Beams IPE 300) – S355
Total primary structure: 23682,8 kg



CASE 0+: New design / new steel (design for deconstruction)
(Columns HEA320 / Beams IPE 300) – S355
Total primary structure: 24593,4 kg



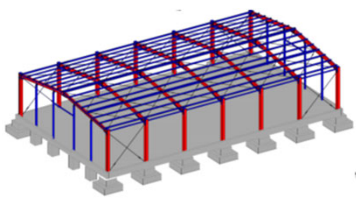
Steel consumption total steel vs. reused steel

Case no.	Total weight [kg]	Reused steel [kg]	%		Purlins [kg]
CASE 1	24812.7	17907.1	72.2		2695.1
CASE 2	27716,3	16795.4	60.6		2550.4
CASE 3	29112.2	19919.7	68.4		2550.4
CASE 4	27716.3	27716.3	100		2550.4
CASE 0	23682.8	-	-		2550.4
CASE 0+	24593.4	-	-		2550.4

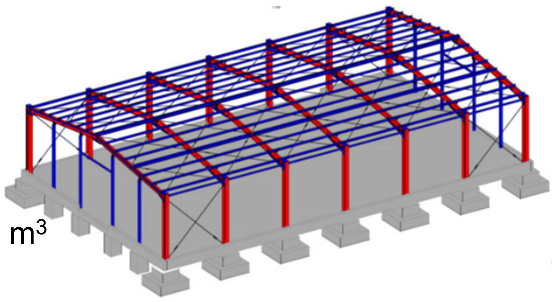
(distance on road 1200 km)

Envelope (1110 m^2): steel sandwich panels with mineral wool insulation
Case 0, 0+: 120 mm roof sandwich panels – new elements
80 mm wall sandwich panels – new elements

Case 1, 2, 3, 4: 80 mm sandwich panels – reused elements
+
60 mm sandwich panels – new elements



The U-values were as follows:
External walls: 0.56 W/m^{2}K
Roof elements: 0.34 W/m^{2}K
Ground floor slab: 0.76 W/m^{2}K.
Windows and entrance-door: 1.3 W/m^{2}K.



Other materials and components:
- concrete foundations and concrete floor: 185 m^3
- triple glazed windows: 22.5 m^2
- sectional sliding gates: 48 m^2.

- for the use phase (module B) only space heating and electricity as operational energy were considered;
- heated floor area: 525 m^2;
- the operational lifetime of the building: 25 years;
- the steel rebars were counted as new material, with an input of 20% steel scrap in the process of manufacturing and an end-of-life scenario with 85% recycling potential plus 15% landfilling/loss material after sorting.

Environmental assessment

- LCA and global warming potential (GWP) evaluation are based on the modular building life cycle approach as described in the European standards EN 15978:2011, EN 15804:2013 and ISO 14044

Assessed scenarios for steel in the superstructure

- **New steel (Case 0)** – demolition and recycling. It was assumed that the new steel contains 20% scrap and that 90% of the steel is recovered for recycling at end of life.
- **New steel (Case 0)** – deconstruction and reuse. It is assumed that the new steel contains 20% scrap, 90% of the steel is reused, and 90% of the remaining steel (9% of the total mass) is recovered for recycling at end of life.
- **New steel (Case 0+)** – deconstruction and reuse. It is assumed that the new steel contains 20% scrap and 100% of the steel is reused at end of life.
- **Reused steel (Case 1-2-3-4)** – demolition and recycling.
- **Reused steel (Case 1-2-3-4)** – deconstruction and reuse.

Modular assessment considers building life cycle stages from A to C and the stage beyond the system boundary, Module D.

End-of-life for steel (recycle scenario)	In			Out		
	New material	Reused material	Recycled material (scrap)	Waste	Material for reuse	Material for recycling (scrap)
Case 0	80%	0%	20%	10%	0%	90%
Case 1	27.92%	65.10%	6.98%	10%	0%	90%
Case 2	35.61%	55.49%	8.90%	10%	0%	90%
Case 3	29.67%	62.91%	7.42%	10%	0%	90%
Case 4	0%	100%	0%	0%	0%	100%

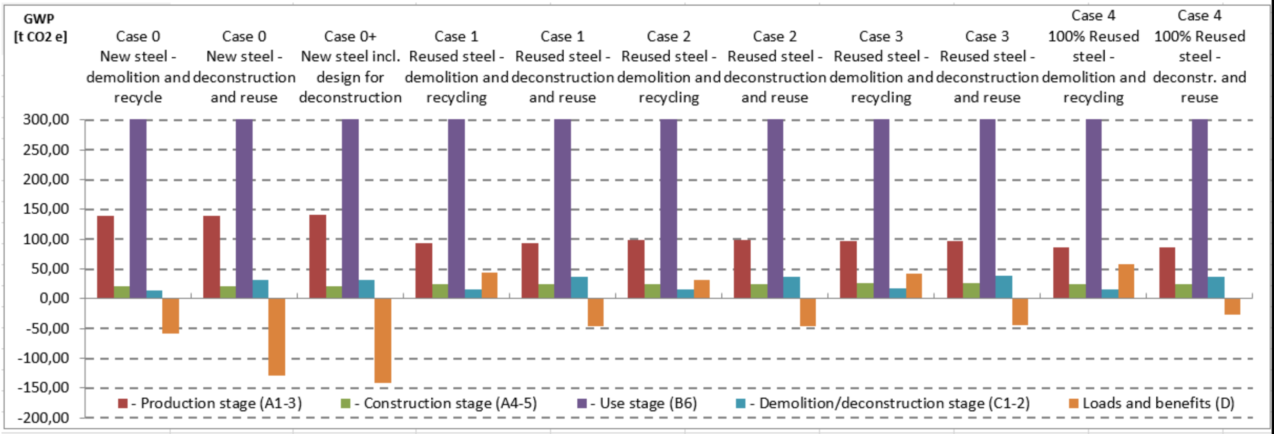
End-of-life for steel (reuse scenario)	In			Out		
	New material	Reused material	Recycled material (scrap)	Waste	Reused material	Material for recycling (scrap)
Case 0	80%	0%	20%	1%	90%	9%
Case 0+	80%	0%	20%	0%	100%	0%
Case 1	27.92%	65.10%	6.98%	3%	72%	25%
Case 2	35.61%	55.49%	8.90%	4.45%	55.49%	40.06%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

- The product stage **(A1–3)** ⇨ the manufacture of the primary and secondary structure, foundations, floor slab, envelope, doors and windows.
- The construction stage **(A4 and A5)** ⇨ finished products are transported to the building site from the factory and assembled on site.
  - 70 km (average distance between the major cities);
  - 1200 km (distance to transport reused steel and sandwich panels).

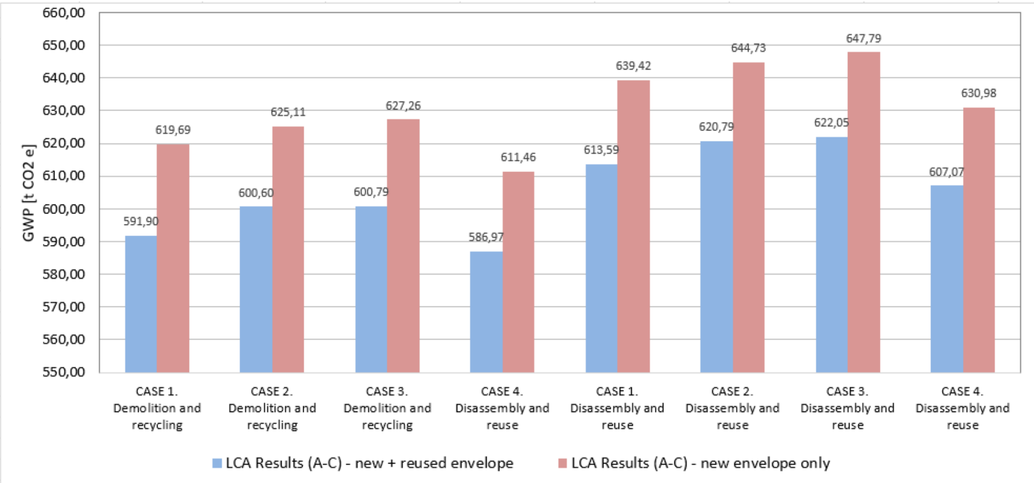
  Construction work included excavation of soil for the floor slab and foundations, concreting and erection of the primary and secondary steelwork and the envelope using cranes, forklifts and man-lifts, including worker transportation.
- Calculation of the use stage **(Module B6)** ⇨ operational lifetime of the building is 25 years. No maintenance, refurbishment, repair or material replacements are considered. It was assumed that the use stages of new and reused buildings have identical environmental impact.

- In the end-of-life stage (demolition/deconstruction, **Module C1–2**) ⇨ deconstruction of the steel structure follows the reverse process to its erection (1.5 times erection time and costs).
- Transportation (**C2**) of the recovered building elements to the nearest salvage yard is also considered in the model.
- The loads and benefits beyond the system boundary (Module D) deriving from recycling and reuse of construction materials are also assessed.

LCA results for the six scenarios (recycling vs. reuse)

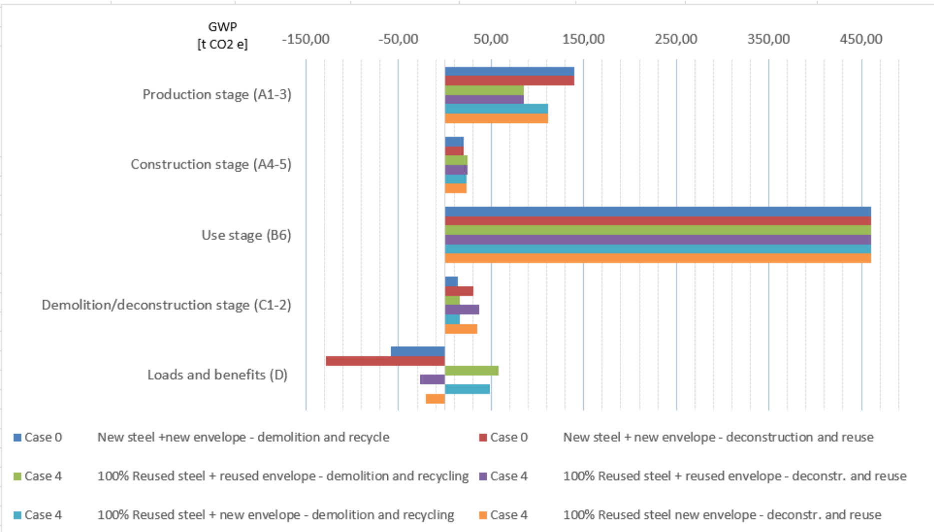


Comparative LCA results for Cases 1-4 (only sandwich panels envelope) new + reused envelope vs. new envelope only



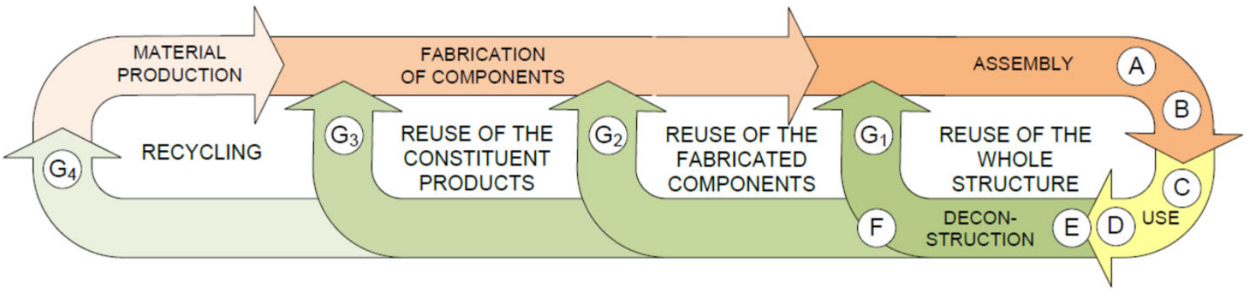
The envelope for cases 1 – 4 is composed by two layers; i.e. reused envelope + new envelop to fulfill the U-values.

Comparative LCA results for cases 0 and 4 only (envelope new sandwich panels vs. new + reused sandwich panels)



Economic assessment

General description of different reuse flows



In case of demolition or deconstruction, the residual value of the building "G" is calculated as the difference between demolition costs and revenue obtained for the sold of secondary materials (e.g. steel scrap or reusable components).

- The economic assessment results are calculated for the same scenarios/modules with new steel and reused steel as in the LCA analysis.

Cost model proposal for Module D

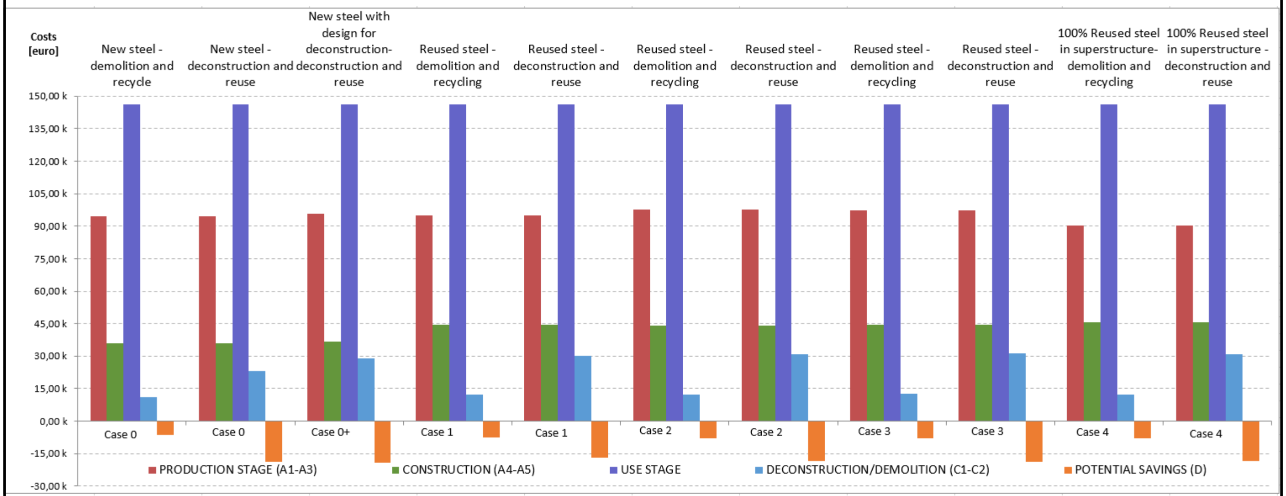
Recycling

-180 €/t (value represents the revenue from sold steel scrap)

Reuse

- 639 €/t (value represents revenue from the sold recovered structure)

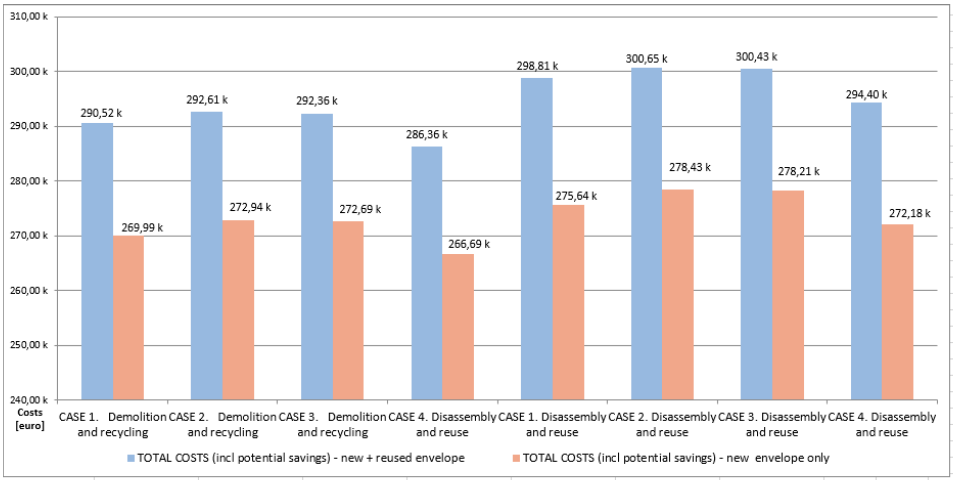
LCC results of the six scenarios (recycling vs. reuse)



Remarks

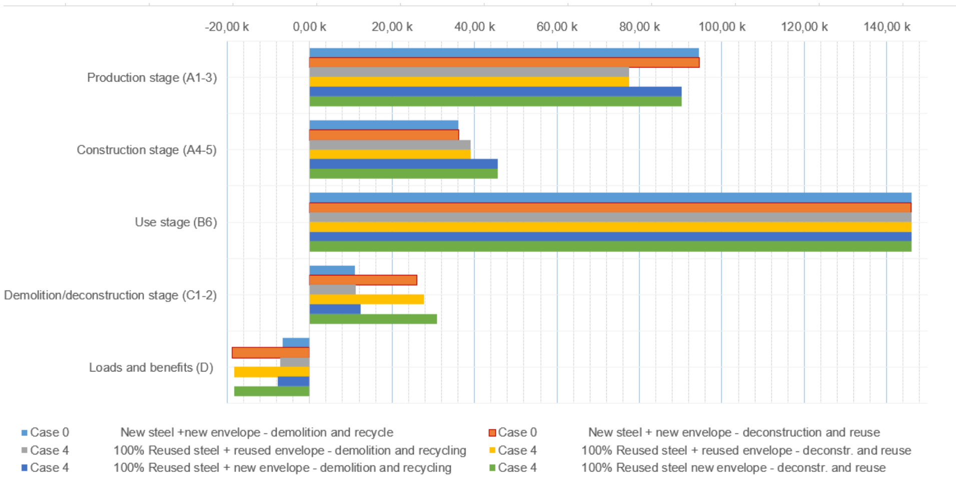
The envelope for cases 1 – 4 is composed by two layers; i.e. reused envelope + new envelop to fulfill the U-values.

However, in the scenarios where the structure is built with reused elements, the costs fall by 6-7% when the envelope consists only of new sandwich panels (new cladding) and just steel is reused.



Total LCC results for the four possible scenarios – new and reused envelope vs. new envelope only

Comparative LCC results for cases 0 and 4 only (envelope new sandwich panels vs. new + reused sandwich panels)



Conclusions

- The end-of-life qualities of construction products play an important role, considering the circular economy, as buildings have a long intended life-span and require a significant amount of material resources and, by default, energy consumption.
- In order to maintain circularity, these resources have to be kept in-use through reuse, reclaim or recycling.
- If the steel structures are designed for reuse and then reused, the economic and environmental benefits are achievable.
- The present assessment considered six cases, where the building is constructed from either new or reused components, and where the components will be either reused or recycled in the future.

Conclusions

- The Life Cycle Assessment results showed that the reuse approach is a strategy that holds environmental benefits superior to recycling approach (modules A-C), the greatest gain being visible in the production stage (A1-3) where GHG emissions are between 29-33% smaller when the structure is built with reused steel (188.51 kg CO_2 e/m^2 for structures built with reused steel in comparison with 266.26 kg CO_2 e/m^2 for structures built with new steel).
- Regarding the economic potential of the reuse stages in various reuse and recycle scenarios, the scenario with reused steel elements resulted in higher potential savings (between 34.70 €/m^2 and 36.66 €/m^2) compared to recycling (between 12.47 €/m^2 and 15.33 €/m^2).
- In cases when the structure is built with reclaimed elements for the main structure, but the envelope consists only of new sandwich panels, the total costs fall by 6-7% in comparison with structures build with new cladding only.
- However, due to the large variation of materials and building practices, LCA and LCC calculations are recommended to be carried out on a case-by-case basis.

Thank you for your attention!