Stainless Steel in Structures
Fourth International Expert Seminar

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STAINLESS STEEL IN STRUCTURES IN VIEW OF SUSTAINABILITY

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Université de Liège

cts

1980-2007, World Population increased by more than 50% & global resource extraction by ~ 62%.

About ½ of the forests that once covered the earth has disappeared.

Human activity ➠ escalating impact on biodiversity of world ecosystems, reducing both their resilience and biocapacity.

~ 7.04 billion today

IPCC : Intergovernmental Panel on Climate Change *"Global warming is caused by increasing concentrations of greenhouse gases (GHG) produced largely by forest clearing and the burning of fossil fuels."*

Many consequences: rise of sea levels, change of precipitation, expansion of subtropical deserts, retreat of glaciers, changes in agricultural yields…

Environment is an issue, resource depletion is an issue, climate change is an issue, changes are accelerating, drivers are global…

ustainable development

Sustainability (Latin *sustenere*) is the capacity to endure.

In 1987, the UN-sponsored Brundtland Commission released *Our Common Future*, a report that captured widespread concerns about the environment and poverty in many parts of the world.

It popularized the term *sustainable development*, which it defined as *development that meets present needs without compromising the ability of future generations to meet their own needs.*

It is usually related to “the three pillars”: sustainable development is at the intersection of social, environmental and economic development.

e construction sector

The construction sector is a vitally important sector manufacturing the built nvironment and putting in place a physical stock of facilities and infrastructure hat determines our degree of freedom and flexibility for anything up to 100 ears after construction" (Agenda 21, International Council for Local Environmental Initiatives ICLE).

- ✓ **Estimated construction investment (EU 27 - 2011) : 1.208 billion €**
- ✓ **9,6 % of GDP**
- ✓ **3,1 million enterprises (EU 27), of which 95% are SMEs with fewer than 20 operatives**
- ✓ **14,6 million operatives representing 7 % of Europe total employment**
- ✓ **43,8 million workers in the EU depend, directly or indirectly, on the construction sector**

e construction sector

Vorldwide, 30-40% of all primary energy used in buildings for operation (heating, cooling, electricity), entertainment nd work equipment.

3 billion tonnes of raw materials – 40-50% of the total flow n the global economy – used in manufacture of building roducts.

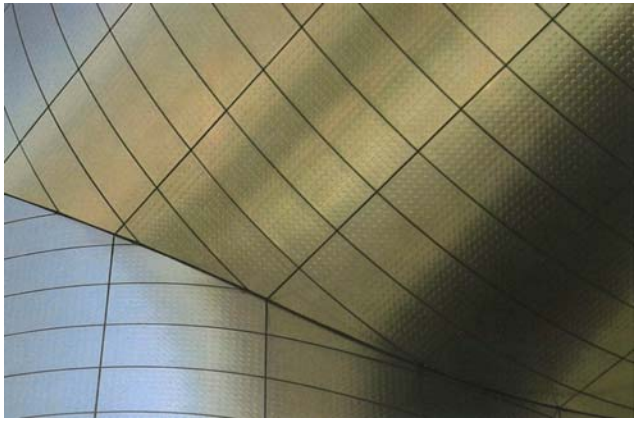
30% of the world total number of lethal accidents happen n a construction site.

Responsible for 20% of the water use and 30-40% of lobal GHG emission in each country.

Construction and demolition waste = 30-50% of total waste enerated in higher income countries

ustainable Construction – Stainless steel in buildings

Used for its aesthetic properties in minor building components than façades/roofing cladding or highly glazed systems, many possibilities of finishes, shape & grades…too many?



ustainable Construction – Stainless steel in buildings

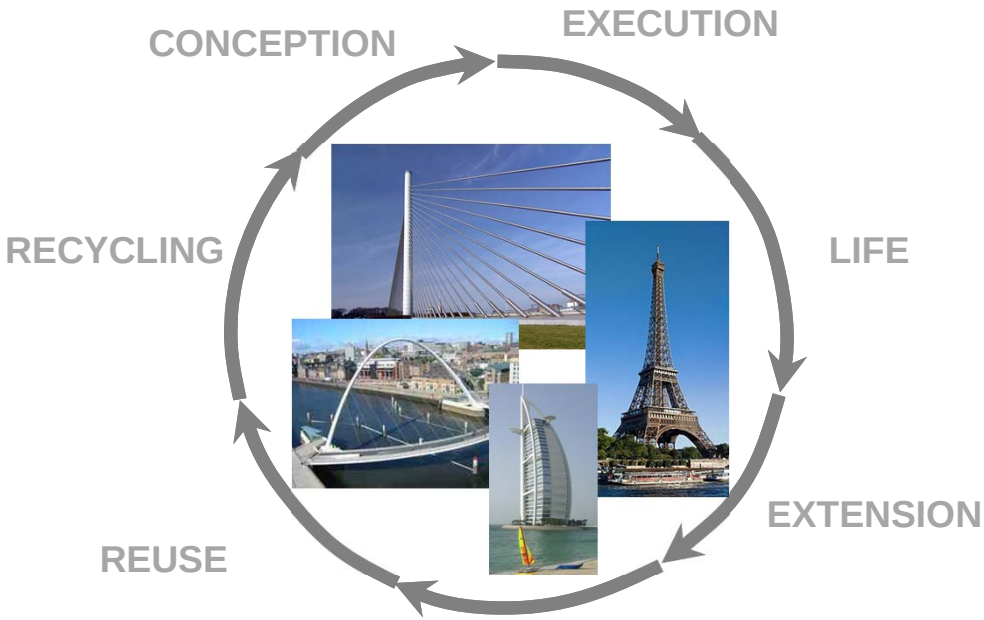
ng systems: the energy
rmance of buildings (&
ciated emissions) is the
highly weighted factor

- Example : LEED – U.S. Green building council
  - « cool roof & façade systems » i.e. high Solar Reflectance Index
  - powerful against air leakage/infiltration
  - But also (in summary for several systems)
    - low roof runoff ➢ valuable non-potable water
    - high recycled content
    - **high recovery rate**
    - in-situ reuse of materials
    - deal for upgrade of façades ➢ Extension of life
    - waste management on construction site
    - **robustness ➢ fire**

int for:
Material longevity & long-term appearance
Subsequent low maintenance
Off-site/dry construction
No VOC emissions (points are awarded to materials with low VOC)

stainable Construction

Sustainability concerns the whole cycle of construction i.e. from raw material acquisition, through planning, design, construction and operation, to final demolition and waste management.
⇒ can be divided in stages, each of them equally important in regard to sustainability.



stainable Construction – Stainless steels opportunities

Design stage:

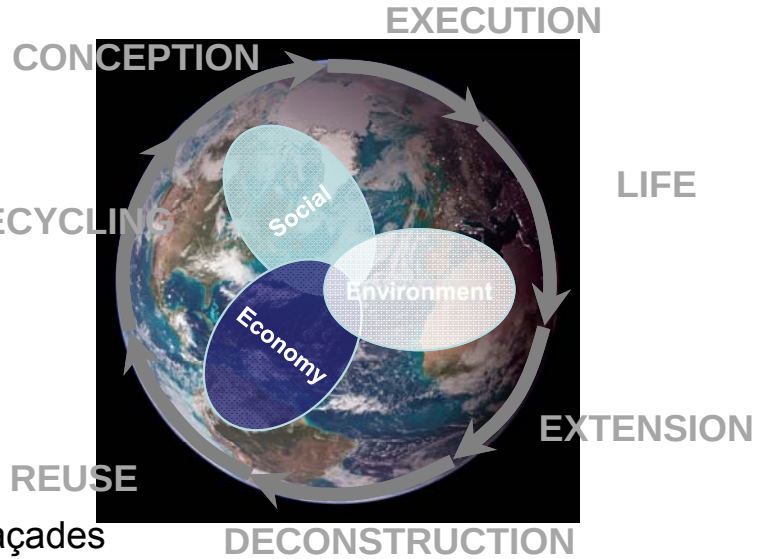
Material avoidance ➢ slender, lighter

Better knowledge of mech. prop. such as resistance to high temperature

➡ decrease embodied impacts

future adaptability: column free spaces/large spans allow flexible use of space

- Execution stage:
- High degree of prefabrication & Dry/dust free construction ➢ Safer work conditions



d-of life stage:

efinitely recyclable
n no change in its
perties

se

Extension of life:

possible cleaning of façades

easily upgraded envelope (over-clad and over-roofed
enveloppes ➢ reduce cool bridge and enhance

- In-use stage:
- Thermal point of view: high reflectivity, powerful against air leakage and infiltration, strength for highly glazed façade, easy installation of ren. energy system (development of coatings involving PV cells)

➠ decrease operational impacts

- healthy indoor environment, odourless, hygienic…
- reduced maintenance

stainable Construction – Stainless steels opportunities

DESIGN

tive importance of Embodied
cts versus Operational impacts is –
ever – increasing in LCEA ➪
rtance of material avoidance in
gn and methodologies for inclusion
cycling into LCA.

stable grade
opment
c ➡ higher strength than
nitic, lower thermal
sion, not prone to stress
sion cracking, localised
sion depends on the

x ➡ higher strength,
or corrosion resistance
ng lighter structures
ially 1.4162 lean duplex
ow nickel content

➪ Importance of lifecycle analysis : **LCEA and LCC**

DURABILITY

Corrosion resistance : stainless steel can sometimes be THE alternative ➡ Ex. rebar in concrete structures in corrosive environments (coastal bridges) or structures in atmospheres containing chlorides when regular cleaning is not possible.

ROBUSTNESS

Fire resistance: austenitic stainless steel structural members retain their load-carrying capacity for a longer time than carbon steel equivalents thanks to higher strength and stiffness retention factors at temperatures above 500° C.

Good energy absorption characteristics ➡ blast walls (offshore applications).

esign of stainless steel structures

"Valuable research activities on the structural behaviour of stainless steel - aimed at overcoming obstacles to the wider use of stainless steel in** sustainable **construction - have been achieved in universities around the world" **N. Baddoo**

Material model ➽ Rasmussen, Mirambel & Real, Gardner, Talja & Hradil…

Section properties ➽ Quach, Gardner, Cruise, Jandera, Rossi…

Design of structural members: Inclusion of new grades in standards, DSM, CSM, GBT ➽ Lecce & Rasmussen, Becque & Rasmussen, Rossi & Rasmussen, Camotim, Gardner, Ashraf, Theofanus, Young…

New grades especially with low nickel content ➽ Baddoo, Cashell, Rossi, Young, Vellasco…

Behaviour under fire conditions ➽ Franssen, Lopes, Baddoo, Manninen, Gardner…

ection properties & design of stainless steel columns

Test programme combined with existing measured stress-strain data on cold-formed stainless steel sections ➡ Predictive model for harnessing the **strength increases in cold-formed sections** as a result of plastic deformation during fabrication.

si B, Afshan S, Gardner L. *Strength enhancements in cold-formed structural sections – Part I: Materila testing*
nal of Constructional Steel Research (Submitted for publication).
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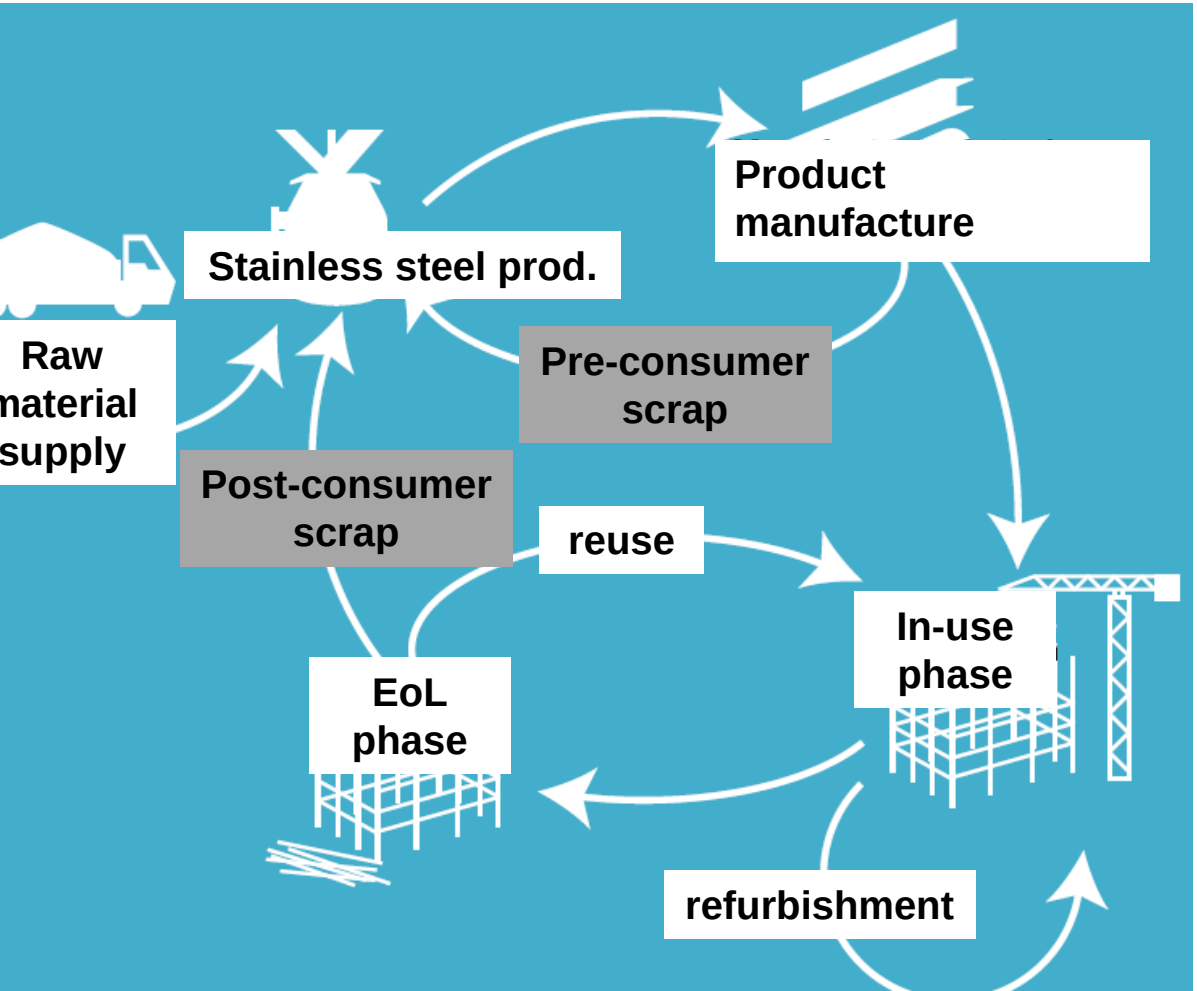
New **DSM equations for distortional, local and local-overall buckling** of stainless steel members in the low slenderness range based on existing DSM equations for stainless steel members.

si B, Rasmussen. KJR. *Carrying capacity of stainless steel columns in the low slenderness range*. Journal of
ctural Engineering (In press).

fe cycle inventory of stainless steel products



Stainless steel scrap content ~ 60%

Stainless steel in buildings recovery rate >90%

fe cycle inventory of stainless steel products

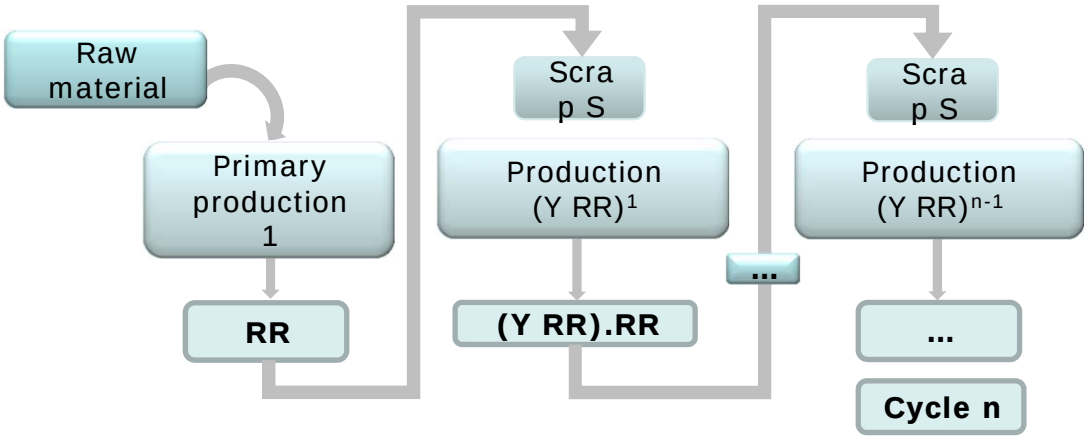
"*cradle to cradle*": module D "*Benefits and loads beyond the system boundary*" in EN 15804 allows credits to be taken now for the eventual reuse or recycling of material in the future.

Recycled material replaces primary stainless steel ➸ **save resources and decrease the environmental impacts**

Easy to take into account during **LCA** using closed-loop recycling methodology i.e. **end-of-life credits** taken into account in the LCI

Important parameters:

overy rate RR: global EOL RR ~90%
d Y : 1kg of scrap → less than 1kg of
rial
R : quantity of material produced
s to scrap
nber of cycles n



fe cycle inventory of stainless steel products

If X_{prim} = LCI for primary production n=①
And X_{sec}= LCI for secondary production n=②③…∞

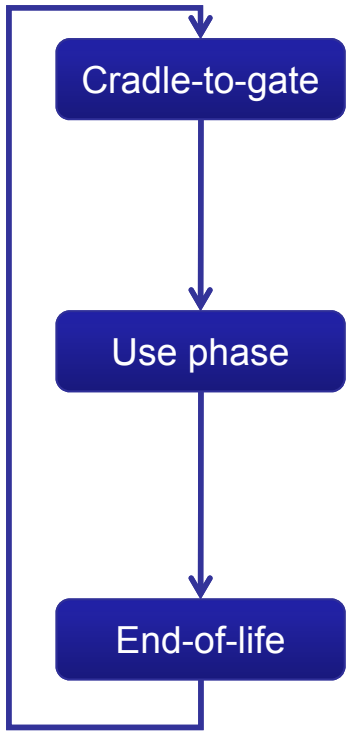
1/ Total LCI
LCI = $X_{prim}+Y.(RR).X_{sec}+\ldots+(Y.(RR))^{n-1}.X_{sec}$

2/ Total mass of material produced
M = $1+Y.(RR)+\ldots+(Y.(RR))^{n-1}$

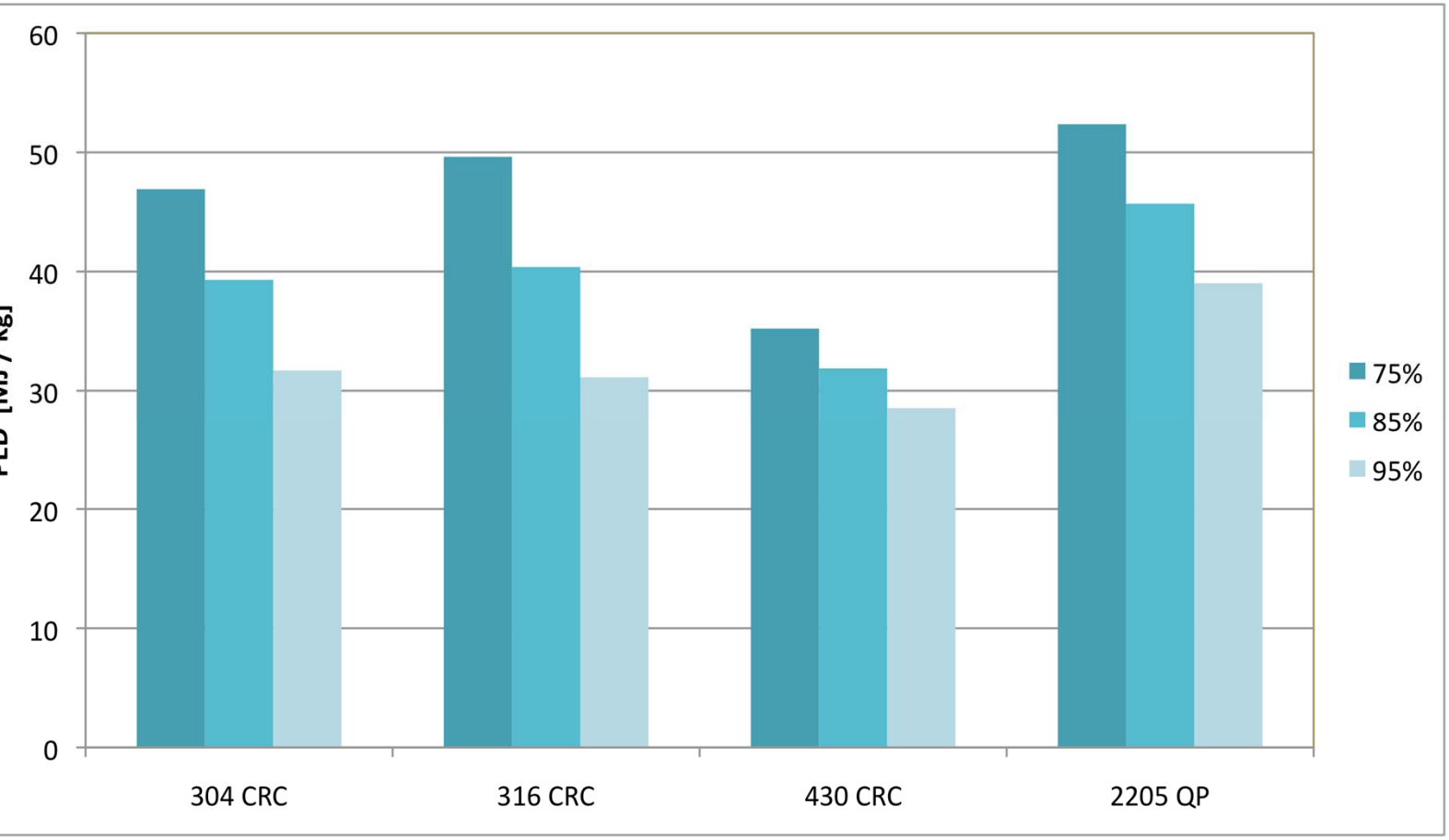
⇒ Total LCI per kg:
X = **LCI / M** = $(X_{prim}-X_{sec}).Q+X_{sec}$

where $Q = (1-Y.RR)/(1-(Y.RR)^{n})$

If $n \rightarrow \infty$: $\mathbf{X = X_{prim}-Y.\ RR.(X_{prim}-X_{sec})}$



e cycle inventory of stainless steel products



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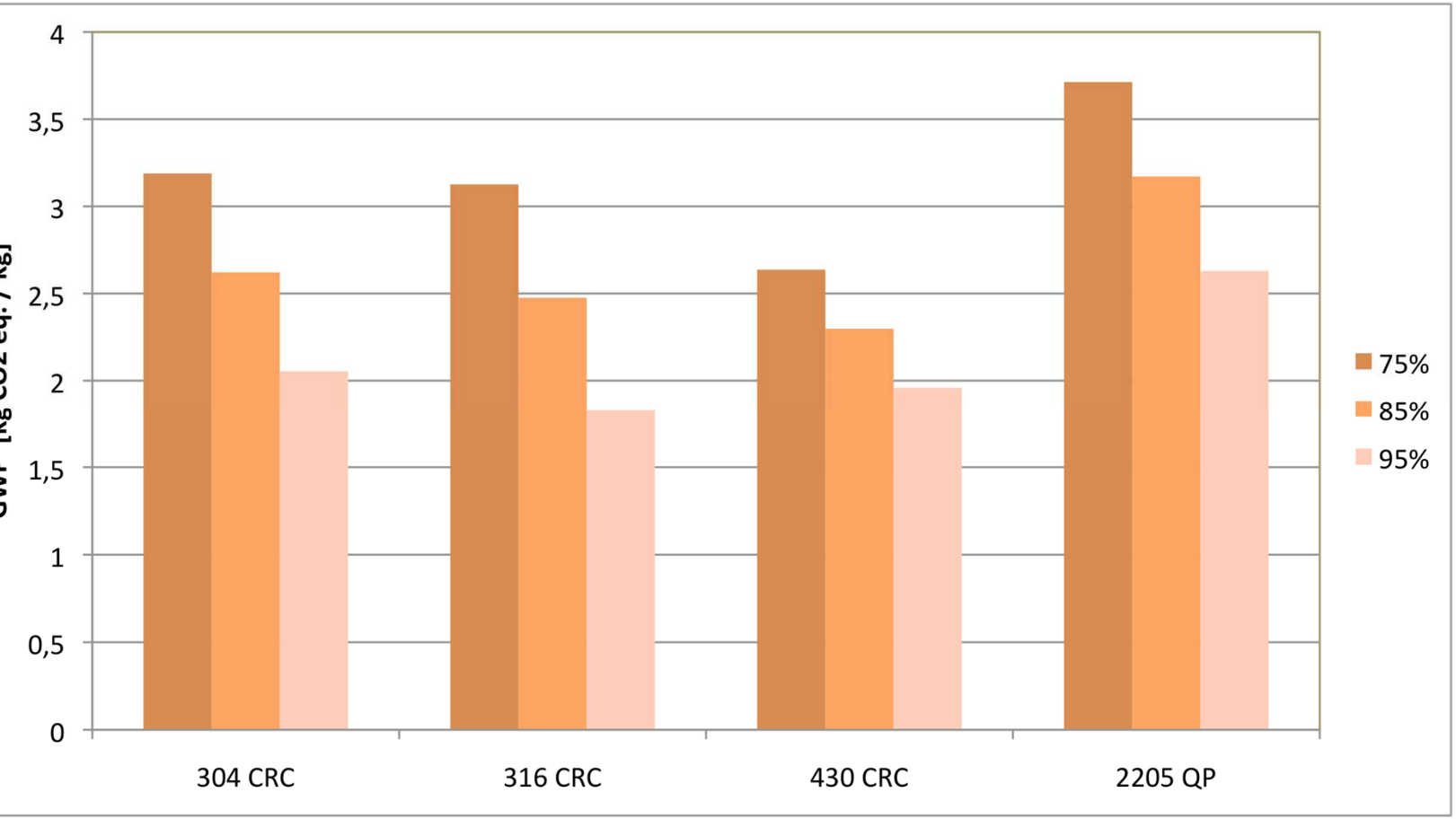

ncluding remarks

ormer times: not known & expensive
aterial, difficult to specify, unusual
echanical properties not exploited to
eir maximum.

oday: combination of several intrinsic
roperties: strength, corrosion
esistance, aesthetics,
rmability…making possible a more
ustainable construction
→ All in all: Lighter & more durable
tructures.

urview of lifecycle analysis increasing
→ importance of embodied impacts
material avoidance), LCC analysis &
ethodologies for EoL credits.

Minor building components, urban furniture (China, India…)

Façades and roofing cladding

Structural parts for highly glazed envelopes (tension rods, cabled stayed)

Connections for timber structures

Rebar

Masonry supports

Arches in bridges

What's next?

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Many thanks for your attention

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fe cycle inventory of stainless steel products

cycling (in this case
wncycling) usually involves
condary production steps.

converts **waste materials**
o **new materials** of lesser
ality and reduced
ctionality.

Ecoinvent data [1995-2007]

Process	GWP [kg CO2-eq/t]
Production of concrete ➔ Linear regression using "Concrete, normal, at plant" and "concrete exacting, at plant"	112 135
Separation of concrete and reinforcement ➔ disposal, building, reinforced concrete, to sorting plant	61
Landfill of reinforced concrete ➔ disposal, building, reinforced concrete, to final disposal	67
Valorisation of crushed concrete ➔ gravel, unspecified, at mine	3
Landfill of sorted concrete ➔ disposal, concrete, 5%water,	7

ncluding remarks

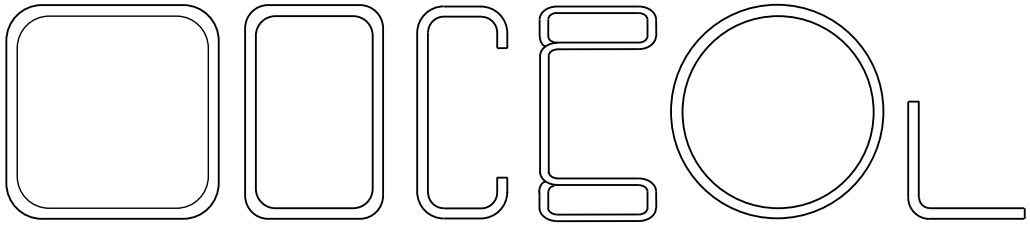
Sustainable construction is more that what we have done so far

- Stable to current and future loading conditions
- Increase longevity of constructions with a wiser choice of materials (durability) and designs (future adaptability)
- Reduce our impacts with less operational impacts & greener materials
- Reduce costs on the basis of lifecycle cost analysis

ection properties

Test programme on 18 cross-section geometries (SHS, RHS & CHS) covering a range of stainless steel grades : austenitic (1.4301, 1.4571 and 1.4404), ferritic (1.4509 and 1.4003), duplex (1.4462) and lean duplex (1.4162) – and one structural carbon steel grade (S355J2H).

Combined with existing measured stress-strain data on cold-formed stainless steel sections.



Predictive model for harnessing the **strength increases in cold-formed sections** as a result of plastic deformation during fabrication

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esign of members using the DSM

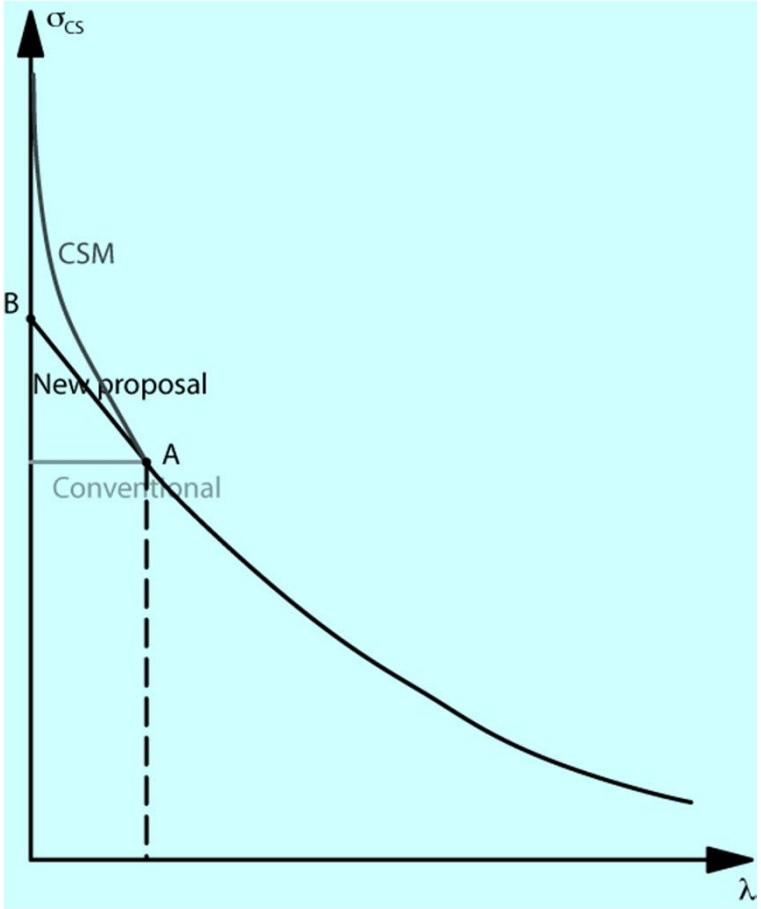
Based on existing DSM equations for stainless steel members.

Conventional approaches propose a yield limit at the level $A \times \sigma_{0.2}$ to be used for slenderness values smaller than a threshold value

Instead → linear expression relating the cross-section resistance to the slenderness λ is proposed.

A compression level equal to σ_u is assumed to be attained as the slenderness approaches zero.

Underlying assumption: the material strength in compression is the same as the material strength in tension.



esign of members using the DSM

Reference test results → stainless steel square, rectangular, channel and lipped channel cross-section columns

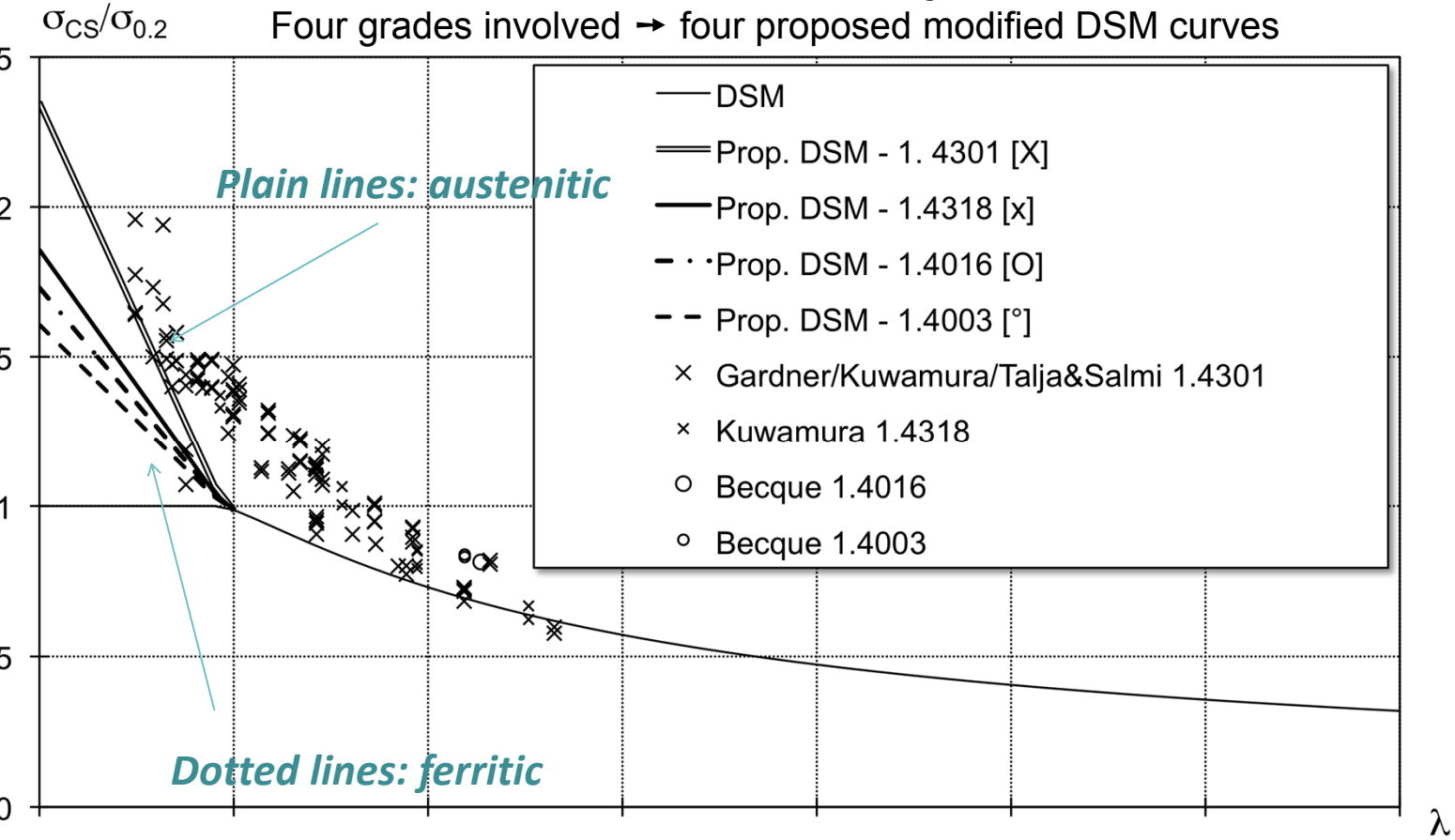
- *Distortional* – 186 points: Lipped channel with or without intermediate stiffeners made of austenitic 1.4301 (UNS30400) and 1.4318 (UNS30103) & ferritic 1.4003 (UNS41003) and 1.4016 (UNS43000) grades.

- *Local* (111 points) & *Local-Overall* (200 points): SHS, RHS, plain and lipped channel made of austenitic 1.4301 (UNS30400) and 1.4318 (UNS30103) & ferritic 1.4003 (UNS41003) and 1.4016 (UNS43000) grades.

esign of members using the DSM

Cross-section resistance, Local buckling

Four grades involved → four proposed modified DSM curves



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