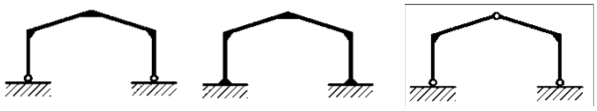
Design of new single-storey steel buildings for reuse

Ricardo Pimentel

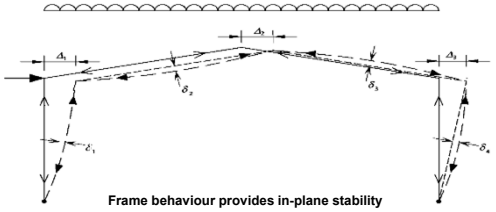
14/05/2020

Single storey buildings overview

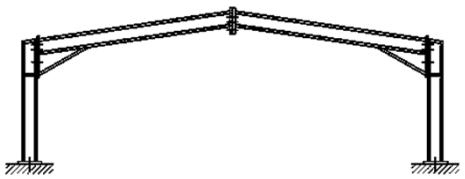
- Structural systems: portal frames



Two-hinged frame | Rigid-base columns | Three-hinged frame



Frame behaviour provides in-plane stability



Typical solution: two-hinged frame

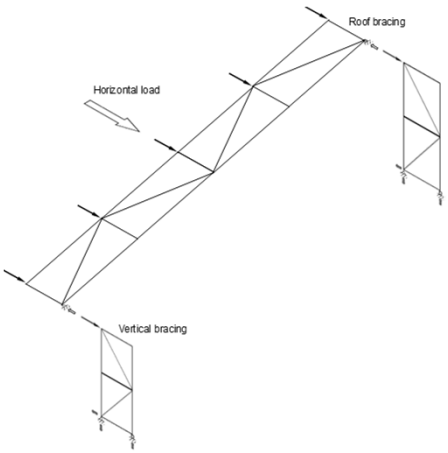
Single storey buildings overview

- Structural systems: portal frames




Single storey buildings overview

- Structural systems: portal frames

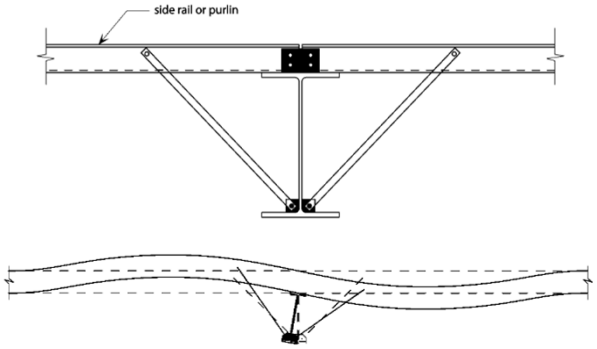


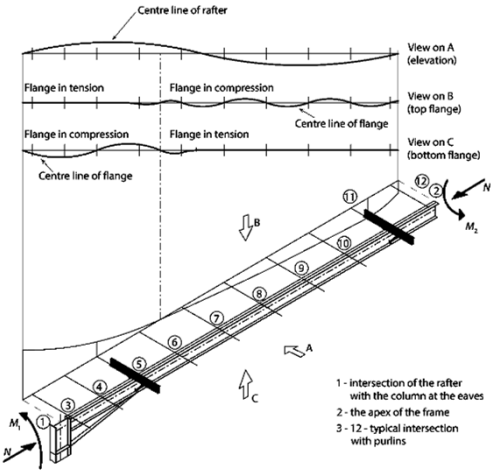
Design of new single-storey steel buildings for reuse

Single storey buildings overview

- Structural systems: portal frames

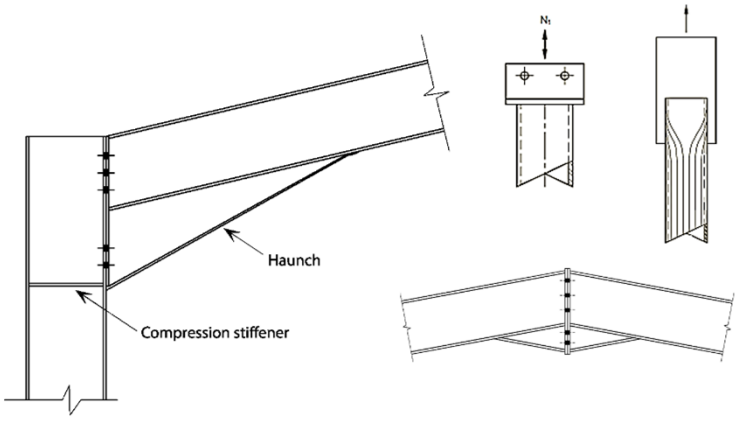
secondary elements as buckling restraints

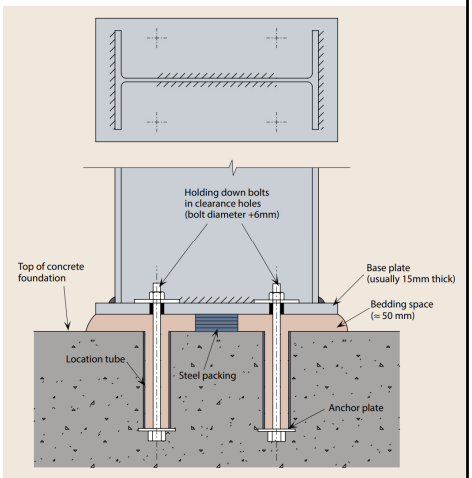




Single storey buildings overview

- Structural systems: portal frame details





Single storey buildings overview

- Structural systems: trussed solutions (longer spans; heavier loads)



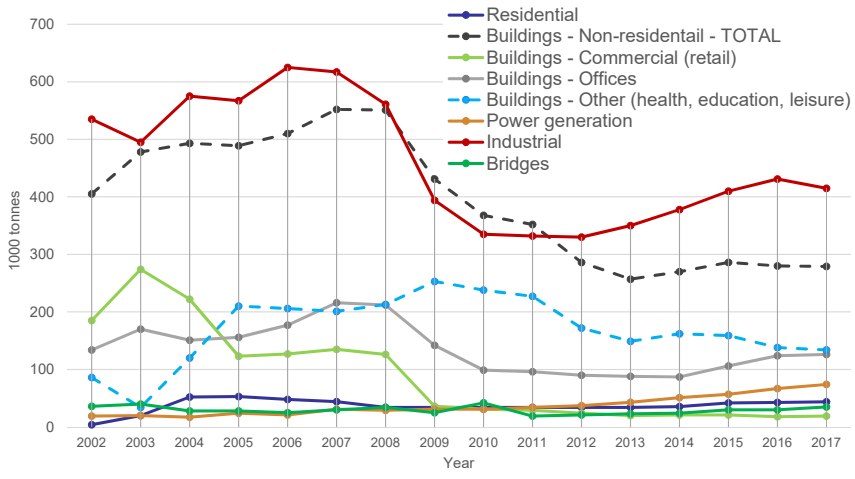

Single storey buildings overview

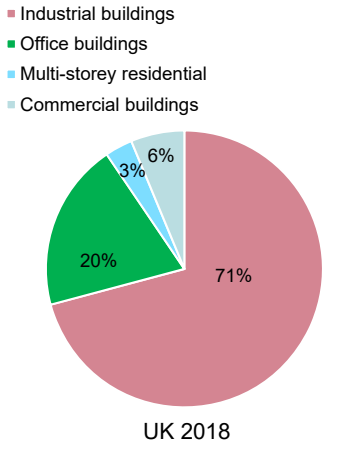
- Typical details: trussed solutions


Single storey buildings overview

- SCI Publications: best practice for portals and connections

Why focus on single-storey steel buildings?



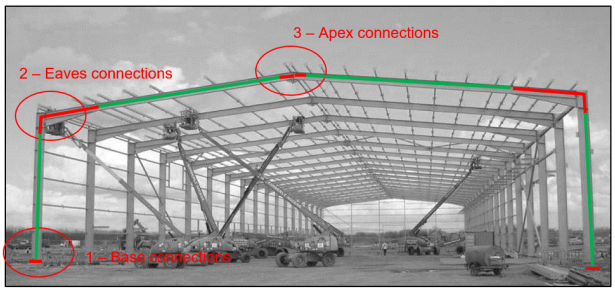


UK 2018

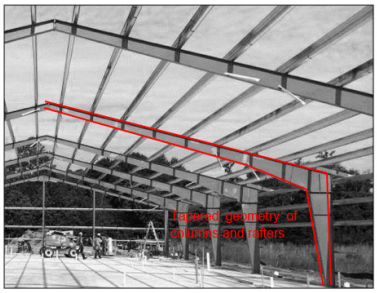
Hot rolled and fabricated profiles

FIGURES CREDITS: World Steel Association, European Steel Association, Primary Interviews, Grand View Research; SCI

Critical details/practices hindering reuse

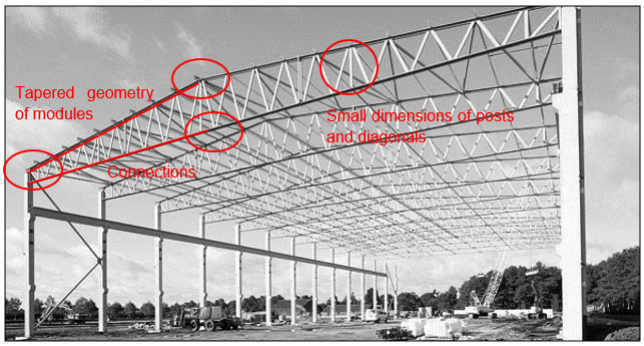


Reuse of frame/structure; reclaim individual components with a considerable length

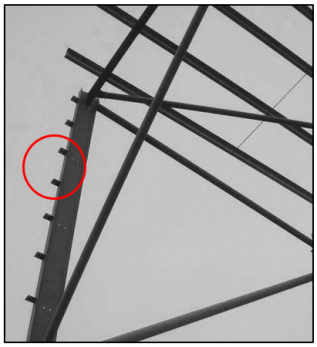


Reuse of frame/structure; bespoke members shape restricts the reuse on different applications

Critical details/practices hindering reuse

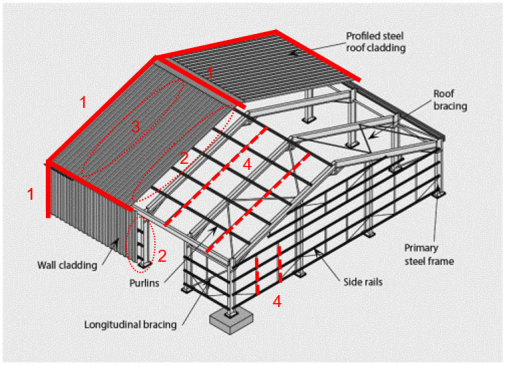


Reuse of frame/structure/truss; large quantity of small elements;



Cleats to support secondary steelwork. Can be removed.

Critical details/practices hindering reuse



Cladding elements as the critical building layer for deconstruction.

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

Welded studs: very difficult to detach beams form slab.

Key concepts for steel reuse

- Standardization (building geometry, detailing, etc.)
- Reduce number of interfaces (number of building layers)
- Reduce number of components (members; connections)
- Design for adaptability and relocation
- Design and detailing for construction, deconstruction and transportation

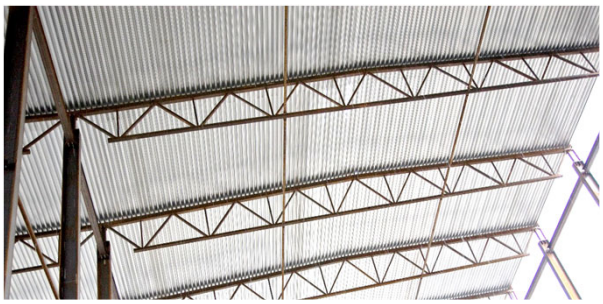
Standardization

FIGURES CREDITS: https://www.wired.com/2016/10/painstaking-process-building-porsche-panamera/

Standardization

FIGURES CREDITS: https://archello.com/ ; https://www.middleeastarchitect.com/

Standardization



FIGURES CREDITS: Progress

Reduce interfaces

- Avoid secondary structure (if possible) – long span cladding

Long span roof claddings (Finland)

Long span roof claddings (Finland)

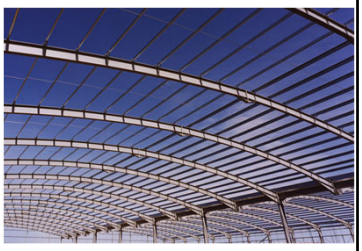
Deep decking system (Portugal)

FIGURES CREDITS: https://www.ruukki.com/; http://www.afaconsult.com/;

Reduce number of diferente components and materials

- Fewer robust members
- Reduce number of different cross-sections
- Reduce number of materials (steel-grades, subgrades)



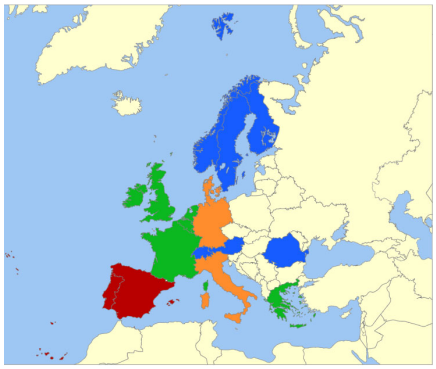
FIGURES CREDITS: https://www.steelconstruction.info

Design for adaptability and relocation

- Environmental loads: snow

Country	s_k (kN/m²)			Class
	Min.[a]	Country average[b]	Min. European value	
Finland	2.00	2.75	2.00	S1
France	0.45	**0.65**	**0.70**	S3
Germany	0.45	0.85	1.00	S2
Ireland	0.40	**0.55**	**0.70**	S3
Italy	0.60	1.00	1.00	S2
The Netherlands	0.70	**0.70**	**0.70**	S3
Norway	1.50	3.50	2.00	S1
Portugal	0.10	0.30	0.40	S4
Romania	1.50	2.00	2.00	S1
Spain	0.30	0.40	0.40	S4
Sweden	1.50	2.50	2.00	S1
United Kingdom	0.45	**0.65**	**0.70**	S3

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



European snow load classes

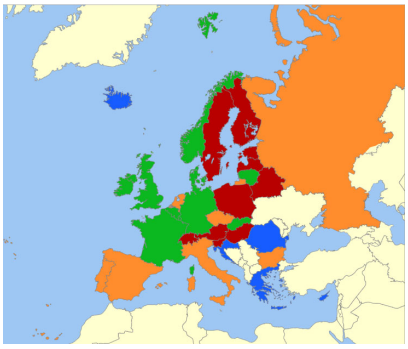
FIGURES CREDITS: Progress

Design for adaptability and relocation

- Environmental loads: wind

Country	$V_{b,0,min}$ [m/s]	$V_{b,0,max}$ [m/s]	$V_{b,0,mean}$ [m/s]	Class - Mean	$V_{b,0,class}$ [m/s]	$q_{b,0,class}$ [kN/m²]
Austria	17.6	28.3	21	W4	23	0.55
Belarus	22.0	24.0	22	W4	23	0.61
Belgium	23.0	26.0	24	W3	26	0.72
Bulgaria	24.0	35.8	27	W2	28	0.91
Croatia	20.0	48.0	29	W1	> 28	1.05
Cyprus	24.0	40.0	29	W1	> 28	1.05
Czech Republic	22.5	36.0	27	W2	28	0.91
Denmark	24.0	27.0	25	W3	26	0.78
Estonia	21.0	21.0	21	W4	23	0.55
Finland	21.0	26.0	22*	W4	23	0.61
France	22.0	28.0	24*	W3	26	0.72
Germany	22.5	30.0	25*	W3	26	0.78
Greece	27.0	33.0	29	W1	> 28	1.05
Hungary	23.6	23.6	23	W4	23	0.66
Iceland	36.0	36.0	36	W1	> 28	1.62
Ireland	25.0	28.0	26	W3	26	0.85
Italy	25.0	31.0	27*	W2	28	0.91
Latvia	21.0	27.0	23	W4	23	0.66
Lithuania	24.0	32.0	26	W3	26	0.85
Luxemburg	24.0	24.0	24	W3	26	0.72
Netherlands	24.5	29.5	27*	W2	28	0.91
Norway	22.0	31.0	25	W3	26	0.78
Poland	22.0	26.0	23	W4	23	0.66
Portugal	27.0	30.0	27*	W2	28	0.91
Romania	27.0	35.0	31*	W1	> 28	1.20
Russia	19.6	43.6	27	W2	28	0.91
Slovakia	24.0	26.0	24	W3	26	0.72
Slovenia	20.0	30.0	23	W4	23	0.66
Spain	26.0	29.0	27*	W2	28	0.91
Sweden	21.0	26.0	22	W4	23	0.61
Switzerland	20.0	24.0	21	W4	23	0.55
United Kingdom	22.0	32.0	25*	W3	26	0.78

* - According to the most usual value defined with the national annex. Other results obtained with a weighted average: (2* $V_{b,0,min}$ + $V_{b,0,max}$)/3. Class W1: 23 m/s; Class W2: 26 m/s; Class W3; 28 m/s; Class W4 >28 m/s



European wind load classes

CREDITS: Progress

Design for adaptability and relocation

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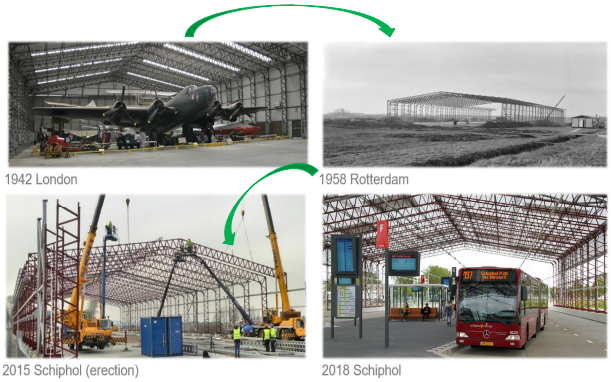
[a] Assuming the average altitude for the less critical zone of the country

[b] Assuming the average altitude for the zone representing most area of the country



1942 London

1958 Rotterdam

2015 Schiphol (erection)

2018 Schiphol

FIGURES CREDITS: Progress

Design for adaptability and relocation

- Design outcome:
  - Standard section sizes (avoid tapered/welded sections)
  - Spare capacity may be available; document the spare capacity
- Design according to Eurocode 3:
  - Elastic global analysis is recommended
  - SLS stress checks to be performed
  - $\gamma_{M1,mod} = 1.15 \times \gamma_{M1}$ (allowing for future relocations)
  - γ_{M0} and γ_{M2}: values from the appropriate NA to be used

CREDITS: Progress; SCI

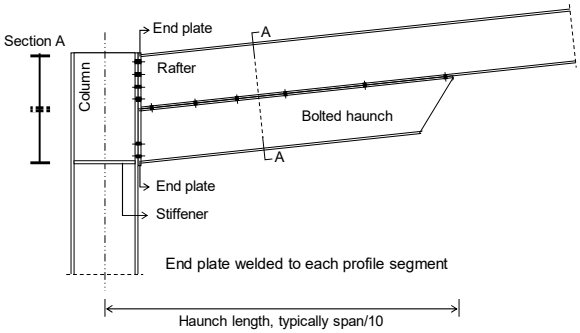
Design and detailing for deconstruction and reuse

- Detailing principles for reuse:
  - Reduce the number of connections and connectors (simple connections);
  - Use bolts/screws instead of other solutions (specially with claddings); reduce welding;
  - Detail for easy access of connections;
  - Repetitive detailing (modular/standard);
  - Avoid permanent attachments (floor systems are critical).

CREDITS: Progress; SCI

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: bolted haunch

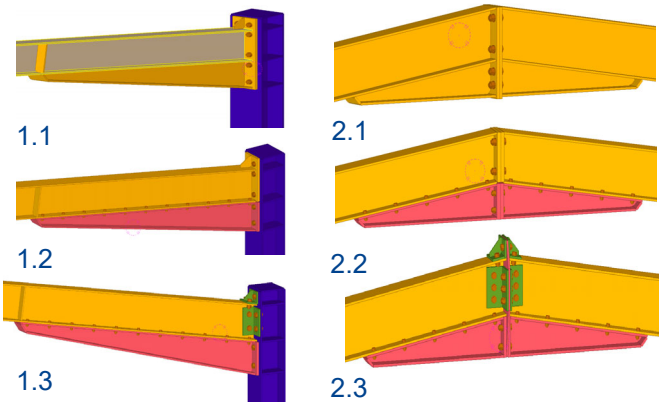


Alternative to use intermittent welds between rafter and haunch.

FIGURES CREDITS: https://www.northlincsstructures.com/;

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: bolted haunch



FIGURES CREDITS: PROGRESS

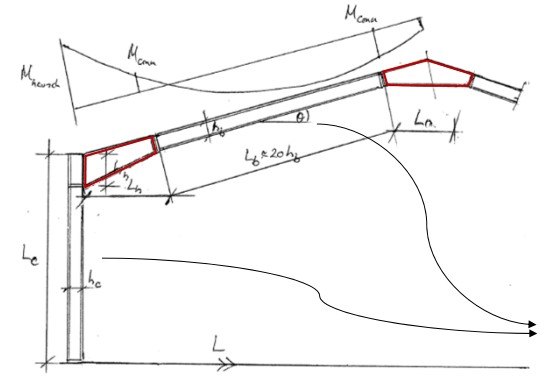
		Description	M_{Ed} [kNm]	M_{Rd} [kNm]	$S_{j,ini}$	BOM			
						Steel [kg]	Bolts		
							No.	d (mm)	class
Eaves Connection	1.1	Classic eaves connection	-119,75	-182,2	33,2	66,4(1)	10	20	8.8
	1.2	Eaves connection with endplate and detachable haunch	-119,75	-183,3	24,2	85,1(2)	10	20	8.8
							22	12	8.8
	1.3	Eaves connection with detachable endplate and haunch using cleat angles (no welding)	-119,75	-138,2	20.7	84(3)	4	20	10.9
							10	20	8.8
							22	12	8.8
Apex Connection	2.1	Classic apex connection	-60	-75,9	Rigid	35,6(1)	8	20	8.8
	2.2	Apex connection with endplate and detachable haunch	-60	-77,8	Rigid	54,1(2)	4	20	8.8
							4	16	8.8
							20	12	8.8
	2.3	Apex connection with detachable endplate and haunch using cleat angles (no welding)	-60	-77,8	15,5	62,1(3)	6	16	10.9
							16	16	8.8
							20	12	8.8

(1) weight of endplate only; (2) weight of endplate and the top flange of the haunch; (3) weight of cleat angles and the top flange and endplate of the haunch

Design of new single-storey steel buildings for reuse

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: standard (expendable) components



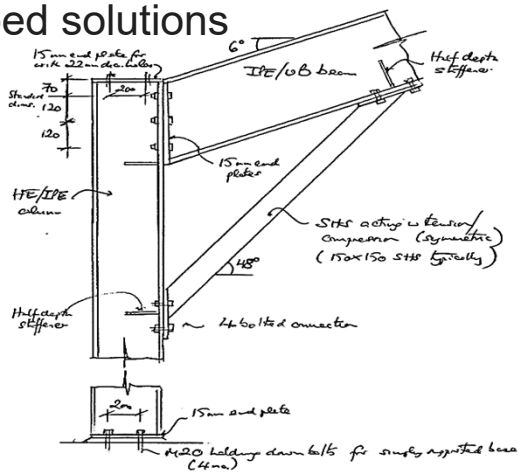
- Fabricated haunch segments 2no) of length $L_h \approx 0.1L$ to $0.12L$, where L is the overall span of the portal frame
- Fabricated apex segment (1no) of length $L_a \approx 0.1L$.
- Beams (2no) of length, $L_b = 20h_b$, where h_b is the beam depth.
- Columns (2no) of overall length, $L_c = 20h_c$, where h_c is the column depth.

$L = 2 (L_b + L_h) \cos\theta + L_a$
where θ is the slope of the rafter to the horizontal = 6°

FIGURES CREDITS: Progress; Ruukki

Design and detailing for deconstruction and reuse

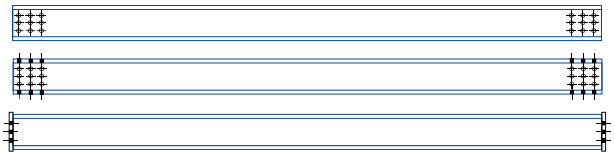
- Detailing principles for reuse: propped solutions (small to medium spans)
- Pin-ended connections;

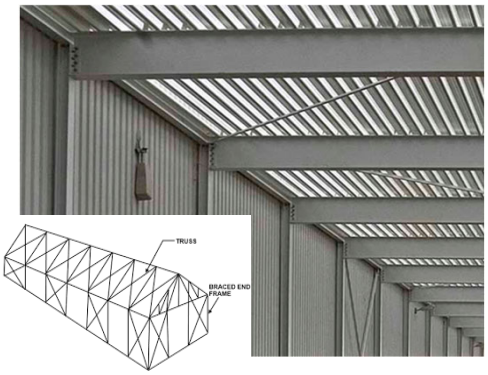


FIGURES CREDITS: Progress

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: braced boxes (small spans)
- Pin-ended connections;
- Roof truss for in-plane stability

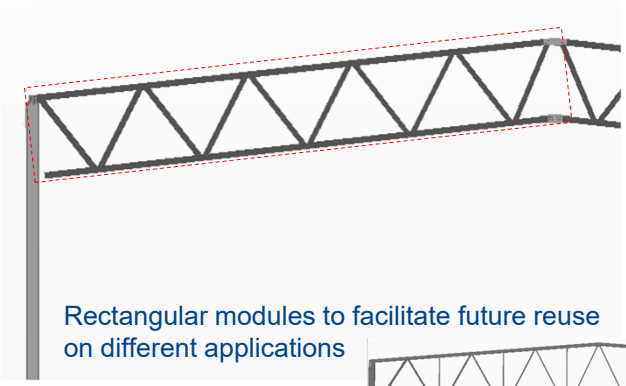




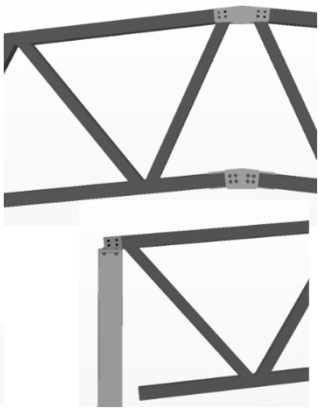
FIGURES CREDITS: Progress

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: standard components



Rectangular modules to facilitate future reuse on different applications



FIGURES CREDITS: Progress; Ruukki

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: mezzanines

Precast units with floor bracing system

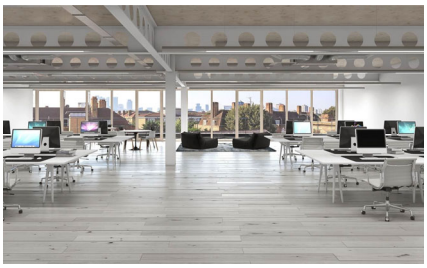
SPS system

FIGURES CREDITS: Progress; www.Steelconstruction.info; https://www.spstechnology.com/; Fokker 7 Building - Schiphol Airport (right)

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: mezzanines

CLT floor system

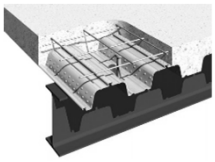


FIGURES CREDITS: https://www.kloecknermetalsuk.com

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: mezzanines

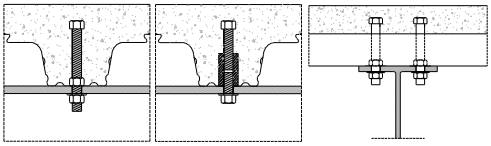
Demountable composite floor system

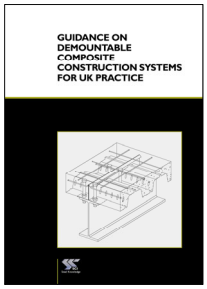


Welded shear studs

vs

Bolts



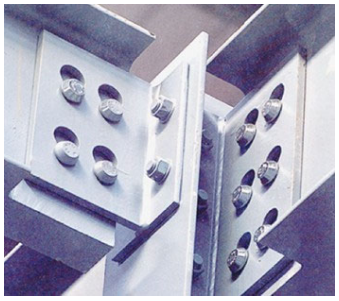


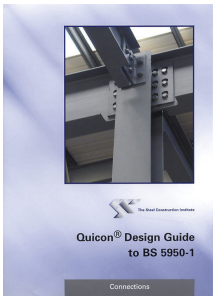
SCI P428: https://portal.steel-sci.com/shop.html?sku=P428

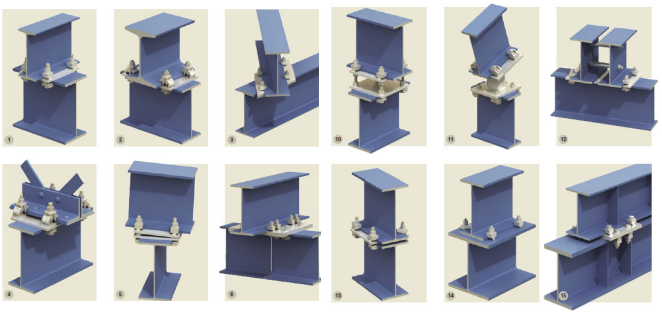
FIGURES CREDITS: REDUCE: Research Fund for Coal and Steel, Grant agreement No: 710040; Figure on the left: https://www.tatasteelconstruction.com

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: bespoke connections







FIGURES CREDITS: SCI; http://www.lindapter.com (right)

Design and detailing for deconstruction and reuse

- Detailing principles for reuse: case study




100% circular design; design for deconstruction and reuse; all structural members were designed to be disassembled; cladding with screwing fixings; BIM and Material Passport to enhance future reuse.

FIGURES CREDITS: Fokker 7 Building ;Schiphol Airport

Final remarks

1. Small improvements to current practice for single storey buildings will have a large impact on the construction market;
2. Seek standardization as much as possible;
3. Facilitate access for all connections;
4. Design for deconstruction, not only construction;
5. Avoid permeant attachment between components;
6. Reduce number or layers, materials and components;
7. Design for relocation/adaptability, not for a single purpose and location;
8. Designers to specify allowable structural capacity to facilitate reuse;

SCI is the leading, independent provider of technical expertise and disseminator of best practice to the steel construction sector. We work in partnership with clients, members and industry peers to help build businesses and provide competitive advantage through the commercial application of our knowledge. We are committed to offering and promoting sustainable and environmentally responsible solutions.

Thank you!