ICWST 2023
32nd International Conference on Wood Science and Technology

Zagreb, 7th – 8th December

Research needs for European species in a scenario of increasing structural wood demand for building

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INNOVAWOOD

EUFORE
European Forest Research and Innovation Ecosystem

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EUFORE

European Forest Research and Innovation Ecosystem

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@eufore_project

The project builds a sustainable, transnational, co-creative environment to define, implement and evaluate a research and innovation (R&I) agenda and roadmap for the forest-based value chains in Europe.

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Contents

The European network for wood science, technology and education

SHARE | CONNECT | INFLUENCE

InnovaWood general presentation
October 2023 | bit.ly/iwpres2023

Members map 2023

bit.ly/iwnetwmap

EU projects & initiatives

INNOVAWOOD

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Forest

ROSEWOOD 4.0 Sustainable Wood for Europe

RESONATE Resilient Forests for Society

ONEforest

Smurf

Wood products, construction, renovation, recycling

wood CIRCUS

BASAJAUN

BUILD IN WOOD

EcoReFibre

AEGIR Incremental Renovation Package

5GT Twin Transition for The Timber Industry

nguma

Furniture & interior

EQ-WOOD

ALL HANDS ON DECK

SUnRISE ENCOURAGING

SMARTRAIN

GIST

Allview

Alliances, platforms

EUFORE European Forest Research and Innovation Ecosystem

wood PoP

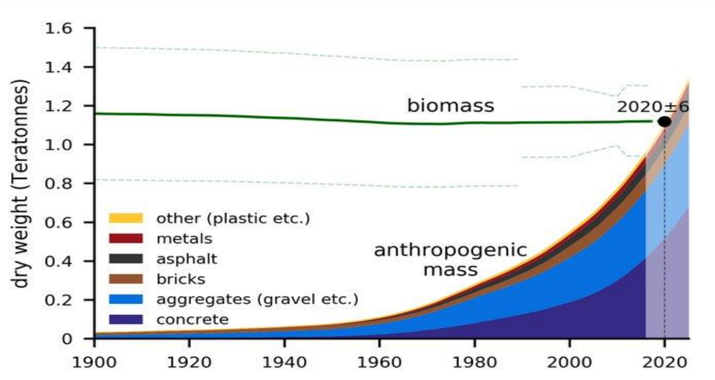
wood4bauhaus Wood Sector Alliance for the New European Bauhaus

WOODRISE

digiNEB.eu digital ecosystem for the New European Bauhaus

Climate crisis

Built environment (construction, usage, renovation and demolition)
~40% of global emissions (expected to double by 2060)
Global human-made mass exceeds all living biomass



Elhacham et al. 2020
https://www.nature.com/articles/s41586-020-3010-5

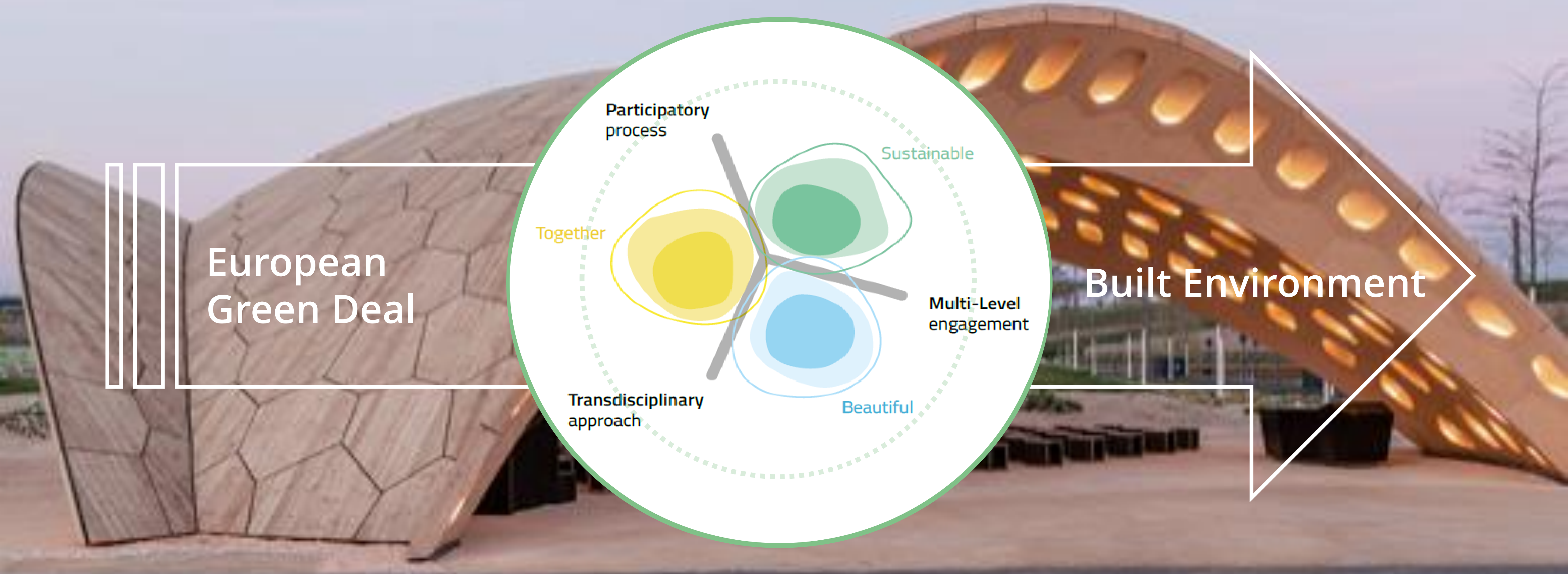
European Commission, 2020. "In focus: Energy Efficiency in Buildings." Brussels

EU policies affecting building with wood

European Commission

- European Green Deal (2019)
- Renovation wave (2020)
- Circular Economy Action Plan (2020)
- Fit for 55 package (2021)
- Carbon Removals Certification Regulation (CRC, 2022)
- Construction Products Regulation (CPR revision, 2022)
- Energy Performance of Buildings Directive (EPBD 2018, recast 2023)
- EU Taxonomy Environmental Delegated Act (Taxonomy, 2023)
- New European Bauhaus (2020): a novel co-creation approach

New European Bauhaus (NEB)
Values & principles



European Commission, 2023. "New European Bauhaus Compass." Brussels

Photo: BUGA Wood Pavilion© European Union, 2022

wood4bauhaus

Wood Sector Alliance for the New European Bauhaus

- InnovaWood - Network of wood research, innovation, education
- European Panel Federation (EPF)
- European Confederation of Woodworking Industries (CEI-Bois)
- European Organisation of the Sawmill Industry (EOS)
- European Federation of Building and Woodworkers (EFBWW)
- InnoRenew CoE

EUROPEAN PANEL FEDERATION
WOOD-BASED PANELS

CEI-Bois

EOS
EUROPEAN ORGANISATION OF THE SAWMILL INDUSTRY

EFBWW

INNOVAWOOD

INNORENEW COE

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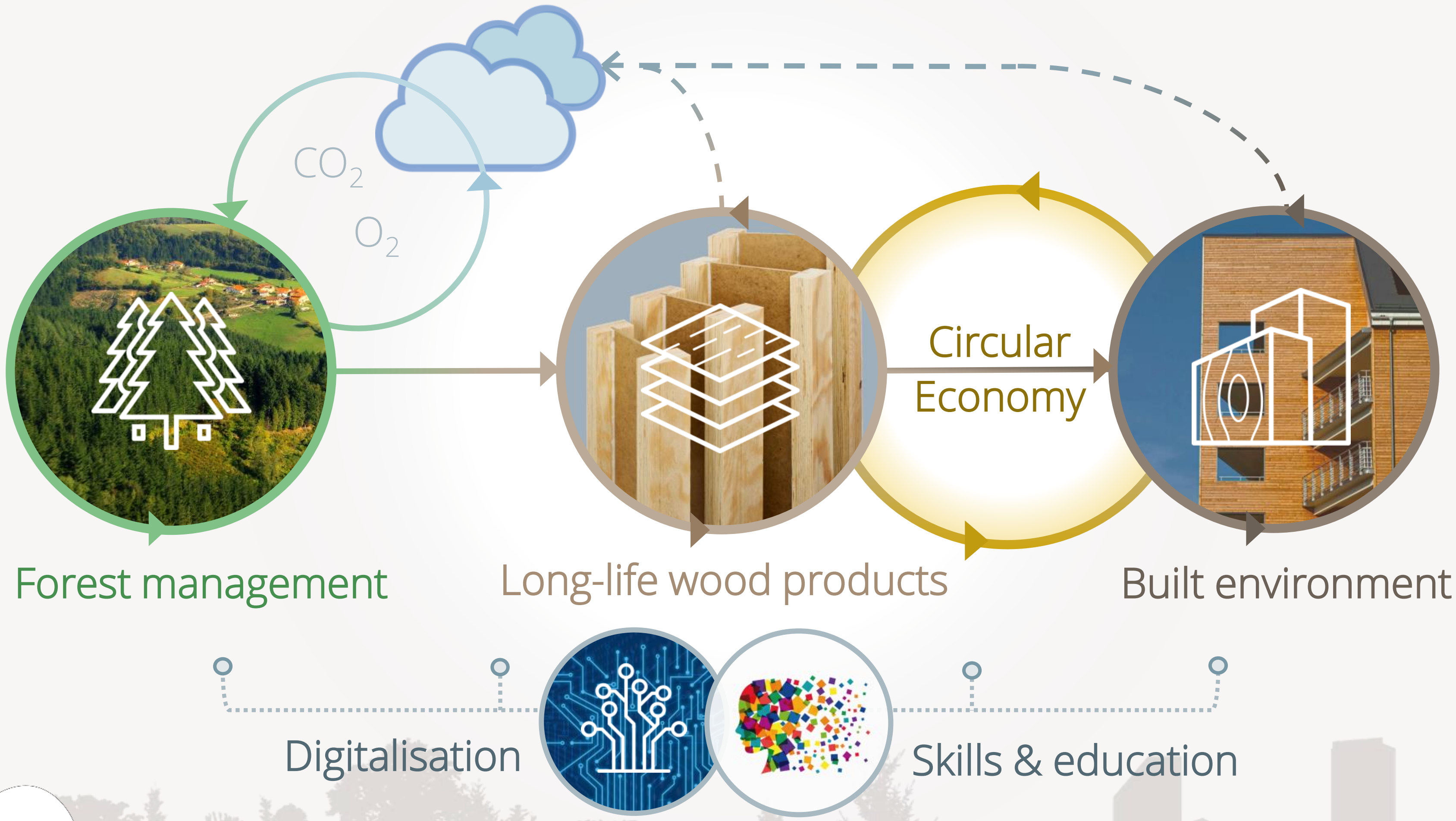
Cities as carbon sinks

Forest-construction chain as a major carbon pump



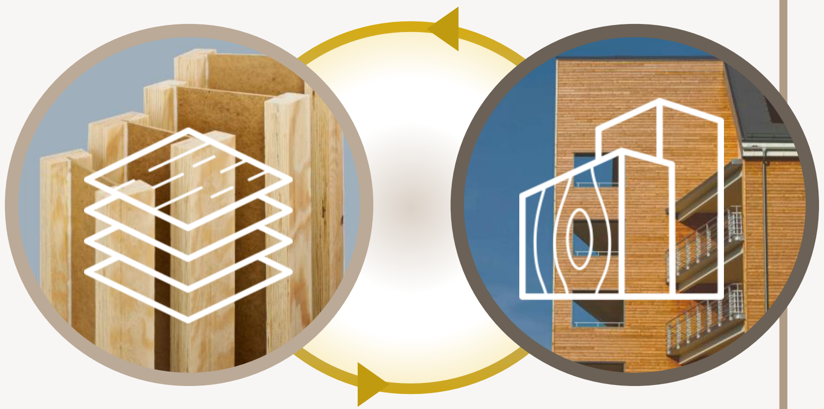
Construction sector
Architecture
Urban planning
Cities and regions
Cultural heritage
Biophilic design
Social inclusion
Nature-based solutions

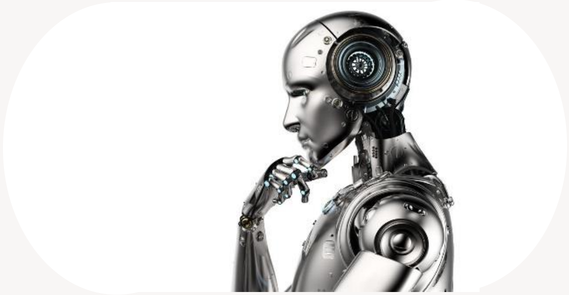
wood4bauhaus

Wood Sector Alliance for the New European Bauhaus

10 Policy recommendations & Research needs/priorities

1. **Upscale the rate of renovation and new build**, incl. social housing
2. **Carbon removal, carbon storage and substitution benefits** of long-life biomaterials should be quantified, incentivised and rewarded
3. **Hybrid engineered wood products & building systems** need to be enhanced towards higher circularity & sustainability: reuse, remanufacture, design-for-disassembly, recovery, resource use
4. **Digitalisation** for more prefabrication and smart manufacturing in
5. **Secure the supply** for wooden raw materials and tree species
6. **Enhance wood recycling**, gain access to post-consumer wood
7. **Future skills and education**, create new jobs
8. **Recover traditional knowledge**, techniques, cultural heritage
9. **Human well-being and health**, benefits from regenerative design
10. **Transdisciplinarity and open innovation** with all relevant disciplines





W4B, 2021. bit.ly/w4bpr | bit.ly/w4brn

In Europe, timber structures can mainly be found in residential housing and long-span structures

Media Madera Ingenieros Consultores, Amorebieta bridge, Spain

© V. Baño 2022. OAK Ingeniería, MACA, Uruguay

Media Madera Ingenieros Consultores, Amorebieta bridge, Spain. www.mediamadera.com

Baño, V., Domenech, L., Mazzey, C., Vieillard, T., & Journot, J. B. (2023). HARDWOOD GLULAM IN COMPLEX STRUCTURES: DESIGN AND CONSTRUCTION OF THE MACA MUSEUM IN URUGUAY. Proceedings from the 13th World Conference on Timber Engineering 2023, 4730. https://doi.org/10.52202/069179-0575

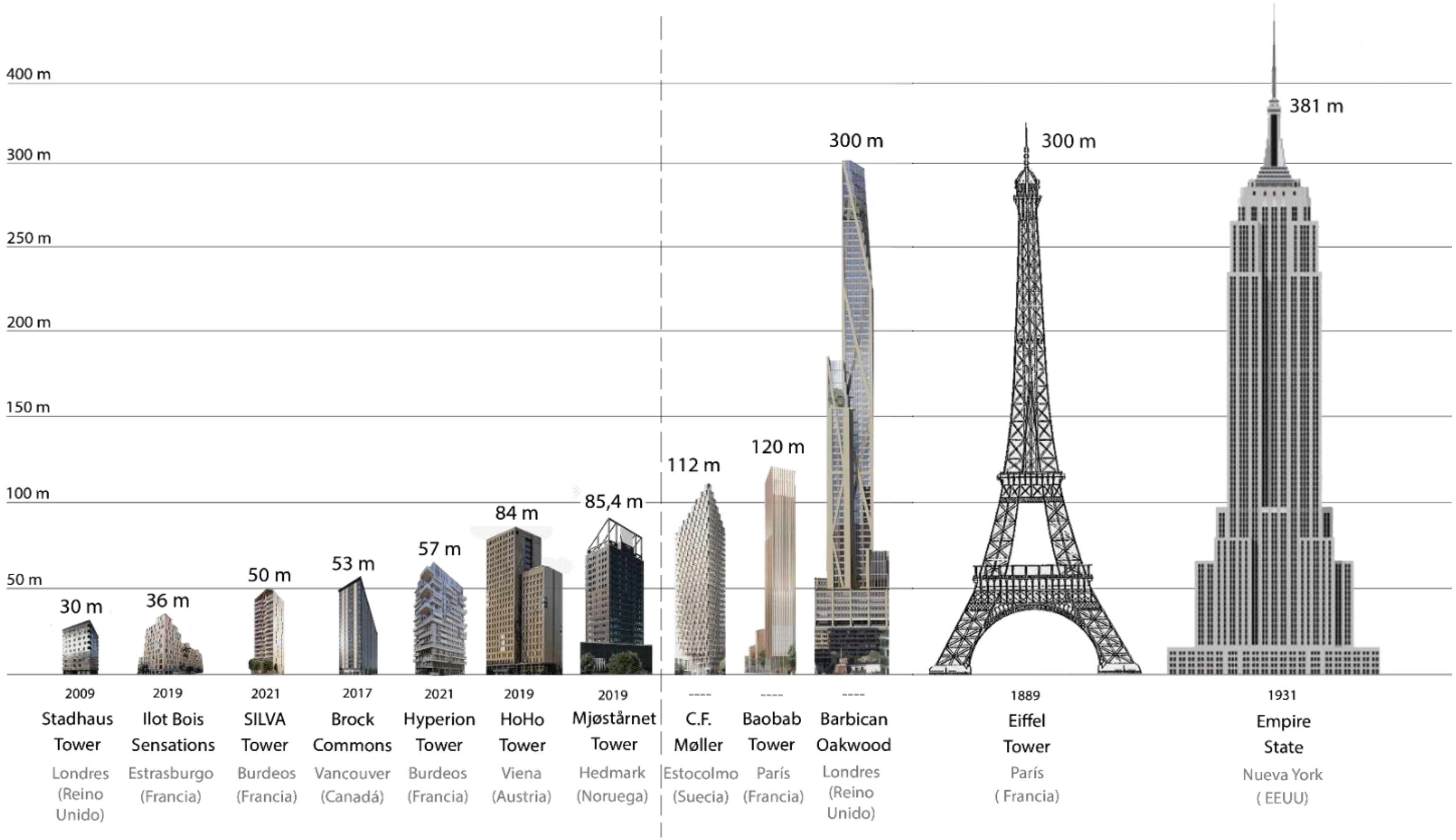
Trends in timber structures

Needs to improve sustainability

Taller multistorey timber buildings

Changes in how buildings are designed and built

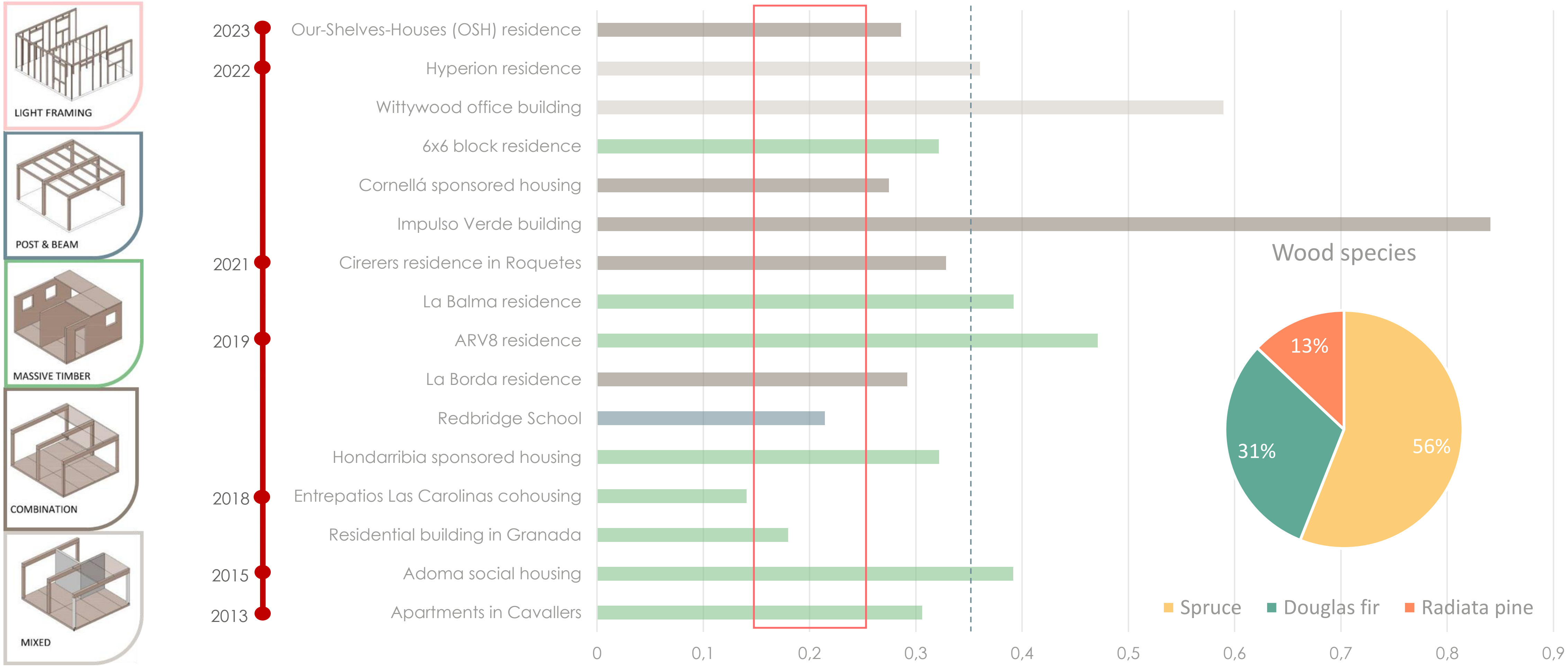
Some of them are inadvertently reducing **structural safety**



Basterra A, Baño V, López G, Vallelado P, García I, Moltini G, Cabrera G. 2022. Application and dissemination of innovative solutions for the promotion of mid-rise timber construction in the SUDOE area: Identification and Analysis. DOI 10.5281/zenodo.7692174

Lawrence, Andrew, Ishan Abeysekera, and Andrew Smith. 2023. “As Structural Engineers, Safety Must Be Our Highest Priority.” https://Www.Arup.Com/Perspectives/as-Structural-Engineers-Safety-Must-Be-Our-Highest-Priority#, 2023

Ratio wood m^3/built m^2 in mid-rise buildings (ES, PT, FR)

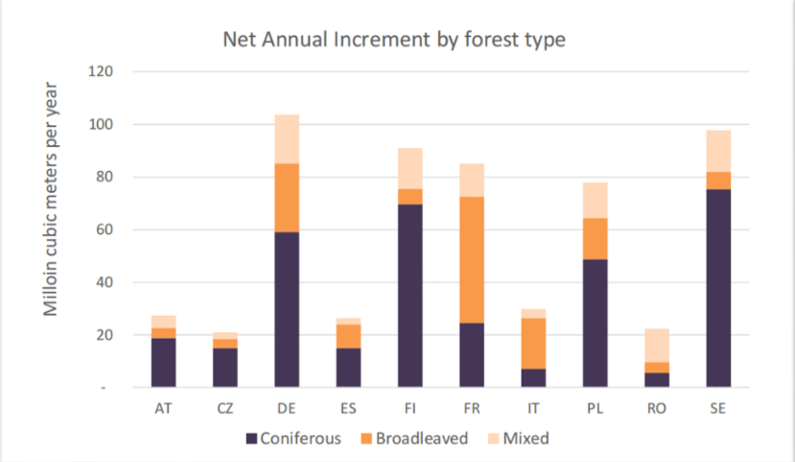


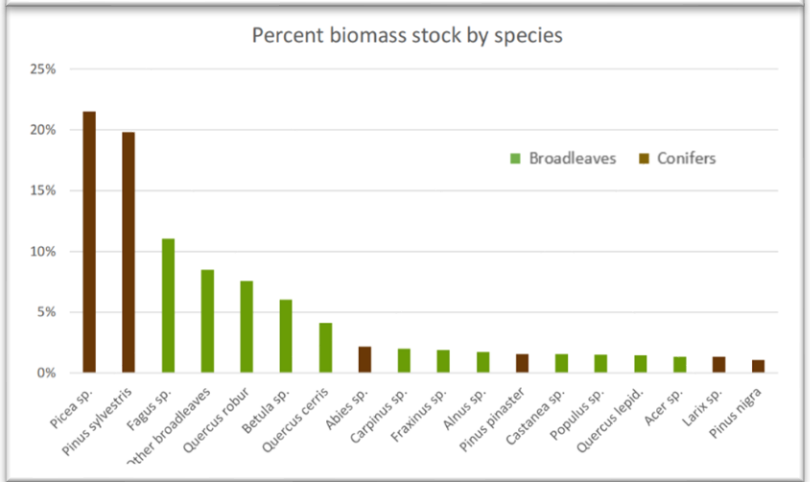
Basterra A, Baño V, López G, Cabrera G, Vallelado P. 2023. Identification and Trend Analysis of Multistorey Timber Buildings in the SUDOE Region. Buildings 2023, 13(6), 1501; https://doi.org/10.3390/buildings13061501

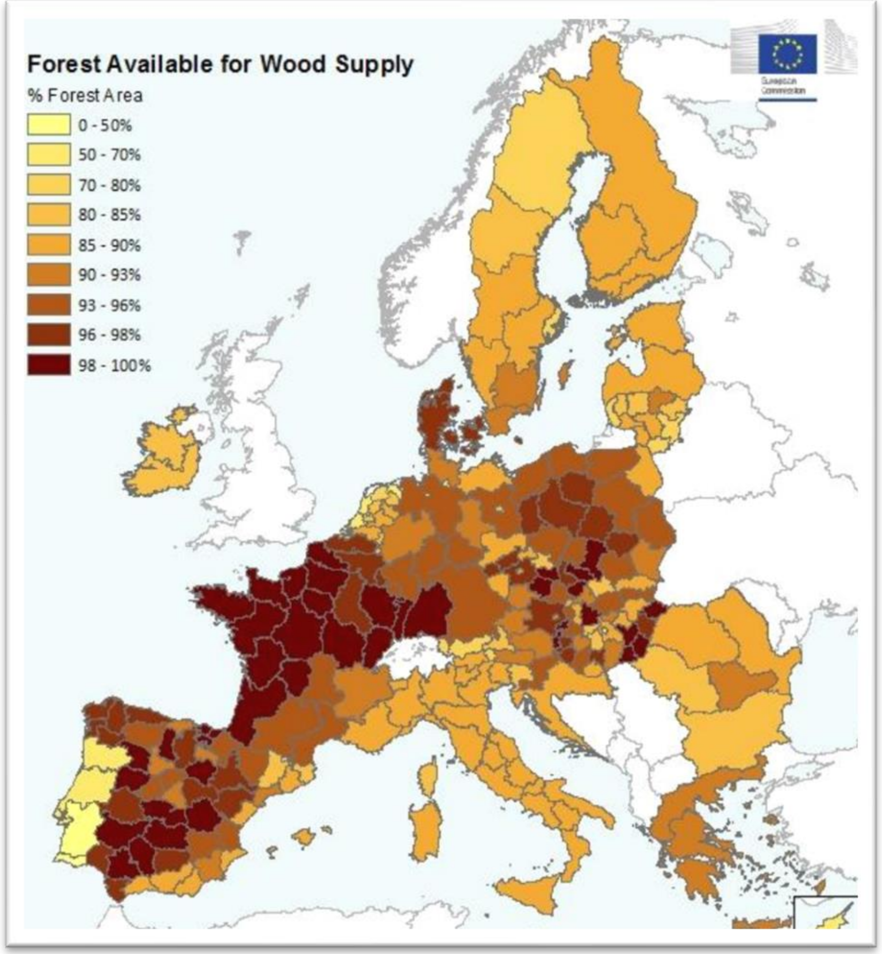
Tree species available for use

Coniferous species predomination (mainly *Picea abies* L. and *Pinus sylvestris* L.)

Most significant broadleaves: *Quercus* spp. and *Fagus sylvatica* L. (in northern regions *Betula* spp.)

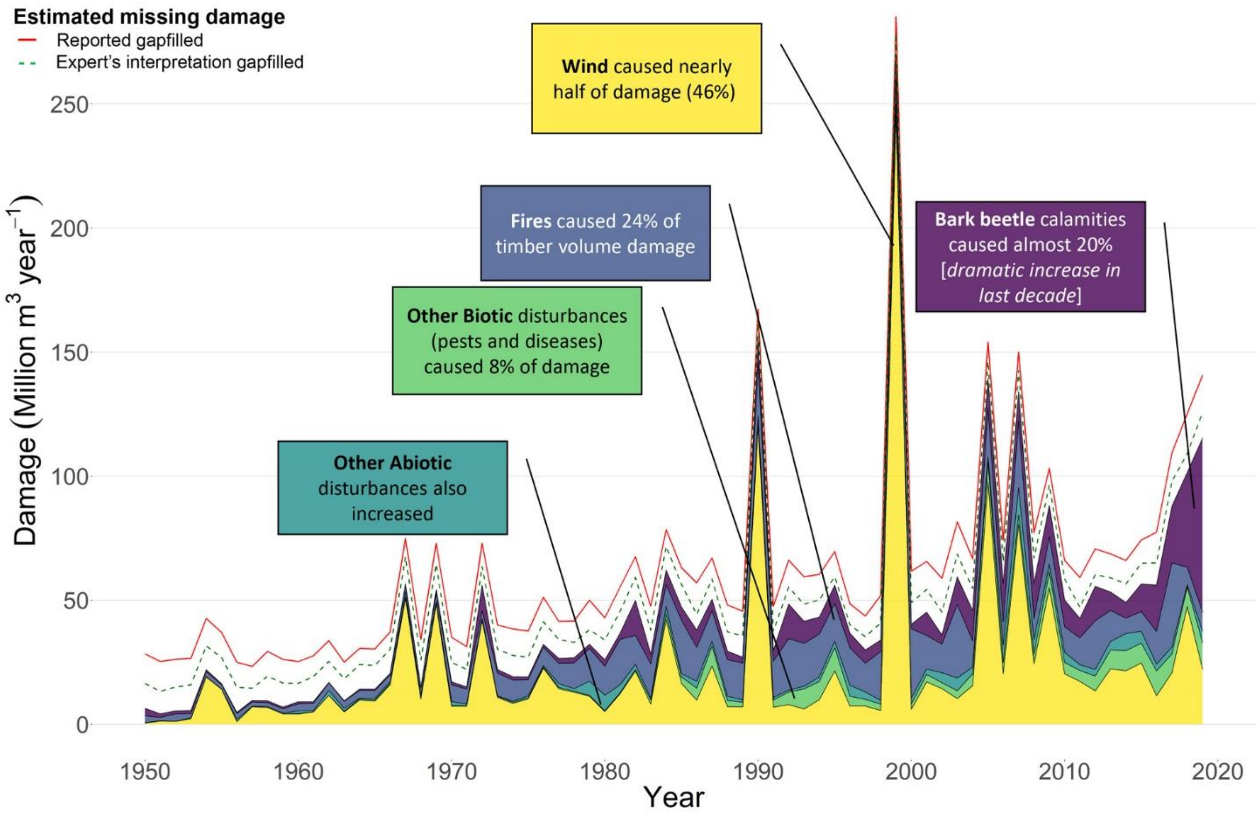






[Avitabile, V, Baldoni E, Baruth B, and Bausano G. 2023. “Biomass Production, Supply, Uses and Flows in the European Union.” EC JRC. https://doi.org/10.2760/484748.](https://doi.org/10.2760/484748)

Climate change impacting on forests



Under this scenario, the availability of species commonly used in wood construction (e.g. spruce from Central Europe) and their properties may be affected in the coming years and the matrix of species available for structural use might vary.

Lindner, Markus, and Hans Verkerk. 2021. "Key Questions on Forests in the EU: How Has Climate Change Affected EU Forests and What Might Happen Next?" EFI Forest Questions Blog. Https://Efi.Int/Forestquestions/Q4. 2021

Contents

EUFORE

State of the art of the European wood species available nowadays for structural purposes

Needs for additional research to boost the efficient use of structural wood in the construction sector

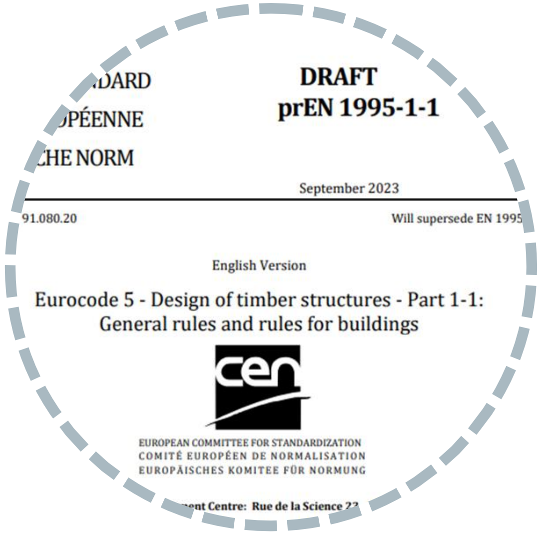
Timber structures value chain

Engineered Wood Products (EWP)

BIM modelling

Architectural design

Wood grading



DARD
OPÉENNE
CHE NORM

DRAFT
prEN 1995-1-1

September 2023

91.080.20

Will supersede EN 1995

English Version

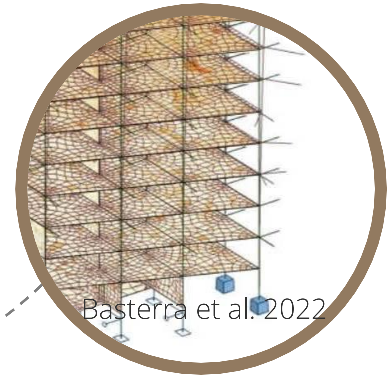
Eurocode 5 - Design of timber structures - Part 1-1:
General rules and rules for buildings

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

ent Centre: Rue de la Science 23

Eurocode 5

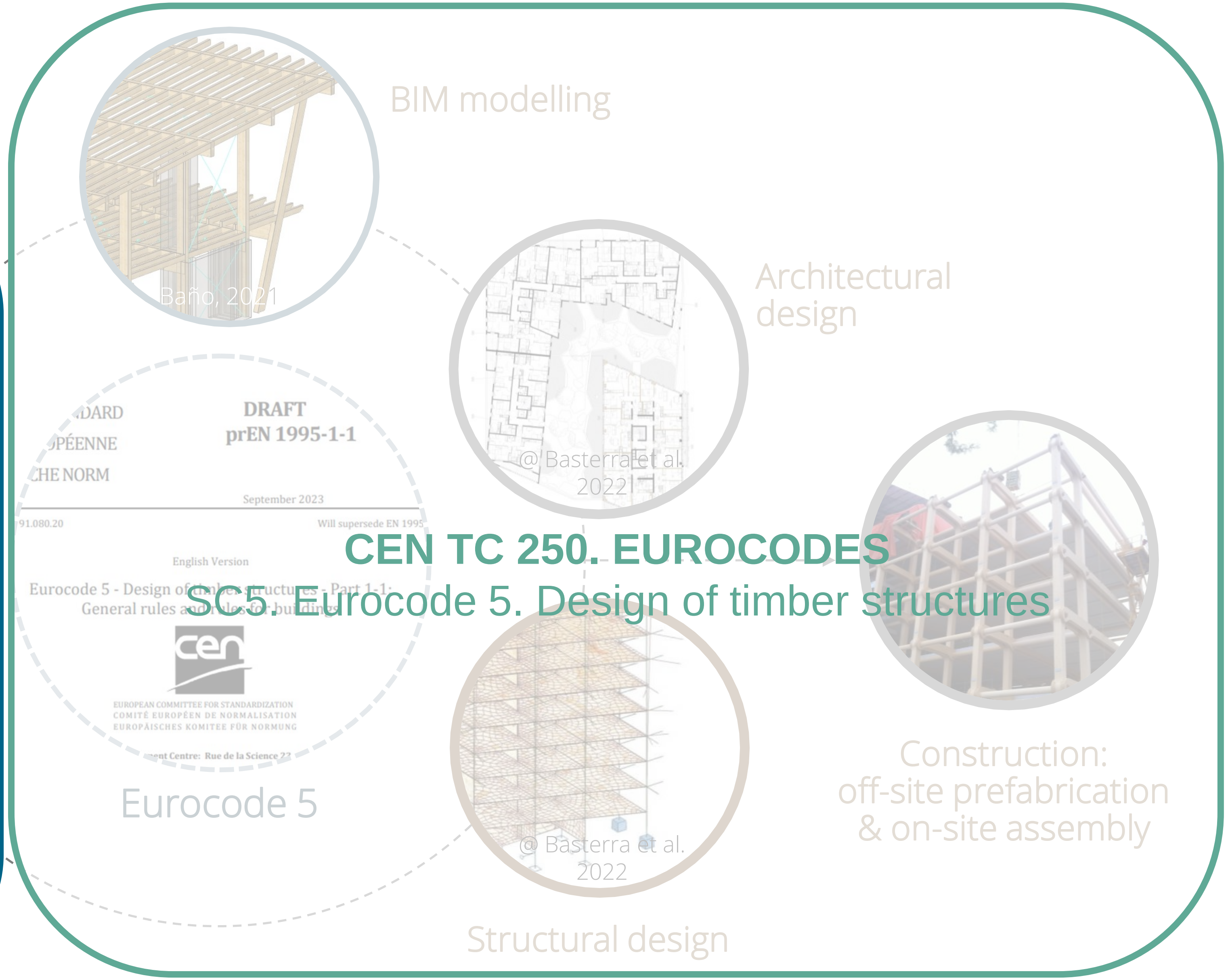
CNC machining



Structural design

Construction:
off-site prefabrication
& on-site assembly

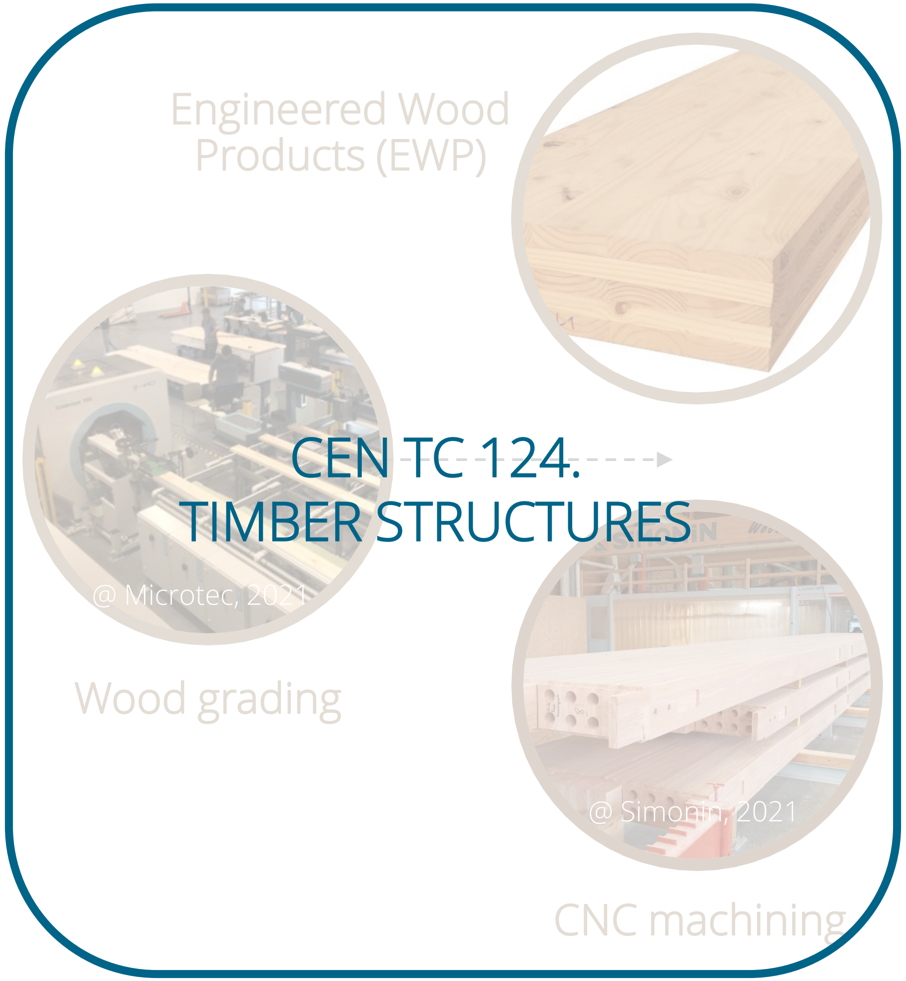
Timber structures value chain



[CEN TC 124. Timber Structures. Brussels]

[CEN TC 250/SC5. Eurocode 5: Design of timber structures. Brussels]

Timber structures value chain



WG1. Test methods

Determination of the physical and mechanical properties

WG2. Solid timber

Strength-graded structural timber with rectangular cross-section

WG3. Glued laminated timber

Glulam (GLT), Cross-laminated timber (CLT), Laminated veneer lumber (LVL), Structural finger-jointed jointed timber; Glued solid timber

WG4. Connectors

Nails, staples, screws, dowels, bolts, steel shear plates, split ring connectors, tooth plate connectors, punched metal plate fasteners and nailing plates

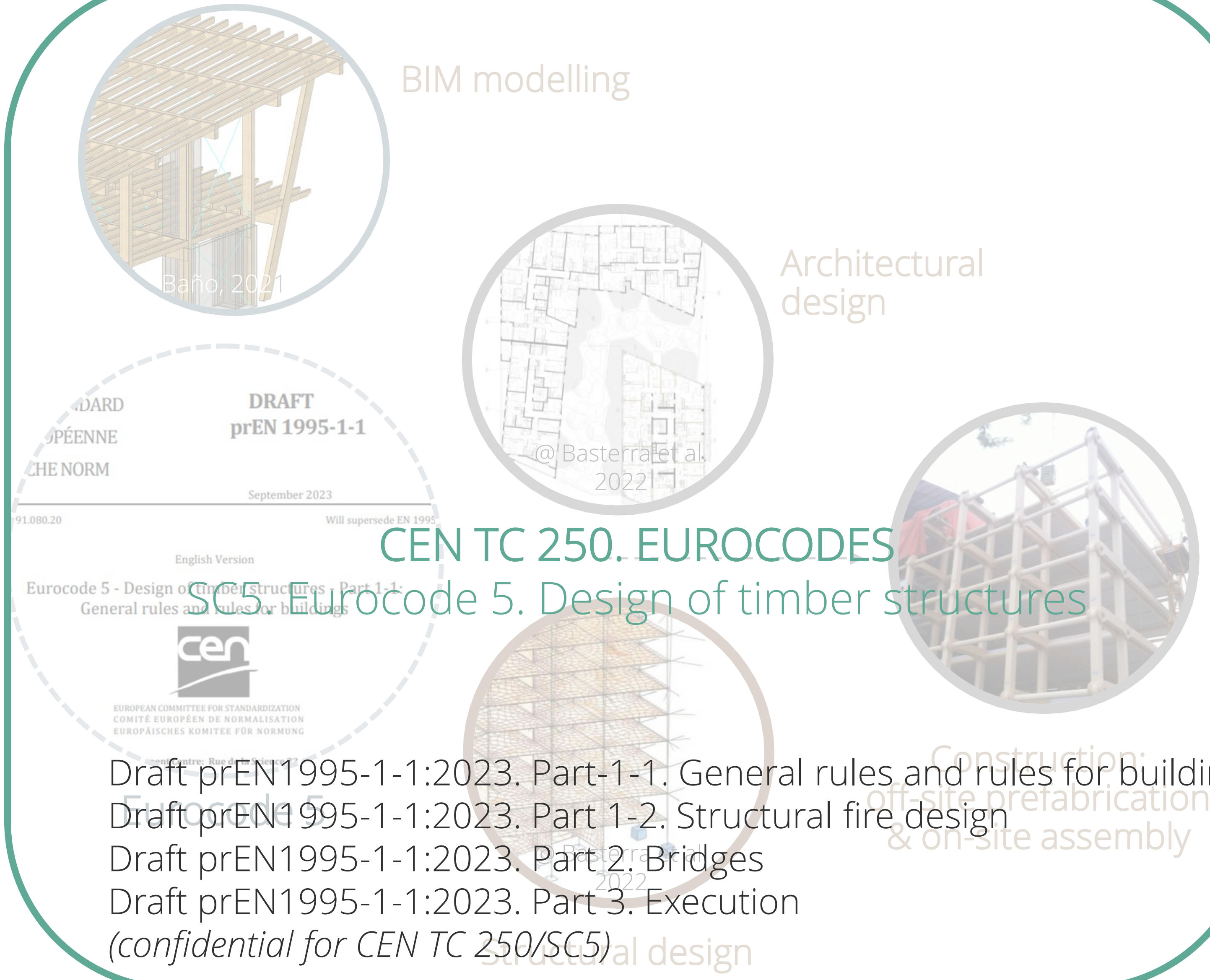
WG5. Prefabricated walls, floors and roofs

Trusses for roofs, walls and floors, frames, composite beams and girders; framing members

Adapted from CEN TC 124. Subcommittees and working groups. Brussels

Timber structures value chain

- WG1. Cross-laminated timber
- WG2. Timber-concrete composites
- WG3. Cluster Eurocode 5
- WG4. Structural fire design
- WG5. Connections and fasteners
- WG6. Timber bridges
- WG7. Reinforcement
- WG8. Seismic design



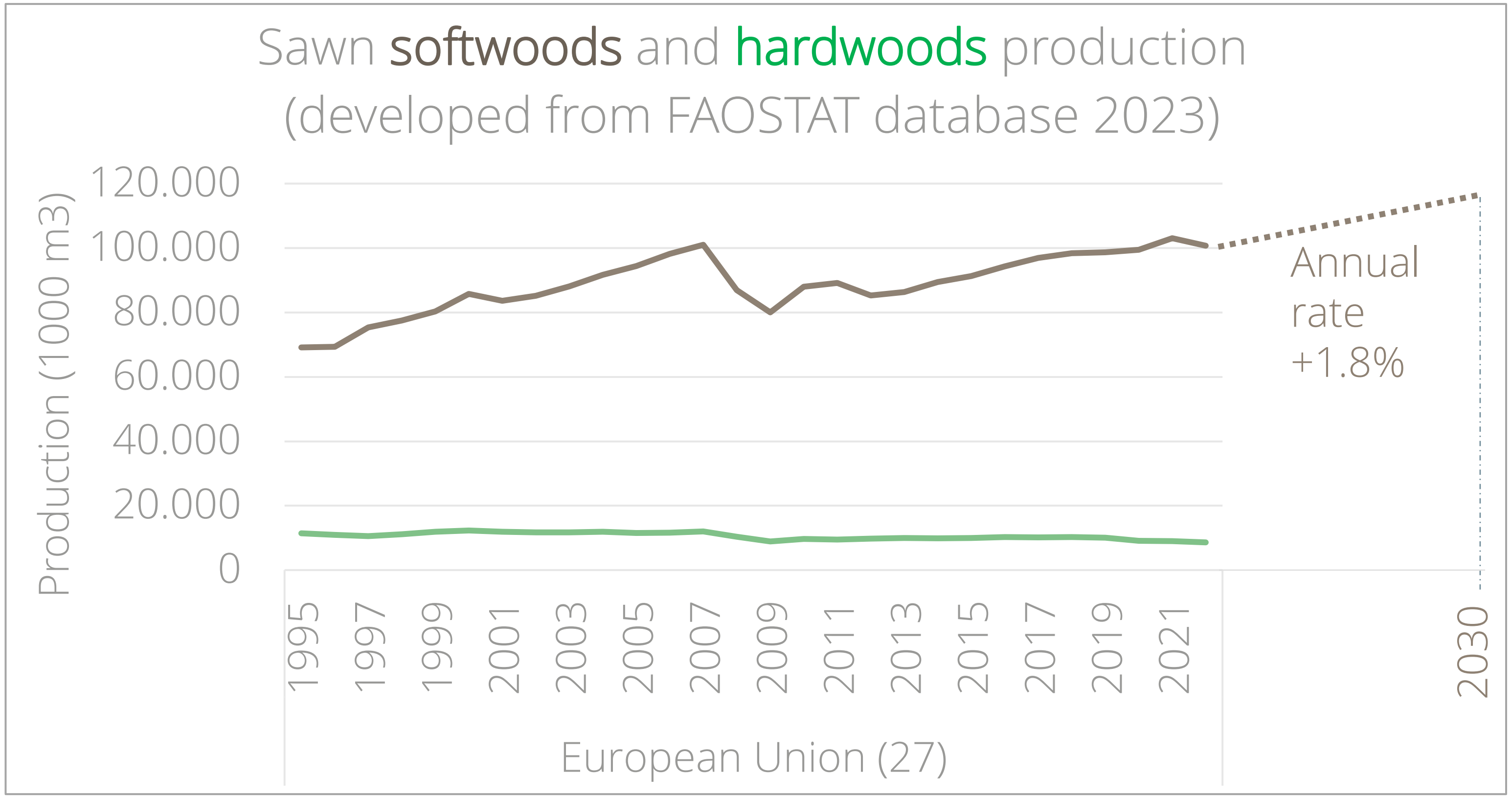
CEN TC 250. EUROCODES

SC5. Eurocode 5. Design of timber structures

Draft prEN1995-1-1:2023. Part-1-1. General rules and rules for buildings
Draft prEN1995-1-1:2023. Part 1-2. Structural fire design
Draft prEN1995-1-1:2023. Part 2. Bridges
Draft prEN1995-1-1:2023. Part 3. Execution
(confidential for CEN TC 250/SC5)

Adapted from CEN TC 250/SC5. Subcommittees and working groups. Brussels

Sawnwood



In 2022, sawn softwood species represented 92% of the total sawnwood production and hardwood species 8%

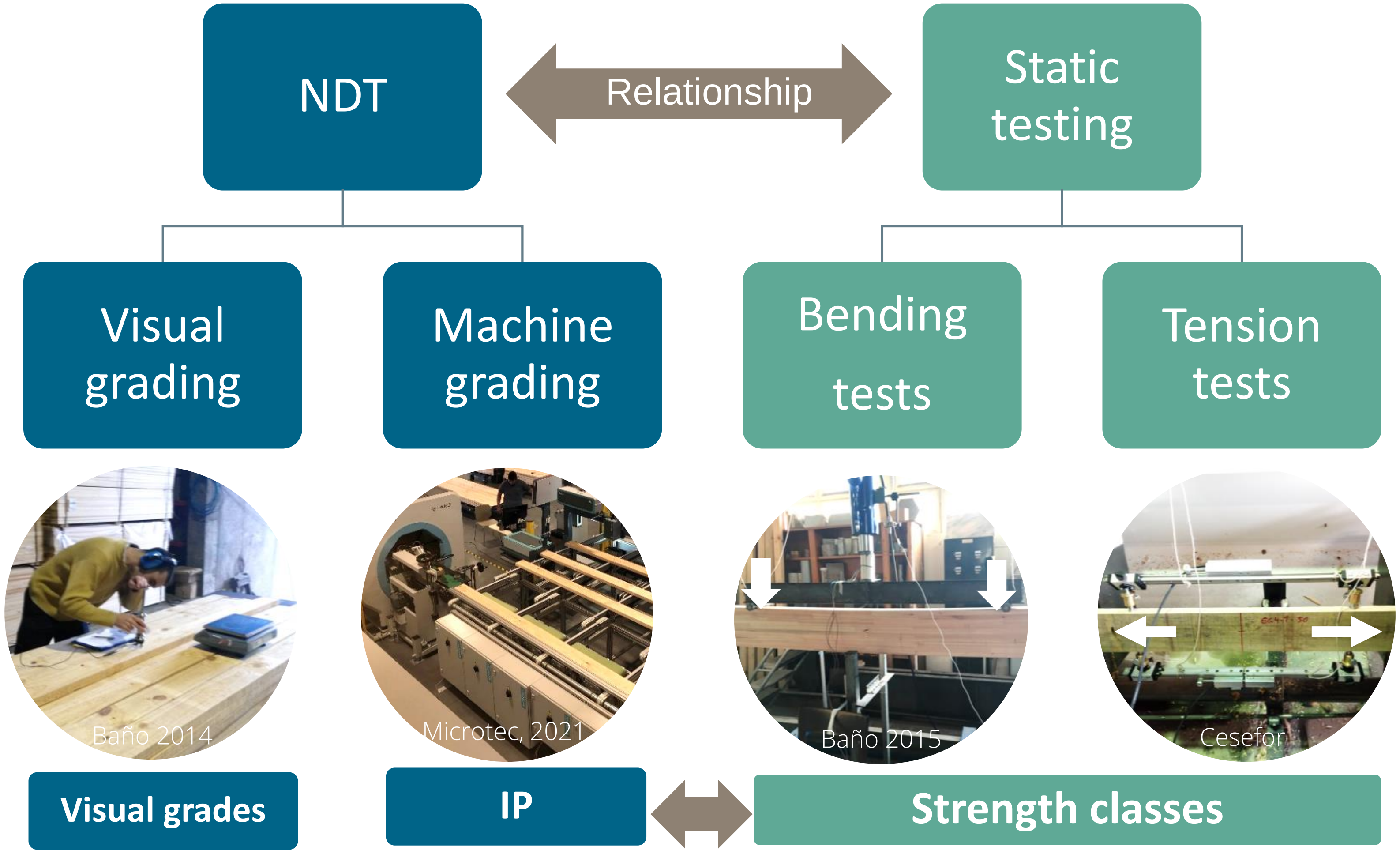
The construction sector consumes most sawn softwood produced in Europe (EOS 2023)

Global softwood production is expected to increase at an annual rate of 1.8% by 2030, with 50% of the wood volume destined for construction purposes as a substitute for steel, concrete and masonry (2022-2030: +15%)

Only a few species are available for structural purposes in Europe

EOS European Organisation of the Sawmill Industry. 2023. "ANNUAL REPORT 2022-2023 OF THE EUROPEAN SAWMILL INDUSTRY". https://eos-oes.eu/annual-reports/

Wood grading



Own figure

Wood grading

Bending tests

Softwoods

	Class	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties in N/mm²													
Bending	$f_{m,k}$	14	**16**	**18**	20	22	**24**	27	**30**	35	40	45	50
Tension parallel	$f_{t,0,k}$	7,2	**8,5**	**10**	11,5	13	**14,5**	16,5	**19**	22,5	26	30	33,5
Tension perpendicular	$f_{t,90,k}$	0,4	**0,4**	**0,4**	0,4	0,4	**0,4**	0,4	**0,4**	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	**17**	**18**	19	20	**21**	22	**24**	25	27	29	30
Compression perpendicular	$f_{c,90,k}$	2,0	**2,2**	**2,2**	2,3	2,4	**2,5**	2.5	**2,7**	2,7	2,8	2,9	3,0
Shear	$f_{v,k}$	3,0	**3,2**	**3,4**	3,6	3,8	**4,0**	4,0	**4,0**	4,0	4,0	4,0	4,0
Stiffness properties in kN/mm²													
Mean modulus of elasticity parallel bending	$E_{m,0,mean}$	7,0	**8,0**	**9,0**	9,5	10,0	**11,0**	11,5	**12,0**	13,0	14,0	15,0	16,0
5 percentile modulus of elasticity parallel bending	$E_{m,0,k}$	4,7	**5,4**	**6,0**	6,4	6,7	**7,4**	7,7	**8,0**	8,7	9,4	10,1	10,7
Mean modulus of elasticity perpendicular	$E_{m,90,mean}$	0,23	**0,27**	**0,30**	0,32	0,33	**0,37**	0,38	**0,40**	0,43	0,47	0,50	0,53
Mean shear modulus	G_{mean}	0,44	**0,50**	**0,56**	0,59	0,63	**0,69**	0,72	**0,75**	0,81	0,88	0,94	1,00
Density in kg/m³													
5 percentile c density	ρ_k	290	**310**	**320**	330	340	**350**	360	**380**	390	400	410	430
Mean density	ρ_{mean}	350	**370**	**380**	400	410	**420**	430	**460**	470	480	490	520

Strength classes C

Hardwoods

	Class	T 8	T 9	T 10	T 11	T 12	T 13	T 14	T 14,5	T 15	T 16	T 18	T 21	T 22	T 24	T 26	T 27	T 28	T 30
Strength properties in N/mm²																			
Bending	$f_{m,k}$	13,5	14,5	16	**17**	18	19,5	**20,5**	21	22	23	**25,5**	**29**	**30,5**	33	35	36,5	37,5	40
Tension parallel	$f_{t,0,k}$	8	9	10	**11**	12	13	**14**	14,5	15	16	**18**	**21**	**22**	24	26	27	28	30
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	**0,4**	0,4	0,4	**0,4**	0,4	0,4	0,4	**0,4**	**0,4**	**0,4**	0,4	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	17	17	**18**	19	20	**21**	21	21	22	**23**	**25**	**26**	27	28	29	29	30
Compression perpendicular	$f_{c,90,k}$	2,0	2,1	2,2	**2,2**	2,3	2,4	**2,5**	2,5	2,5	2,6	**2,7**	**2,7**	**2,7**	2,8	2,9	2,9	2,9	3,0
Shear	$f_{v,k}$	2,8	3,0	3,2	**3,4**	3,6	3,8	**4,0**	4,0	4,0	4,0	**4,0**	**4,0**	**4,0**	4,0	4,0	4,0	4,0	4,0
Stiffness properties in kN/mm²																			
Mean modulus of elasticity parallel tension	$E_{t,0,mean}$	7,0	7,5	8,0	**9,0**	9,5	10,0	**11,0**	11,0	11,5	11,5	**12,0**	**13,0**	**13,0**	13,5	14,0	15,0	15,0	15,5
5 percentile modulus of elasticity parallel tension	$E_{t,0,k}$	4,7	5,0	5,4	**6,0**	6,4	6,7	**7,4**	7,4	7,7	7,7	**8,0**	**8,7**	**8,7**	9,0	9,4	10,1	10,1	10,4
Mean modulus of elasticity perpendicular	$E_{t,90,mean}$	0,23	0,25	0,27	**0,30**	0,32	0,33	**0,37**	0,37	0,38	0,38	**0,40**	**0,43**	**0,43**	0,45	0,47	0,50	0,50	0,52
Mean shear modulus	G_{mean}	0,44	0,47	0,50	**0,56**	0,59	0,63	**0,69**	0,69	0,72	0,72	**0,75**	**0,81**	**0,81**	0,84	0,88	0,94	0,94	0,97
Density in kg/m³																			
5 percentile density	ρ_k	290	300	310	**320**	330	340	**350**	350	360	370	**380**	**390**	**390**	400	410	410	420	430
Mean density	ρ_{mean}	350	360	370	**380**	400	410	**420**	420	430	440	**460**	**470**	**470**	480	490	490	500	520

Strength classes D

Tensile tests

	Class	D18	D24	D27	D30	D35	D40	D45	D50	D55	D60	D65	D70	D75	D80
Strength properties in N/mm²															
Bending	$f_{m,k}$	18	**24**	27	**30**	35	**40**	45	**50**	55	**60**	65	**70**	75	80
Tension parallel	$f_{t,0,k}$	11	**14**	16	**18**	21	**24**	27	**30**	33	**36**	39	**42**	45	48
Tension perpendicular	$f_{t,90,k}$	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	0,6
Compression parallel	$f_{c,0,k}$	18	**21**	22	**24**	25	**27**	29	**30**	32	**33**	35	**36**	37	38
Compression perpendicular	$f_{c,90,k}$	4,8	**4,9**	5,1	**5,3**	5,4	**5,5**	5,8	**6,2**	6,6	**10,5**	11,3	**12,0**	12,8	13,5
Shear	$f_{v,k}$	3,5	**3,7**	3,8	**3,9**	4,1	**4,2**	4,4	**4,5**	4,7	**4,8**	5,0	**5,0**	5,0	5,0
Stiffness properties in kN/mm²															
Mean modulus of elasticity parallel bending	$E_{m,0,mean}$	9,5	**10,0**	10,5	**11,0**	12,0	**13,0**	13,5	**14,0**	15,5	**17,0**	18,5	**20,0**	22,0	24,0
5 percentile modulus of elasticity parallel bending	$E_{m,0,k}$	8,0	**8,4**	8,8	**9,2**	10,1	**10,9**	11,3	**11,8**	13,0	**14,3**	15,5	**16,8**	18,5	20,2
Mean modulus of elasticity perpendicular	$E_{m,90,mean}$	0,63	**0,67**	0,70	**0,73**	0,80	**0,87**	0,90	**0,93**	1,03	**1,13**	1,23	**1,33**	1,47	1,60
Mean shear modulus	G_{mean}	0,59	**0,63**	0,66	**0,69**	0,75	**0,81**	0,84	**0,88**	0,97	**1,06**	1,16	**1,25**	1,38	1,50
Density in kg/m³															
5 percentile density	ρ_k	475	**485**	510	**530**	540	**550**	580	**620**	660	**700**	750	**800**	850	900
Mean density	ρ_{mean}	570	**580**	610	**640**	650	**660**	700	**740**	790	**840**	900	**960**	1020	1080

Strength classes T

Strength classes TD??

[Adapted from EN 338: 2016. Structural timber - Strength classes](#)

Visual grading

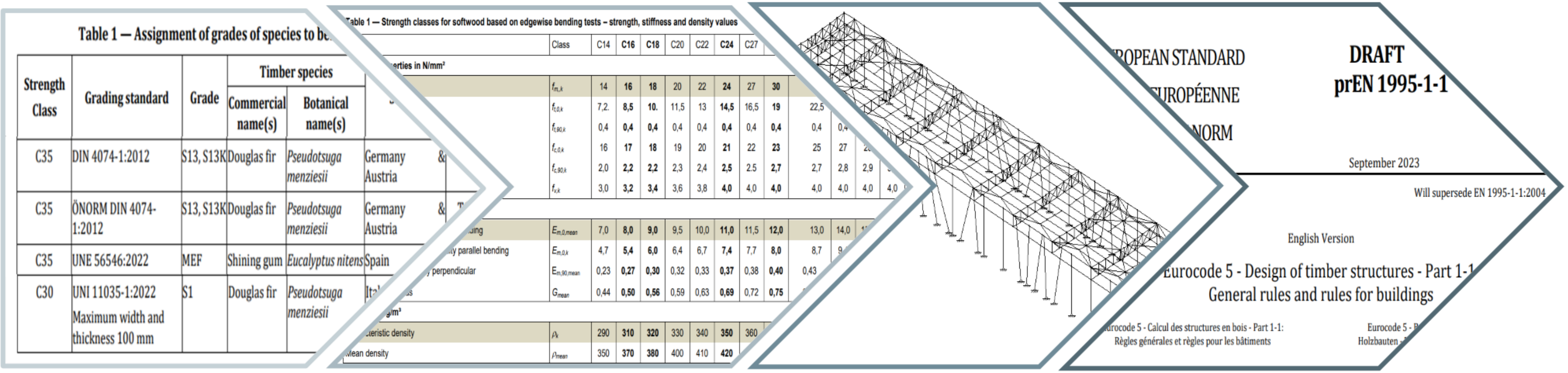
EU-27

Softwoods	Strength classes	
	C	T
Abies alba	CNE Europe, Northern Europe, FR, IT, SI, IE	AT, CZ, DE, SI, SK
Larix decidua	CNE Europe, Northern Europe, FR, IT	AT, CZ, DE, IT
Picea abies	NE Europe, Northern Europe, SI, FR, IT, SK	AT, CZ, DE
Pinus pinaster	FR, ES, PT	-
Pinus radiata	ES	
Pinus sylvestris	CNE Europe, Northern Europe, ES, FR	AT, CZ, DE, PL
Pinus nigra, ssps. laricio/Salzmannii/ nigra	FR, IT, ES	-
Pseudotsuga menziessii	DE, IT, AT, FR	AT, BE, DE

Hardwoods	Strength classes		
	C	D	T
Acer pseudoplatanus	-	DE	-
Castanea sativa	FR	IT, ES	-
Eucalyptus globulus	-	ES	-
Eucalyptus nitens	-	-	ES
Fagus sylvatica	-	IT, FR, BE, DE	-
Fraxinus excelsior	-	DE	-
Populus x canadensis	FR	-	-
Populus nigra	DE	-	-
Quercus robur/petraea	-	FR, BE, DE	-

Avitabile, V, Baldoni E, Baruth B, and Bausano G. 2023. "Biomass Production, Supply, Uses and Flows in the European Union." https://doi.org/10.2760/484748.
FprEN 1912: 2023. Structural Timber - Strength classes - Assignment of visual grades and species (under approval)
EC JRC, 2016. The European Atlas of Forest Tree Species. https://forest.jrc.ec.europa.eu/en/european-atlas/atlas-download-page

How to design timber structures
from visually graded wood species?



EN 1912

Relationship between the visual grades and the strength classes

EN 338

Physical and mechanical properties for the strength classes

Numerical simulation

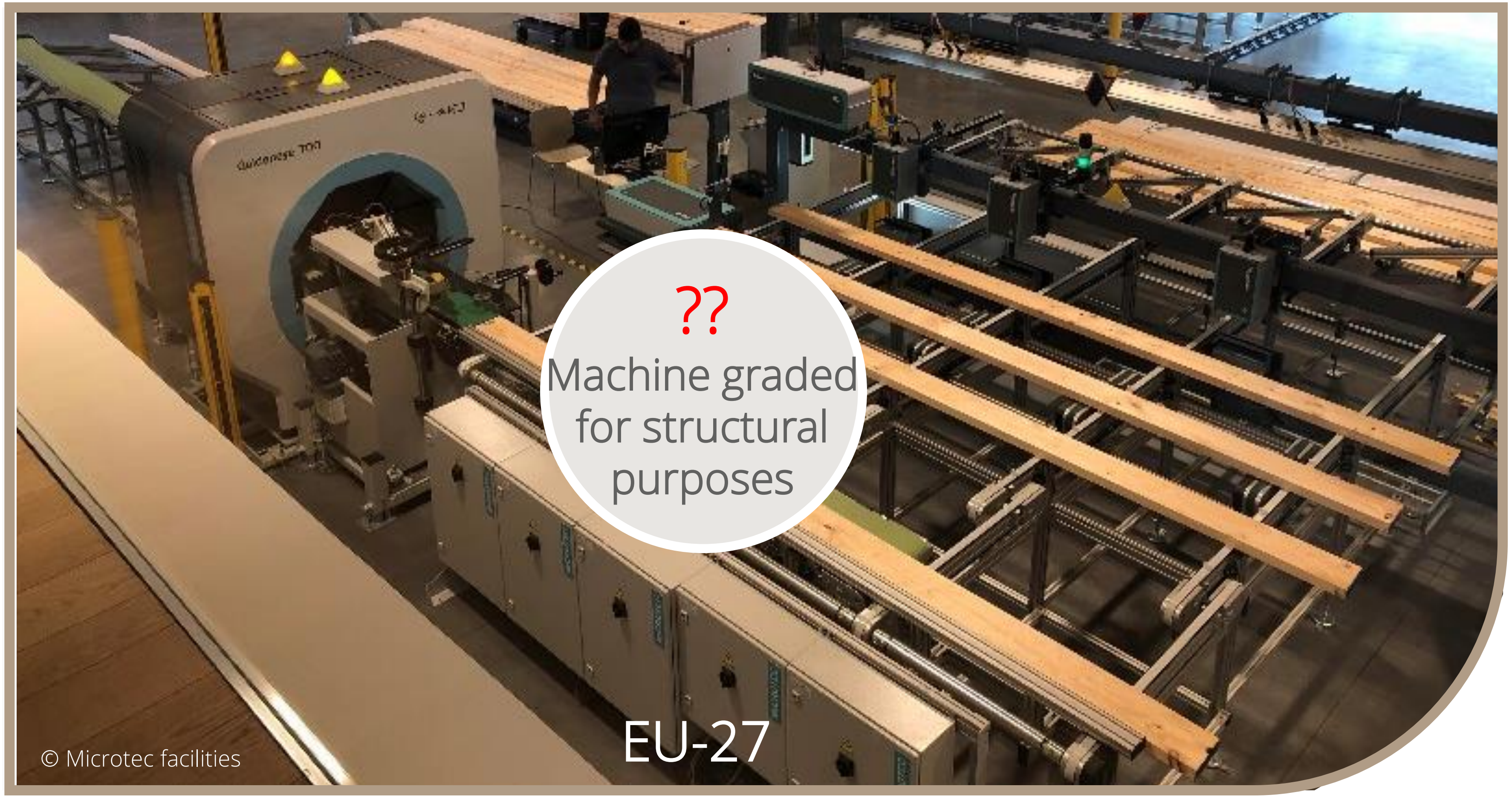
Lineal elements

Eurocode 5

Dimensioning

[FprEN 1912: 2023. Structural Timber - Strength classes - Assignment of visual grades and species (under approval)]
[EN 338: 2016. Structural timber - Strength classes]

Machine grading
CEN TC124 WG2



- Not published in EN standards
- Results remain available for the CEN TC124 WG2 and through the websites of the sawmills
- Difficult to know how many species are machine-graded and what are their strength classes

State of the art of the European wood species available nowadays for structural purposes

Needs for additional research to boost the efficient use of structural wood in the construction sector

1) Raw material

2) Reclaimed wood

3) FEM

4) LCA

1) Raw material

Are the properties of wood species known for the structural design according to Eurocode 5?
Are wood resources locally available in EU-27 countries that are suited for structural purposes?

2) Reclaimed wood

Can reclaimed wood be used for structural purposes?
Are there any EN or national standards which provide their properties?

3) Finite element model

Are the isotropic/orthotropic properties known for the finite element model (FEM) design of complex structures beyond the Eurocode 5?

4) LCA

Is an optimal structural efficiency in building design considered in the carbon storage of buildings?

1) Raw material

Bending tests

Softwoods

	Class	C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties in N/mm²													
Bending	$f_{m,k}$	14	**16**	**18**	20	22	**24**	27	**30**	35	40	45	50
Tension parallel	$f_{t,0,k}$	7,2	**8,5**	**10**	11,5	13	**14,5**	16,5	**19**	22,5	26	30	33,5
Tension perpendicular	$f_{t,90,k}$	0,4	**0,4**	**0,4**	0,4	0,4	**0,4**	0,4	**0,4**	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	**17**	**18**	19	20	**21**	22	**24**	25	27	29	30
Compression perpendicular	$f_{c,90,k}$	2,0	**2,2**	**2,2**	2,3	2,4	**2,5**	2.5	**2,7**	2,7	2,8	2,9	3,0
Shear	$f_{v,k}$	3,0	**3,2**	**3,4**	3,6	3,8	**4,0**	4,0	**4,0**	4,0	4,0	4,0	4,0
Stiffness properties in kN/mm²													
Mean modulus of elasticity parallel bending	$E_{m,0,mean}$	7,0	**8,0**	**9,0**	9,5	10,0	**11,0**	11,5	**12,0**	13,0	14,0	15,0	16,0
5 percentile modulus of elasticity parallel bending	$E_{m,0,k}$	4,7	**5,4**	**6,0**	6,4	6,7	**7,4**	7,7	**8,0**	8,7	9,4	10,1	10,7
Mean modulus of elasticity perpendicular	$E_{m,90,mean}$	0,23	**0,27**	**0,30**	0,32	0,33	**0,37**	0,38	**0,40**	0,43	0,47	0,50	0,53
Mean shear modulus	G_{mean}	0,44	**0,50**	**0,56**	0,59	0,63	**0,69**	0,72	**0,75**	0,81	0,88	0,94	1,00
Density in kg/m³													
5 percentile c density	ρ_k	290	**310**	**320**	330	340	**350**	360	**380**	390	400	410	430
Mean density	ρ_{mean}	350	**370**	**380**	400	410	**420**	430	**460**	470	480	490	520

Strength classes C

Hardwoods

	Class	T 8	T 9	T 10	T 11	T 12	T 13	T 14	T 14,5	T 15	T 16	T 18	T 21	T 22	T 24	T 26	T 27	T 28	T 30
Strength properties in N/mm²																			
Bending	$f_{m,k}$	13,5	14,5	16	**17**	18	19,5	**20,5**	21	22	23	**25,5**	**29**	**30,5**	33	35	36,5	37,5	40
Tension parallel	$f_{t,0,k}$	8	9	10	**11**	12	13	**14**	14,5	15	16	**18**	**21**	**22**	24	26	27	28	30
Tension perpendicular	$f_{t,90,k}$	0,4	0,4	0,4	**0,4**	0,4	0,4	**0,4**	0,4	0,4	0,4	**0,4**	**0,4**	**0,4**	0,4	0,4	0,4	0,4	0,4
Compression parallel	$f_{c,0,k}$	16	17	17	**18**	19	20	**21**	21	21	22	**23**	**25**	**26**	27	28	29	29	[illegible]
Compression perpendicular	$f_{c,90,k}$	2,0	2,1	2,2	**2,2**	2,3	2,4	**2,5**	2,5	2,5	2,6	**2,7**	**2,7**	**2,7**	2,8	2,9	2,9	[illegible]	3,0
Shear	$f_{v,k}$	2,8	3,0	3,2	**3,4**	3,6	3,8	**4,0**	4,0	4,0	4,0	**4,0**	**4,0**	**4,0**	4,0	[illegible]	[illegible]	[illegible]	4,0
Stiffness properties in kN/mm²																			
Mean modulus of elasticity parallel tension	$E_{t,0,mean}$	7,0	7,5	8,0	**9,0**	9,5	10,0	**11,0**	11,0	11,5	11,5	**12,0**	**13,0**	[illegible]	13,5	14,0	15,0	[illegible]	[illegible]
5 percentile modulus of elasticity parallel tension	$E_{t,0,k}$	4,7	5,0	5,4	**6,0**	6,4	6,7	**7,4**	7,4	7,7	[illegible]	[illegible]	**8,7**	[illegible]	[illegible]	[illegible]	10,1	[illegible]	10,4
Mean modulus of elasticity perpendicular	$E_{t,90,mean}$	0,23	0,25	0,27	**0,30**	0,32	0,33	**0,37**	0,37	0,38	[illegible]	[illegible]	**0,43**	[illegible]	[illegible]	0,47	[illegible]	0,50	0,52
Mean shear modulus	G_{mean}	0,44	0,47	0,50	**0,56**	0,59	0,63	**0,69**	0,69	0,72	0,72	[illegible]	[illegible]	[illegible]	[illegible]	0,88	0,94	0,94	0,97
Density in kg/m³																			
5 percentile density	ρ_k	290	300	310	**320**	330	340	**350**	350	360	370	[illegible]	**390**	**390**	400	410	410	420	430
Mean density	ρ_{mean}	350	360	370	**380**	400	410	**420**	420	430	440	**460**	**470**	**470**	480	490	490	500	520

Strength classes D

Tensile tests

	Class	D18	D24	D27	D30	D35	D40	D45	D50	D55	D60	D65	D70	D75	D80
Strength properties in N/mm²															
Bending	$f_{m,k}$	18	**24**	27	**30**	35	**40**	45	**50**	55	**60**	65	**70**	75	80
Tension parallel	$f_{t,0,k}$	11	**14**	16	**18**	21	**24**	27	**30**	33	**36**	39	[illegible]	45	[illegible]
Tension perpendicular	$f_{t,90,k}$	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	0,6	**0,6**	[illegible]	**0,6**	[illegible]	[illegible]
Compression parallel	$f_{c,0,k}$	18	**21**	22	**24**	25	**27**	29	**30**	32	**33**	[illegible]	**36**	[illegible]	[illegible]
Compression perpendicular	$f_{c,90,k}$	4,8	**4,9**	5,1	**5,3**	5,4	**5,5**	5,8	**6,2**	[illegible]	[illegible]	[illegible]	**12,0**	[illegible]	13,5
Shear	$f_{v,k}$	3,5	**3,7**	3,8	**3,9**	4,1	[illegible]	4,4	**4,5**	4,7	[illegible]	5,0	[illegible]	[illegible]	5,0
Stiffness properties in kN/mm²															
Mean modulus of elasticity parallel bending	$E_{m,0,mean}$	9,5	**10,0**	10,5	**11,0**	12,0	[illegible]	13,5	**14,0**	[illegible]	**17,0**	18,5	[illegible]	22,0	24,0
5 percentile modulus of elasticity parallel bending	$E_{m,0,k}$	8,0	**8,4**	8,8	**9,2**	[illegible]	**10,9**	[illegible]	**11,8**	13,0	**14,3**	15,5	**16,8**	18,5	20,2
Mean modulus of elasticity perpendicular	$E_{m,90,mean}$	0,63	**0,67**	[illegible]	[illegible]	[illegible]	**0,87**	[illegible]	**0,93**	1,03	**1,13**	1,23	**1,33**	1,47	1,60
Mean shear modulus	G_{mean}	0,59	**0,63**	[illegible]	[illegible]	[illegible]	**0,81**	[illegible]	**0,88**	0,97	**1,06**	1,16	**1,25**	1,38	1,50
Density in kg/m³															
5 percentile density	ρ_k	475	[illegible]	[illegible]	**530**	[illegible]	**550**	580	**620**	660	**700**	750	**800**	850	900
Mean density	ρ_{mean}	570	[illegible]	[illegible]	[illegible]	650	**660**	700	**740**	790	**840**	900	**960**	1020	1080

Strength classes T

Strength classes TD??

Softwoods	Strength classes from visual grading	
	C	T
Abies alba	CNE Europe, Northern Europe, FR, IT, SI, IE	AT, CZ, DE, SI, SK
Larix decidua	CNE Europe, Northern Europe, FR, IT	AT, CZ, DE, IT
Picea abies	NE Europe, Northern Europe, SI, FR, IT, SK	AT, CZ, DE
Pinus pinaster	FR, ES, PT	-
Pinus radiata	ES	
Pinus sylvestris	CNE Europe, Northern Europe, ES, FR	AT, CZ, DE, PL
Pinus nigra, ssps. laricio/Salzmannii/ nigra	FR, IT, E[illegible]	-
Pseudotsuga menziesii	DE, IT, AT, FR	AT, BE, DE

Hardwoods	Strength classes from visual grading		
	C	D	T
Acer pseudoplatanus	-	DE	-
Castanea sativa	FR	IT, ES	-
Eucalyptus globulus	-	ES	-
Eucalyptus nitens	-	-	ES
Fagus sylvatica	-	IT, FR, BE, DE	-
Fraxinus excelsior	-	DE	-
Populus x canadensis	FR	-	-
Populus nigra	DE	-	-
Quercus robur/petraea	-	FR, BE, DE	-

More wood species, more origins

2) Reclaimed wood

CEN TC 124. TIMBER STRUCTURES

WG2R?. **Reused** Solid timber

Llana 2023

Llana 2023

“Requirements for visual grading in reclaimed wood should be different than in the case of new timber” (Llana 2023)

What about …machine grading?

…strength classes for softwoods tested in bending (CR?) and in tension (TR?)?

…strength classes in hardwoods in bending (DR?) and in tension (DTR?)?

Llana D, Íñiguez G, Plos M, Turk G. 2023. Grading of recovered Norway spruce (Picea abies) timber for structural purposes. Construction and Building Materials. Volume 398, 22. https://doi.org/10.1016/j.conbuildmat.2023.132440

2) Reclaimed wood

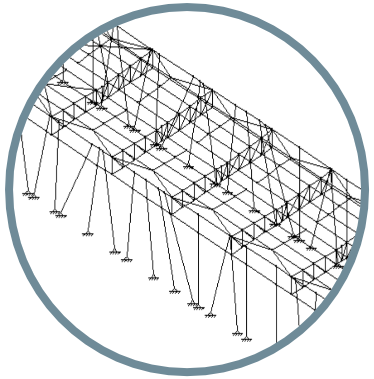
CEN TC 124. TIMBER STRUCTURES

- WG2R?. **Reused** Solid timber
- WG3R?. Glued laminated timber
- WG4R?. Connectors
- WG5R?. Prefabricated walls, floors and roofs

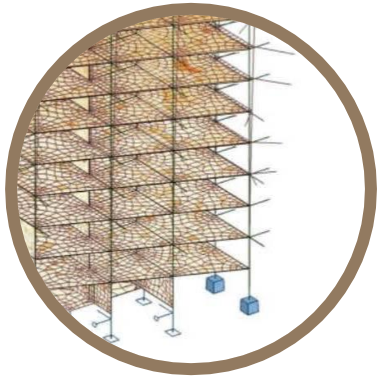
Can the reused/reclaimed solid timber be used for manufacturing EWP?

How to design the connections in structural components made from reclaimed wood?

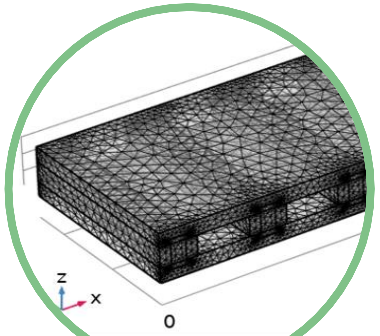
3) Finite element modelling (FEM)



Line elements

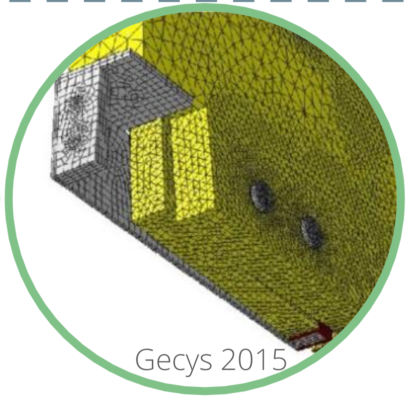


Shell elements



Baño 2021

Gecys 2015



Gecys 2015

Solid elements

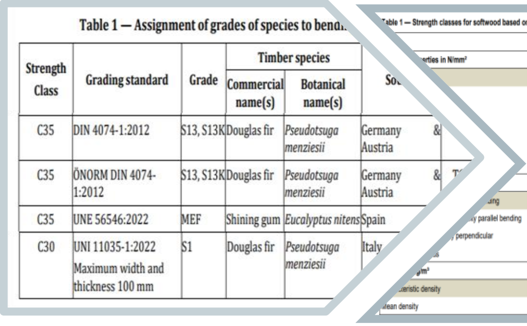


Table 1 — Assignment of grades of species to bendi…

Strength Class	Grading standard	Grade	Timber species: Commercial name(s)	Timber species: Botanical name(s)	So…
C35	DIN 4074-1:2012	S13, S13K	Douglas fir	*Pseudotsuga menziesii*	Germany Austria
C35	ÖNORM DIN 4074-1:2012	S13, S13K	Douglas fir	*Pseudotsuga menziesii*	Germany Austria
C35	UNE 56546:2022	MEF	Shining gum	*Eucalyptus nitens*	Spain
C30	UNI 11035-1:2022 Maximum width and thickness 100 mm	S1	Douglas fir	*Pseudotsuga menziesii*	Italy

EN 1912

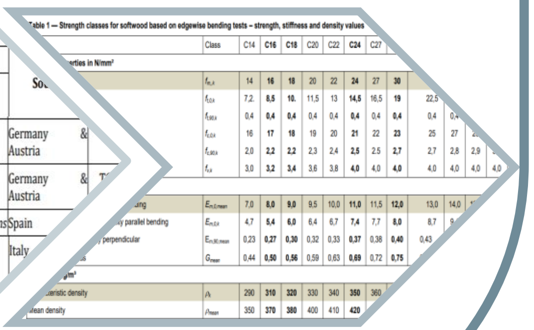


Table 1 — Strength classes for softwood based on edgewise bending tests – strength, stiffness and density values

EN 338

$$
\begin{pmatrix}\varepsilon_R\\ \varepsilon_T\\ \varepsilon_L\\ \gamma_{TL}\\ \gamma_{LR}\\ \gamma_{RT}\end{pmatrix}
=
\begin{pmatrix}
\frac{1}{E_R} & \frac{-\nu_{TR}}{E_T} & \frac{-\nu_{LR}}{E_L} & 0 & 0 & 0\\
\frac{-\nu_{RT}}{E_R} & \frac{1}{E_T} & \frac{-\nu_{LT}}{E_L} & 0 & 0 & 0\\
\frac{-\nu_{RL}}{E_R} & \frac{-\nu_{TL}}{E_T} & \frac{1}{E_L} & 0 & 0 & 0\\
0 & 0 & 0 & \frac{1}{G_{TL}} & 0 & 0\\
0 & 0 & 0 & 0 & \frac{1}{G_{LR}} & 0\\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{RT}}
\end{pmatrix}
\cdot
\begin{pmatrix}\sigma_R\\ \sigma_T\\ \sigma_L\\ \tau_{TL}\\ \tau_{LR}\\ \tau_{RT}\end{pmatrix}
$$

Standards for these properties???

Baño V & Moltini G. 2021. Experimental and numerical analysis of novel adhesive-free structural floor panels (TTP) manufactured from timber-to-timber joints. Journal of Building Engineering 35. DOI: 10.1016/j.jobe.2020.102065
Gecys T, Daniunas A, Bader T K, Wagner L, Eberhardsteiner J. 2015. 3D finite element analysis and experimental investigations of a new type of timber beam-to-beam connection. Engineering Structures 86(2). DOI: 10.1016/j.engstruct.2014.12.037

3) Finite element modelling (FEM)

- Properties not available in EN standards
- Publication of reference:
  Wood handbook – USDA for the US
- Some scientific papers with properties for European species

$$
\begin{pmatrix} \varepsilon_R \\ \varepsilon_T \\ \varepsilon_L \\ \gamma_{TL} \\ \gamma_{LR} \\ \gamma_{RT} \end{pmatrix} =
\begin{pmatrix}
\frac{1}{E_R} & \frac{-\nu_{TR}}{E_T} & \frac{-\nu_{LR}}{E_L} & 0 & 0 & 0 \\
\frac{-\nu_{RT}}{E_R} & \frac{1}{E_T} & \frac{-\nu_{LT}}{E_L} & 0 & 0 & 0 \\
\frac{-\nu_{RL}}{E_R} & \frac{-\nu_{TL}}{E_T} & \frac{1}{E_L} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{G_{TL}} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{G_{LR}} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{RT}}
\end{pmatrix} \cdot
\begin{pmatrix} \sigma_R \\ \sigma_T \\ \sigma_L \\ \tau_{TL} \\ \tau_{LR} \\ \tau_{RT} \end{pmatrix}
$$

Properties for the US wood species

Species	μ_{LR}	μ_{LT}	μ_{RT}	μ_{TR}	μ_{RL}	μ_{TL}
Hardwoods						
Ash, white	0.371	0.440	0.684	0.360	0.059	0.051
Aspen, quaking	0.489	0.374	—	0.496	0.054	0.022
Balsa	0.229	0.488	0.665	0.231	0.018	0.009
Basswood	0.364	0.406	0.912	0.346	0.034	0.022
Birch, yellow	0.426	0.451	0.697	0.426	0.043	0.024
Cherry, black	0.392	0.428	0.695	0.282	0.086	0.048
Cottonwood, eastern	0.344	0.420	0.875	0.292	0.043	0.018
Mahogany, African	0.297	0.641	0.604	0.264	0.033	0.032
Mahogany, Honduras	0.314	0.533	0.600	0.326	0.033	0.034
Maple, sugar	0.424	0.476	0.774	0.349	0.065	0.037
Maple, red	0.434	0.509	0.762	0.354	0.063	0.044
Oak, red	0.350	0.448	0.560	0.292	0.064	0.033
Oak, white	0.369	0.428	0.618	0.300	0.074	0.036
Sweet gum	0.325	0.403	0.682	0.309	0.044	0.023
Walnut, black	0.495	0.632	0.718	0.378	0.052	0.035
Yellow-poplar	0.318	0.392	0.703	0.329	0.030	0.019
Softwoods						
Baldcypress	0.338	0.326	0.411	0.356	—	—
Cedar, northern white	0.337	0.340	0.458	0.345	—	—
Cedar, western red	0.378	0.296	0.484	0.403	—	—
Douglas-fir	0.292	0.449	0.390	0.374	0.036	0.029
Fir, subalpine	0.341	0.332	0.437	0.336	—	—
Hemlock, western	0.485	0.423	0.442	0.382	—	—
Larch, western	0.355	0.276	0.389	0.352	—	—
Pine						
Loblolly	0.328	0.292	0.382	0.362	—	—
Lodgepole	0.316	0.347	0.469	0.381	—	—
Longleaf	0.332	0.365	0.384	0.342	—	—
Pond	0.280	0.364	0.389	0.320	—	—
Ponderosa	0.337	0.400	0.426	0.359	—	—
Red	0.347	0.315	0.408	0.308	—	—
Slash	0.392	0.444	0.447	0.387	—	—
Sugar	0.356	0.349	0.428	0.358	—	—
Western white	0.329	0.344	0.410	0.334	—	—
Redwood	0.360	0.346	0.373	0.400	—	—
Spruce, Sitka	0.372	0.467	0.435	0.245	0.040	0.025
Spruce, Engelmann	0.422	0.462	0.530	0.255	0.083	0.058

Species	E_T/E_L	E_R/E_L	G_{LR}/E_L	G_{LT}/E_L	G_{RT}/E_L
Hardwoods					
Ash, white	0.080	0.125	0.109	0.077	—
Balsa	0.015	0.046	0.054	0.037	0.005
Basswood	0.027	0.066	0.056	0.046	—
Birch, yellow	0.050	0.078	0.074	0.068	0.017
Cherry, black	0.086	0.197	0.147	0.097	—
Cottonwood, eastern	0.047	0.083	0.076	0.052	—
Mahogany, African	0.050	0.111	0.088	0.059	0.021
Mahogany, Honduras	0.064	0.107	0.066	0.086	0.028
Maple, sugar	0.065	0.132	0.111	0.063	—
Maple, red	0.067	0.140	0.133	0.074	—
Oak, red	0.082	0.154	0.089	0.081	—
Oak, white	0.072	0.163	0.086	—	—
Sweet gum	0.050	0.115	0.089	0.061	0.021
Walnut, black	0.056	0.106	0.085	0.062	0.021
Yellow-poplar	0.043	0.092	0.075	0.069	0.011
Softwoods					
Baldcypress	0.039	0.084	0.063	0.054	0.007
Cedar, northern white	0.081	0.183	0.210	0.187	0.015
Cedar, western red	0.055	0.081	0.087	0.086	0.005
Douglas-fir	0.050	0.068	0.064	0.078	0.007
Fir, subalpine	0.039	0.102	0.070	0.058	0.006
Hemlock, western	0.031	0.058	0.038	0.032	0.003
Larch, western	0.065	0.079	0.063	0.069	0.007
Pine					
Loblolly	0.078	0.113	0.082	0.081	0.013
Lodgepole	0.068	0.102	0.049	0.046	0.005
Longleaf	0.055	0.102	0.071	0.060	0.012
Pond	0.041	0.071	0.050	0.045	0.009
Ponderosa	0.083	0.122	0.138	0.115	0.017
Red	0.044	0.088	0.096	0.081	0.011
Slash	0.045	0.074	0.055	0.053	0.010
Sugar	0.087	0.131	0.124	0.113	0.019
Western white	0.038	0.078	0.052	0.048	0.005
Redwood	0.089	0.087	0.066	0.077	0.011
Spruce, Sitka	0.043	0.078	0.064	0.061	0.003
Spruce, Engelmann	0.059	0.128	0.124	0.120	0.010

Senalik C A, Farber B. 2021. Chapter 5. Mechanical properties of wood. Wood Handbook: wood as an engineering material. Forest Products Laboratory. USDA. US

4) Life Cycle Assessment (LCA)

Resource efficiency in construction

"Greenhouse gas emissions from **material extraction**, manufacturing of construction products, as well as construction and renovation of buildings are estimated at 5-12% of total national GHG emissions. **Greater material efficiency could save 80% of those emissions**." (European Commission 2023)

Timber buildings as carbon sinks

"**Mid-rise urban buildings** designed with engineered timber can provide **long-term storage of carbon** and avoid the carbon-intensive production of mineral-based construction materials" (Churkina et al., 2020)

How to consider the resource efficiency (raw material) in carbon storage of timber buildings?

More efficiency in the structural design (less m^3 wood /m^2 built) could result in less carbon stored in buildings

European_Commission (6th Dec. 2023). Single market and standards. Industry. Sustainability. Buildings and construction.

Churkina, Galina, Alan Organschi, Christopher P.O. Reyer, Andrew Ruff, Kira Vinke, Zhu Liu, Barbara K. Reck, T. E. Graedel, and Hans Joachim Schellnhuber. 2020. "Buildings as a Global Carbon Sink." *Nature Sustainability*. Nature Research. https://doi.org/10.1038/s41893-019-0462-4

Conclusions

1. EU Green Deal for climate neutrality by 2050 is boosting wood construction, with structural components representing the highest wood volume in buildings.

2. Timber components in buildings as a substitute for steel and concrete are expected to increase, yet with a focus on a few main softwood species.

3. Climate change is however affecting the future wood supply of these species.

4. The **identified gaps** to answer the need for more supply of sustainable materials as structural components in the construction sector are:

   4.1. Limited matrix of graded wood species from a few of origins: ➡ Standards need a revision to provide the properties for new species from different EU countries from both bending and tensile testing.

   4.2. No EN standards for grading reclaimed wood or for manufacturing EWPs from reclaimed wood are currently available.

   4.3. No EN standards with isotropic/orthotropic properties and elastic constants for modelling complex structures using finite element modelling (FEM)

   4.4. There is a need for connecting the structural efficiency of timber buildings with the carbon storage potential in buildings. According to the current methodologies, using less raw wood could result in lower carbon storage in buildings.

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Research needs for European species in a scenario of increasing structural wood demand for building

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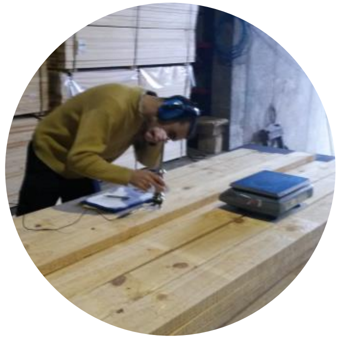
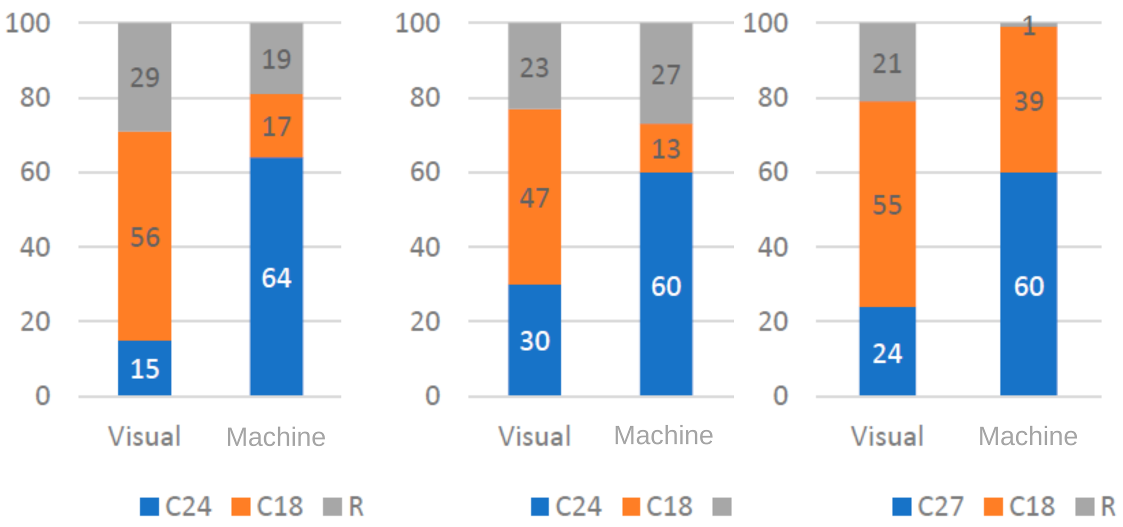
Timber structures
advantages of machine vs. visual grading

Example for softwoods in Spain





(a) Maritime pine (b) Radiata pine (c) Scots pine

Moltini, G.; Íñiguez-González, G.; Cabrera, G.; Baño, V. Evaluation of Yield Improvements in Machine vs. Visual Strength Grading for Softwood Species. Forests **2022**, 13, 2021. https://doi.org/10.3390/f13122021