Transforming trees

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SIRT
Strategic Integrated Research in Timber

Forest Products Research Institute

Structural timber on the scales

Dan Ridley-Ellis

Edinburgh Napier UNIVERSITY


Image : wood for good

Structural engineering design

- About buildings
  - Staying safe
  - Staying fit for use
- Dealing with uncertainty
  - Of material
  - Of the actions on a structure
  - Of analysis and construction
- Irrespective of the material

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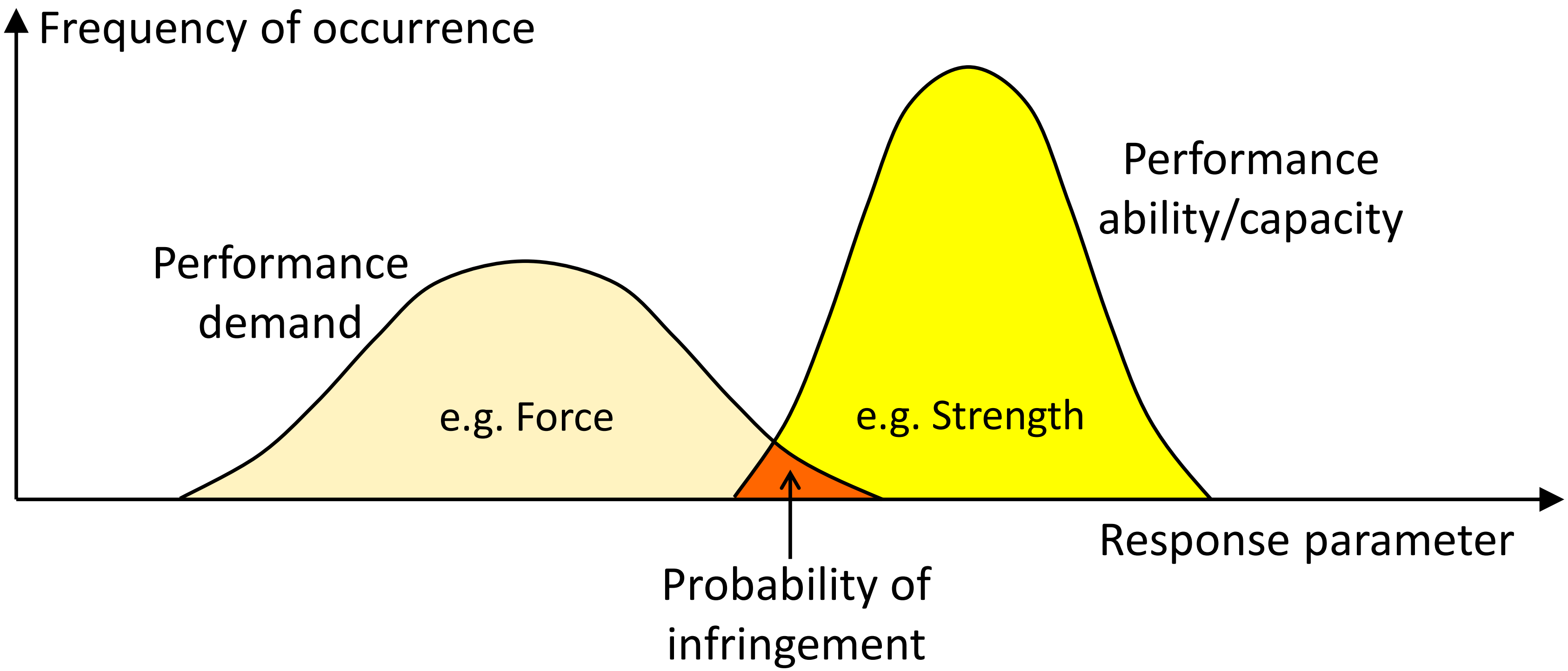
Dealing with uncertainty



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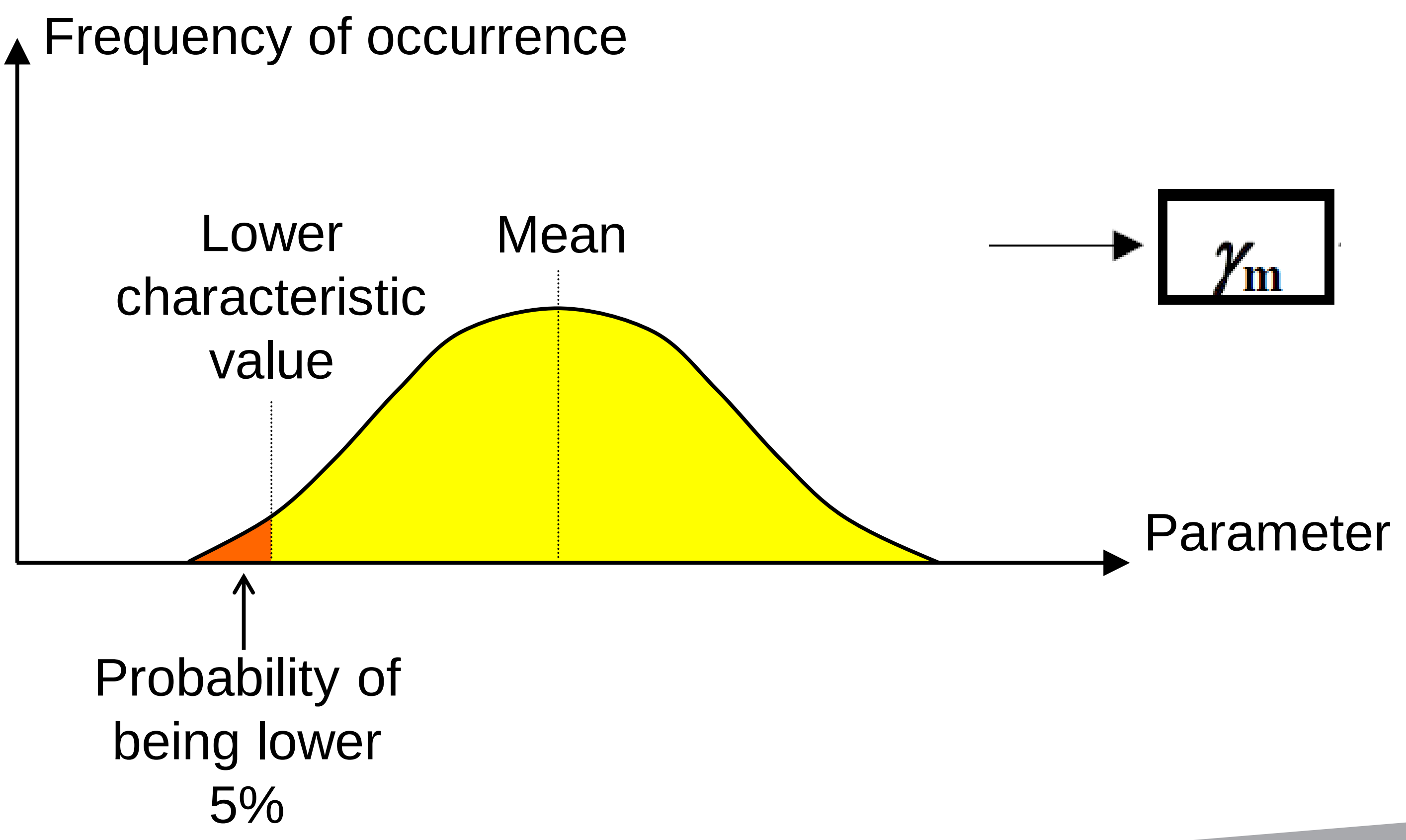
Characteristic values



EN 338

		Softwood species											
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties (in N/mm^2)													
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	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
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2
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/mm^2)													
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16
5 % modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7
Mean modulus of elasticity perpendicular	$E_{90,mean}$	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	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00
Density (in kg/m^3)													
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460
Mean density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550

EN 338

+ drying distortion

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		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
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Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2
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
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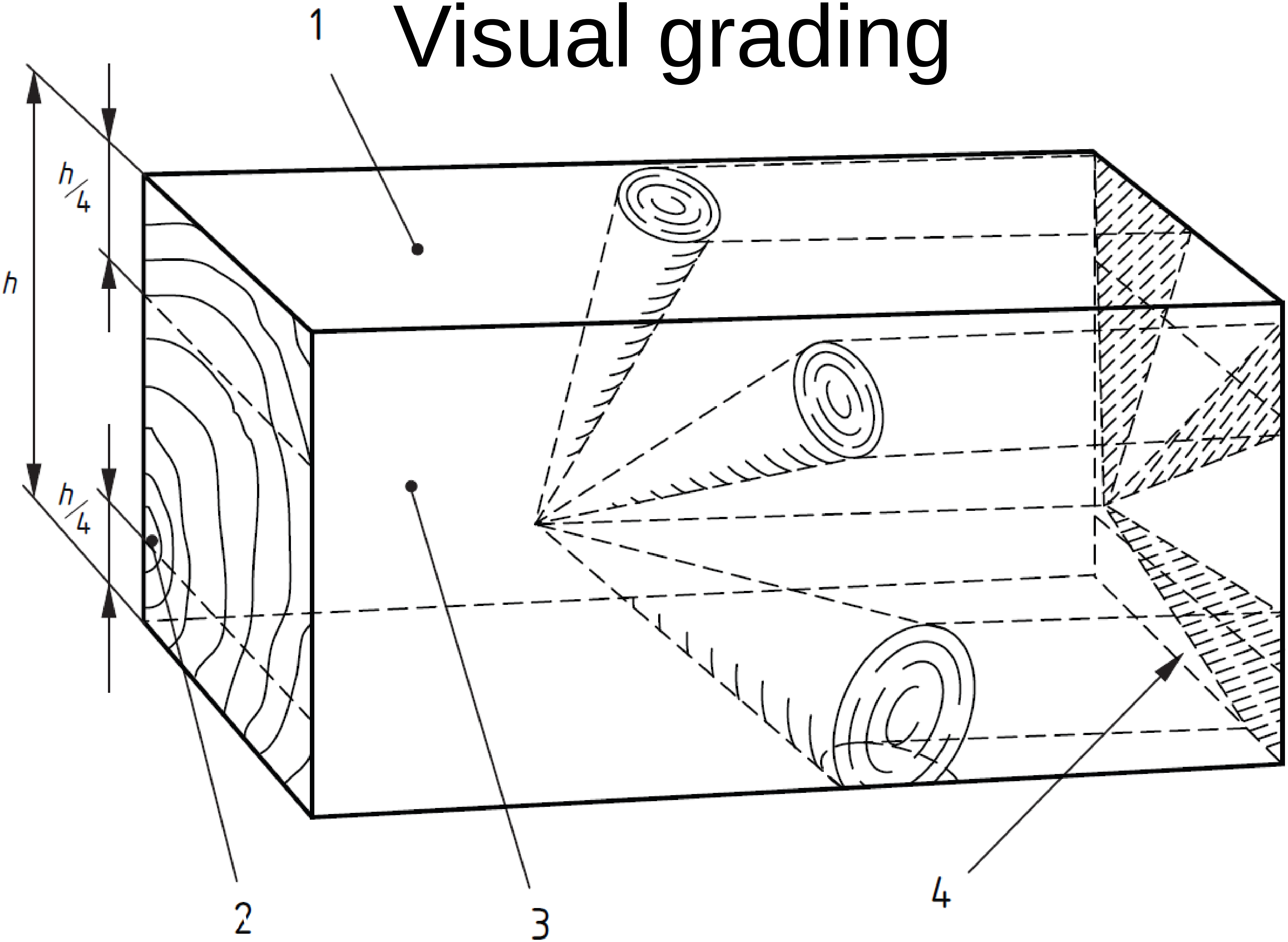
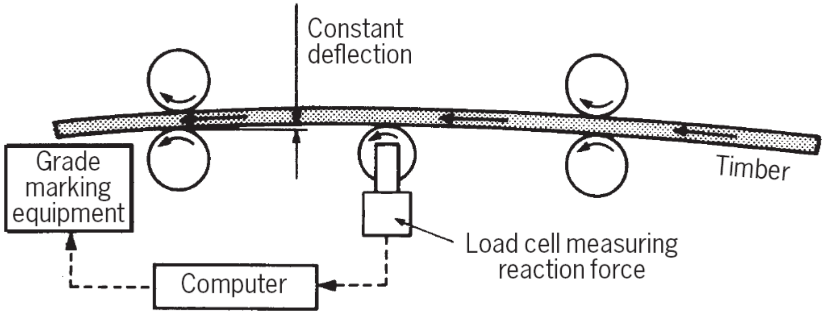
Visual grading

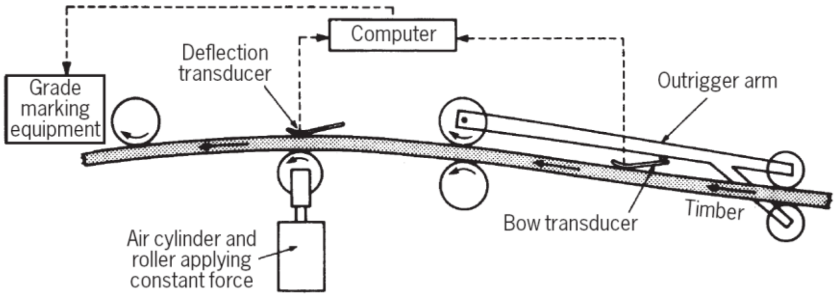


Bending graders

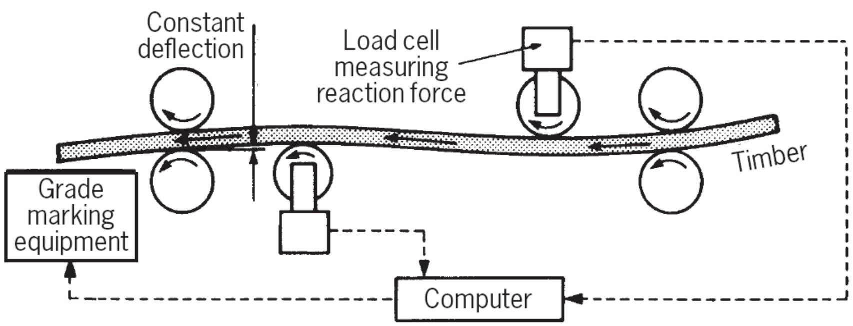
Cook-Bolinder



Computermatic



Timgrader



Figures from BRE Digest 476 “Guide to machine strength grading of timber”

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Acoustic graders

ViSCAN (MiCROTEC)

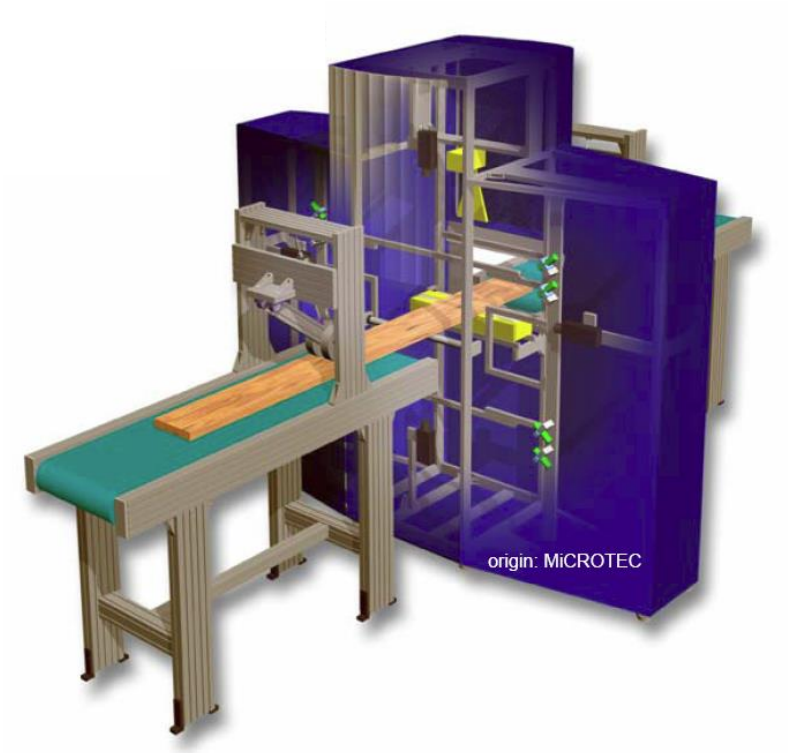
MTG (Brookhuis)

Precigrader (Dynalyse AB)

Triomatic (CBS-CBT)

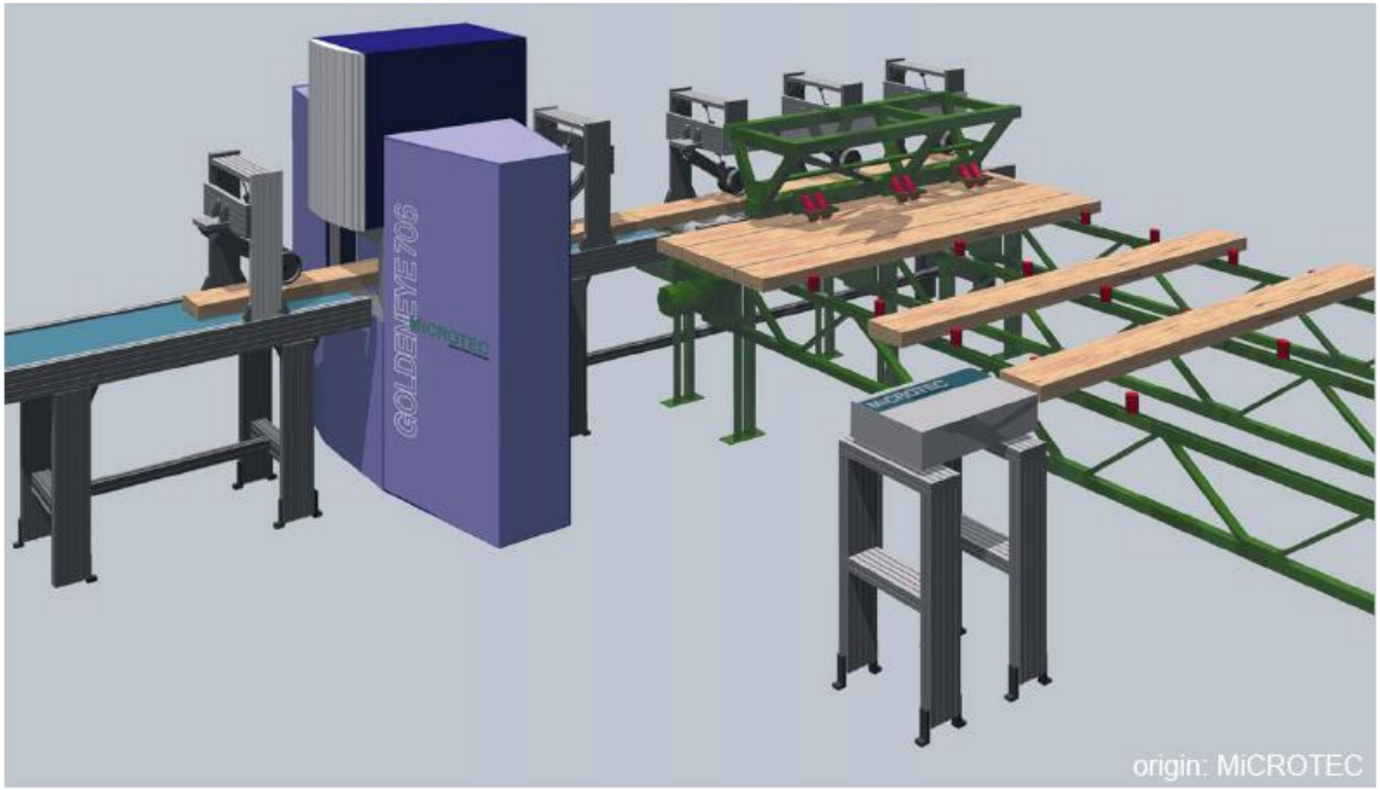
X-ray graders

GOLDENEYE 702 (MiCROTEC)



Combination graders

GOLDENEYE 706 (MiCROTEC)



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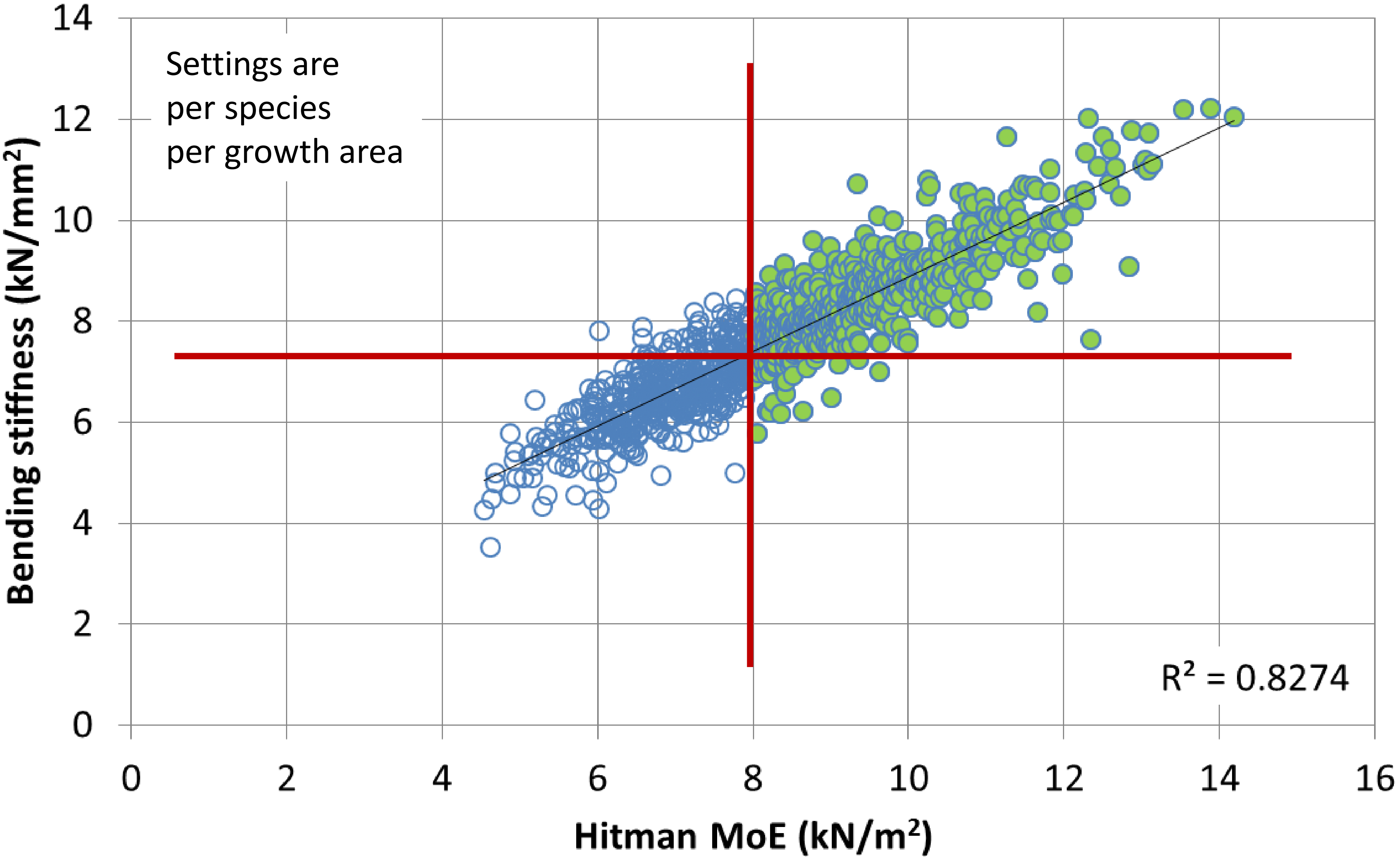
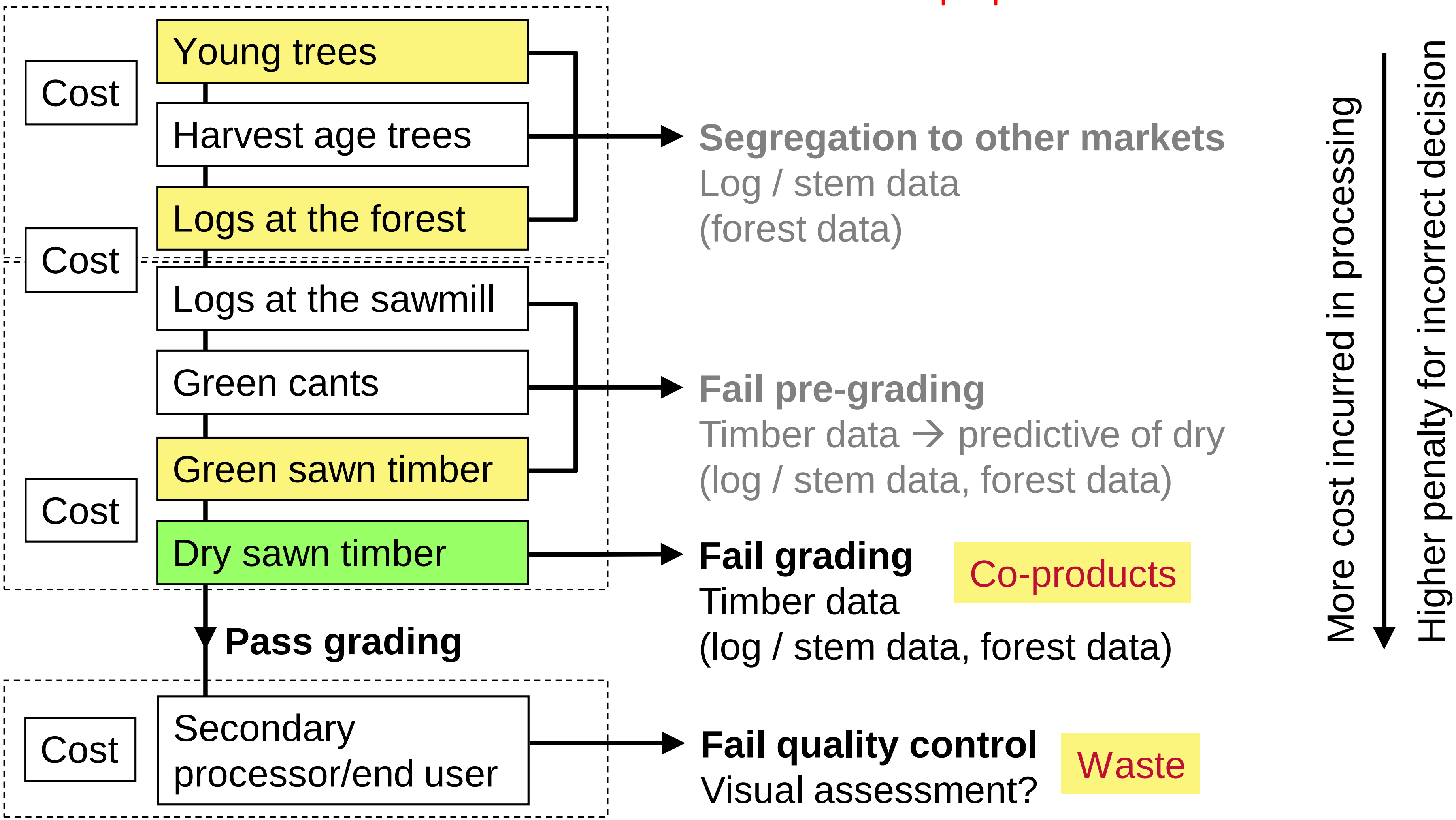
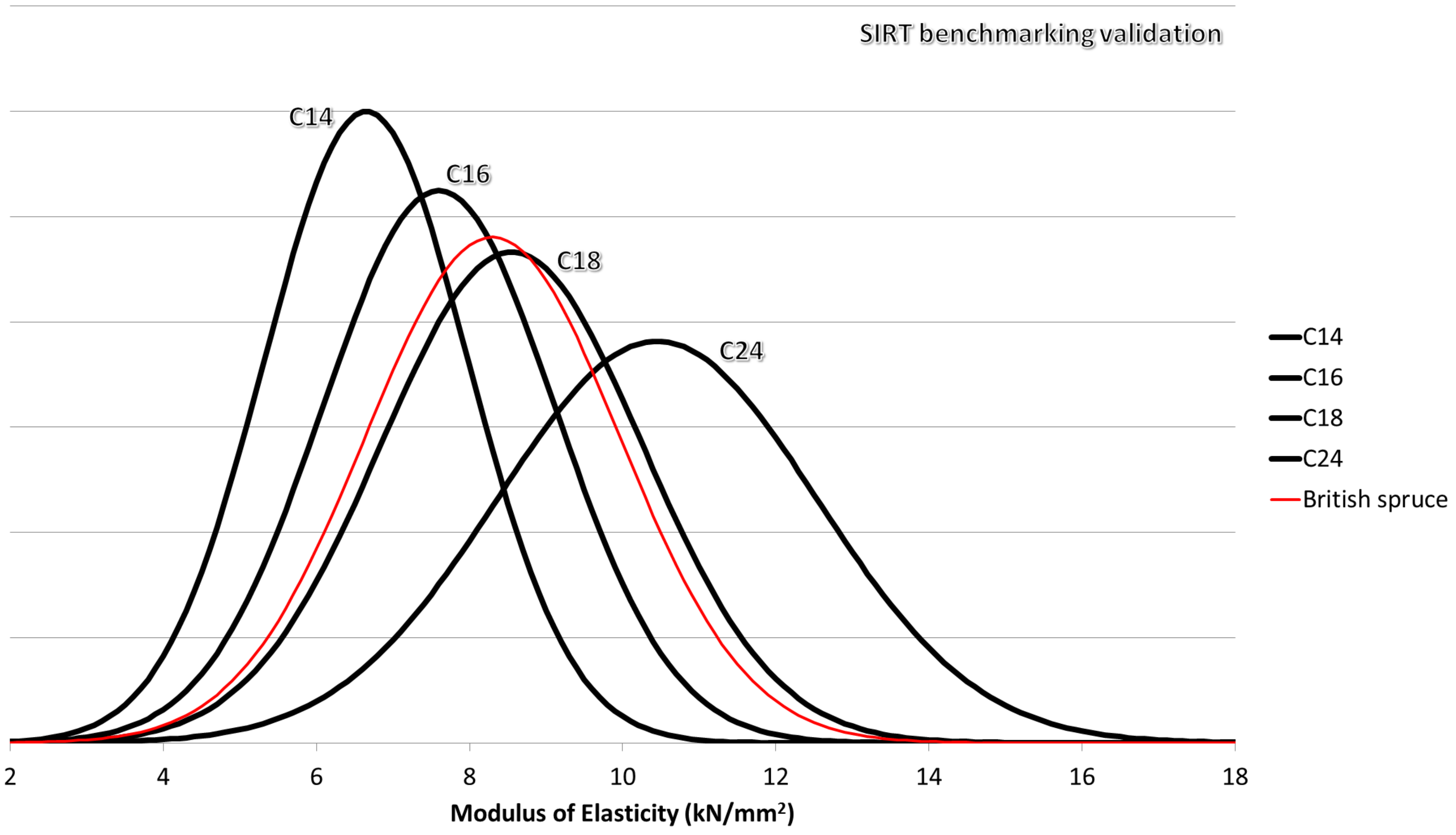

Settings are
per species
per growth area
Bending stiffness (kN/mm²)
Hitman MoE (kN/m²)
R² = 0.8274
0
2
4
6
8
10
12
14
16

Grading and segregation

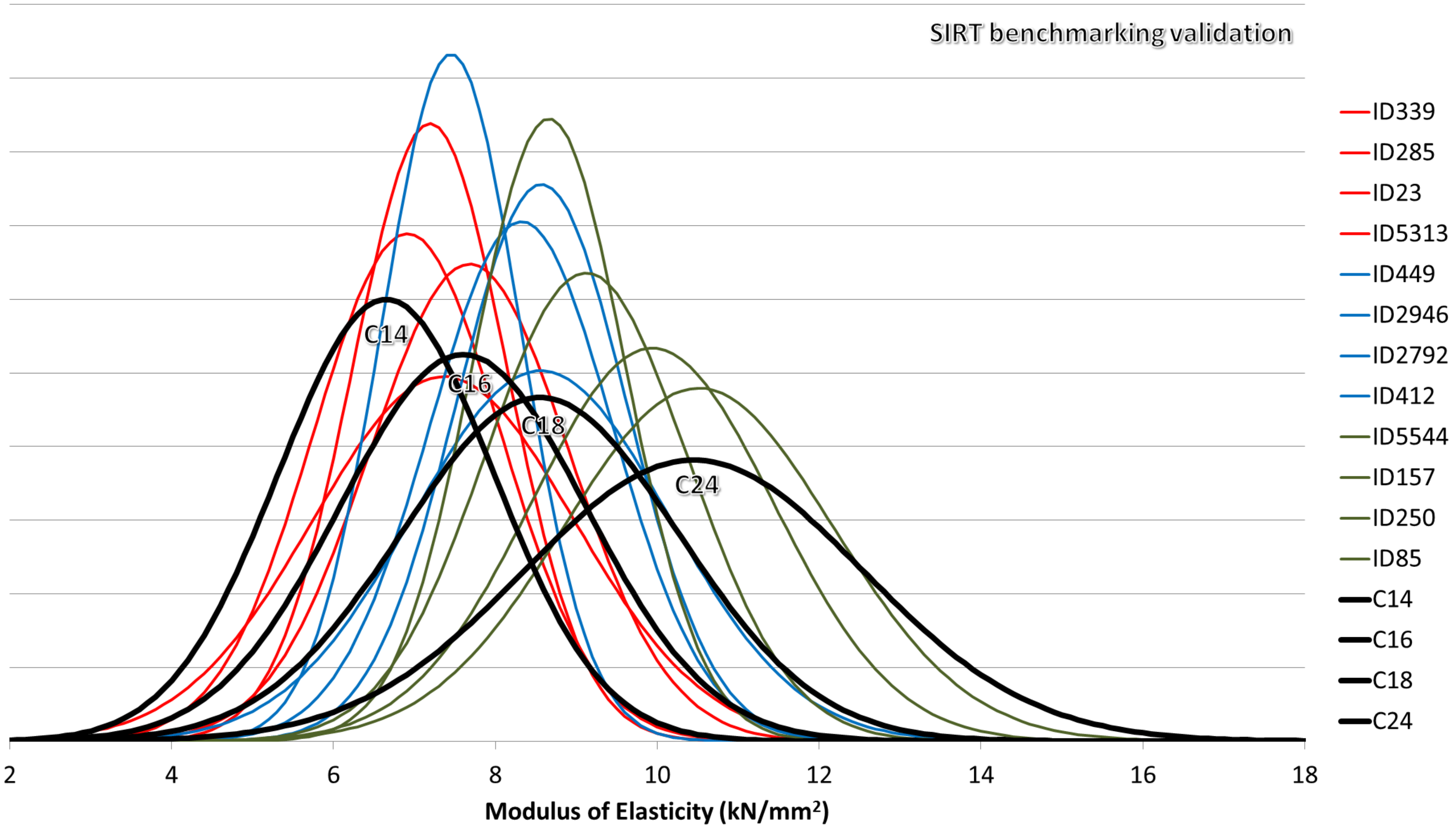
Mechanical properties & distortion



Variation within the resource



Quality shifts in production



Sources of the variation

Source	Density	Strength	Stiffness
Between sites	23%	18%	26%
Between trees on a site	51%	25%	36%
Between logs in a tree	2%	5%	2%
Within log	25%	52%	35%

Moore, J. R., Lyon, A. J., Searles, G. J., Lehneke, S. A., Ridley-Ellis, D. J. Within- and between-stand variation in selected properties of Sitka spruce sawn timber in the United Kingdom: implications for segregation and grade recovery. Annals of Forest Science (in press)

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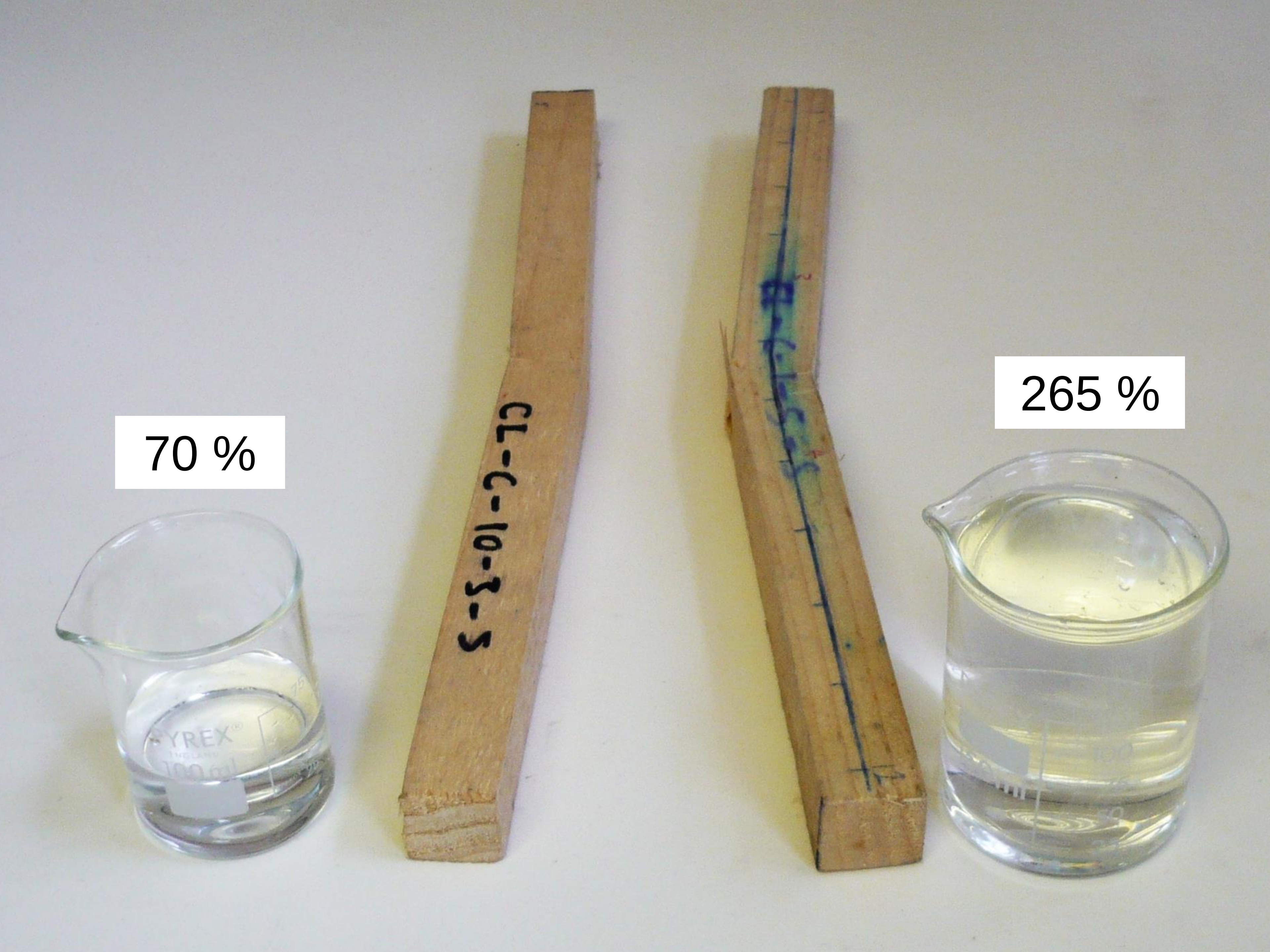
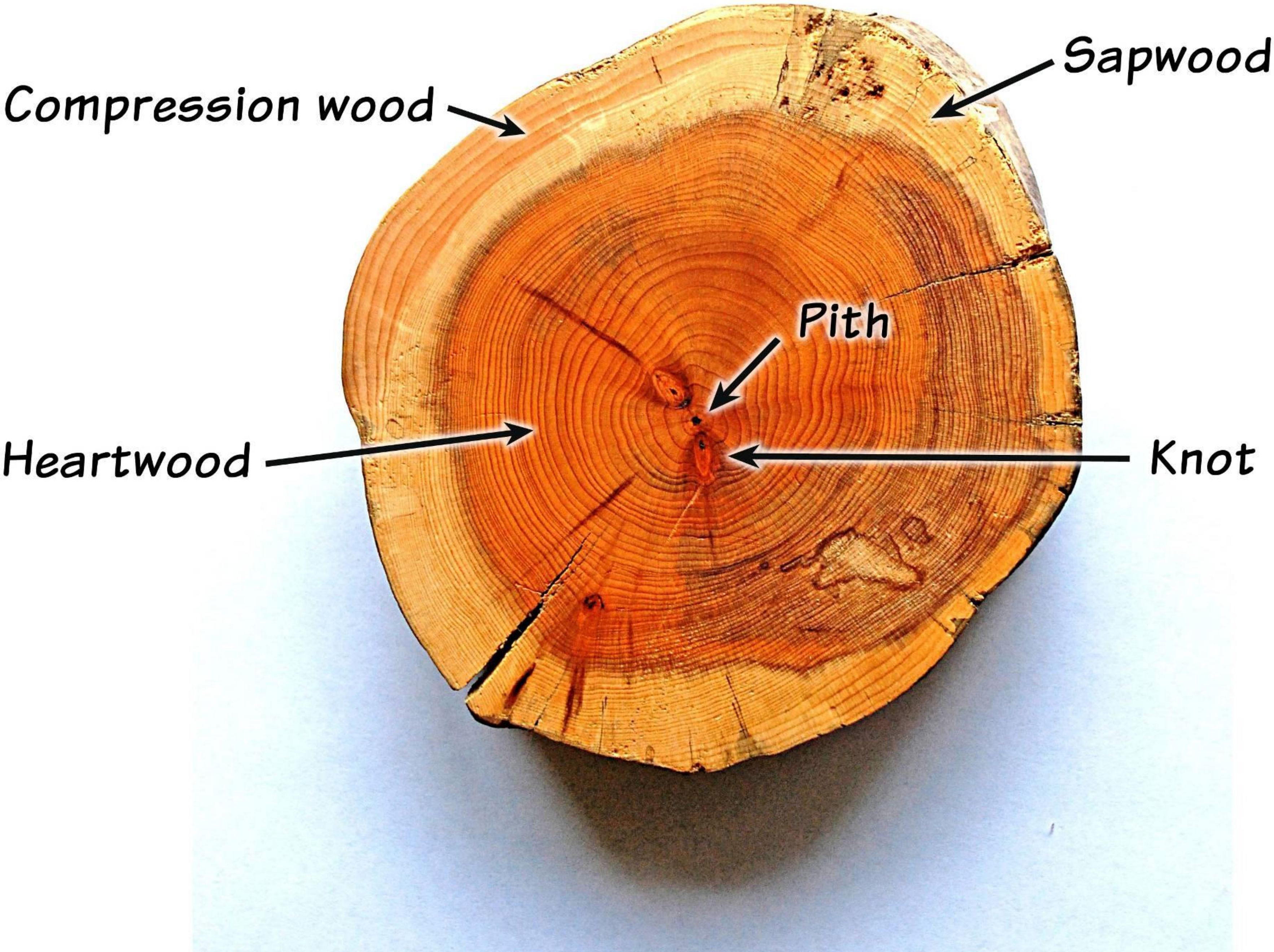
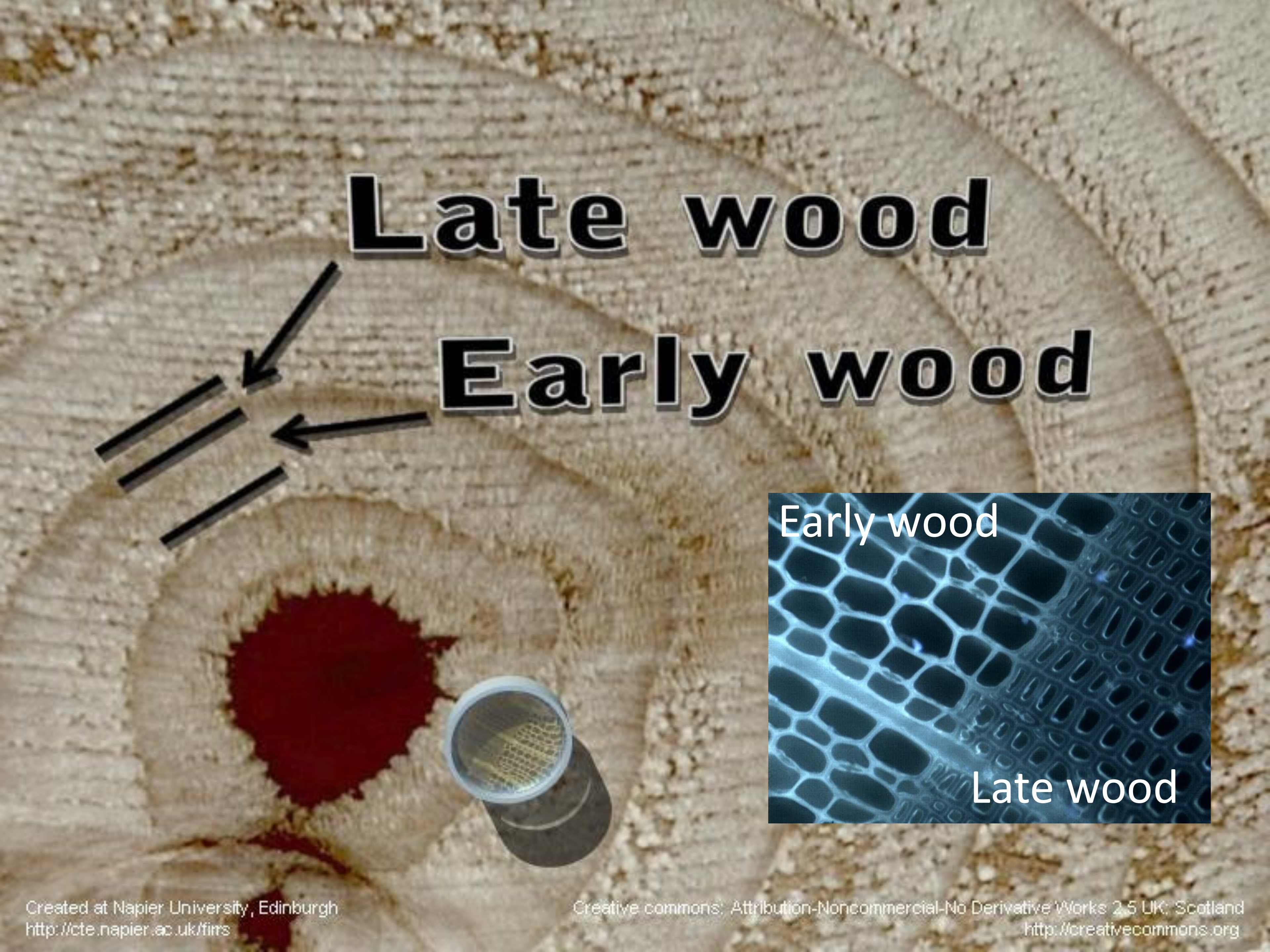
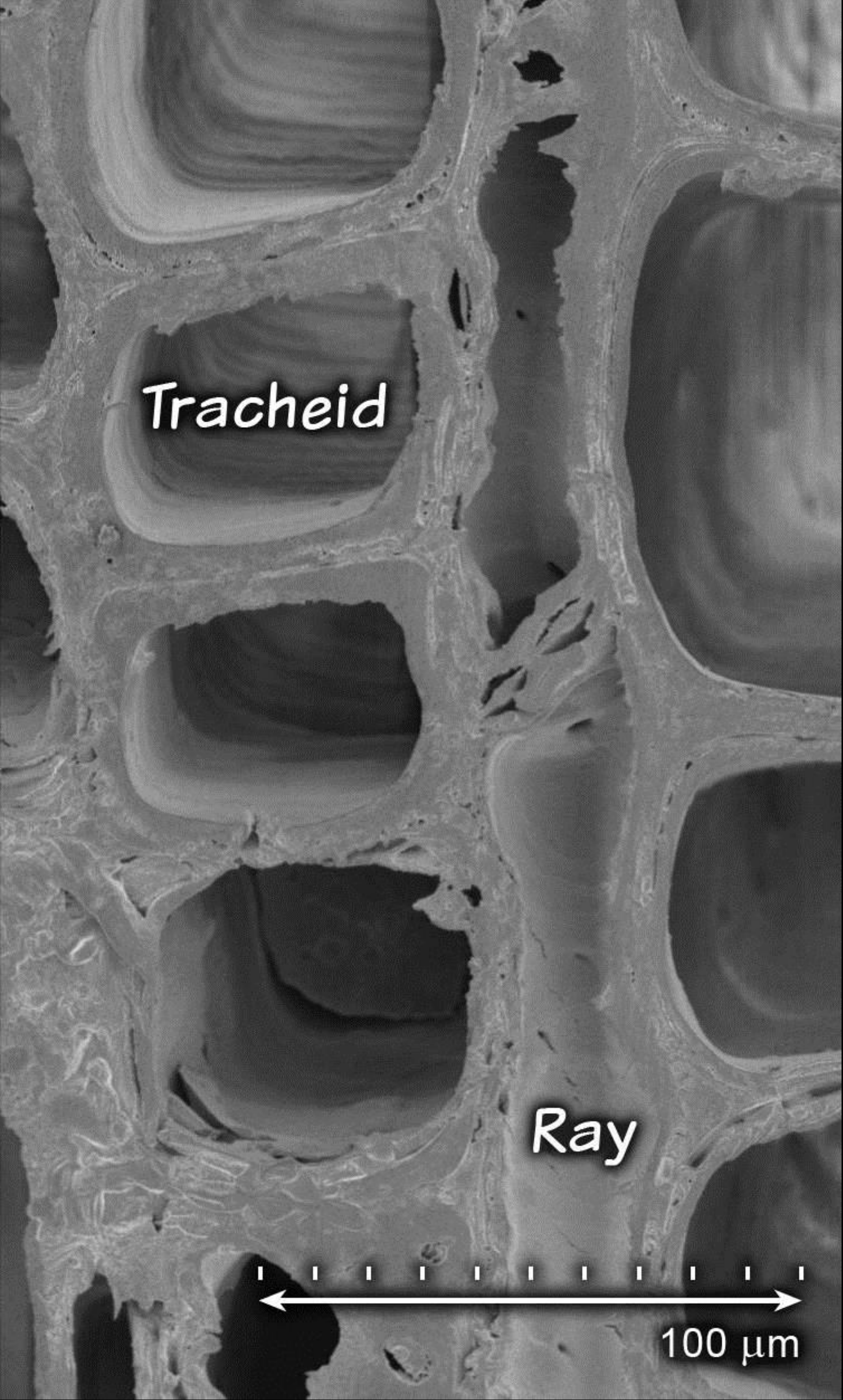
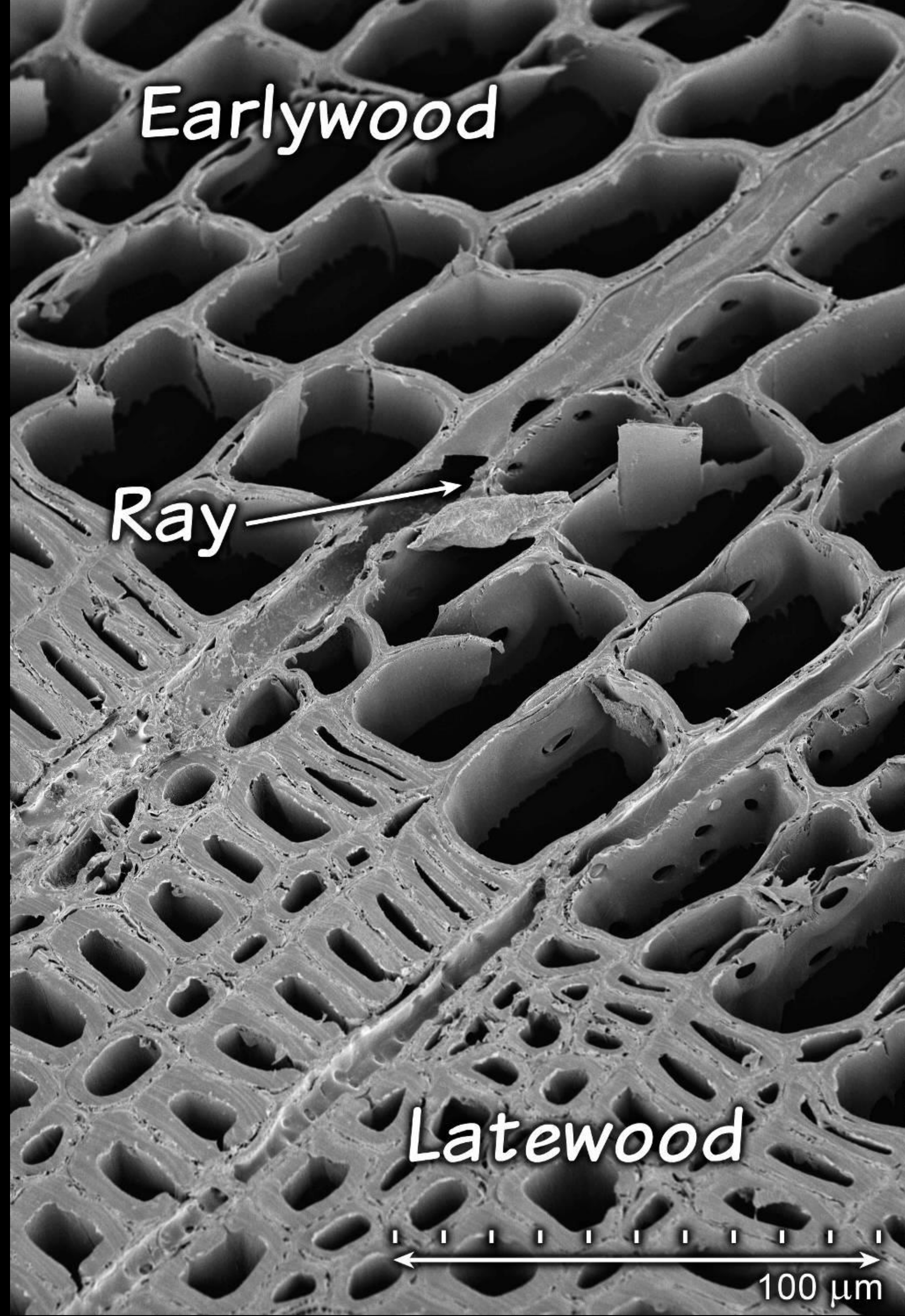

70 %
265 %


Compression wood
Sapwood
Pith
Heartwood
Knot

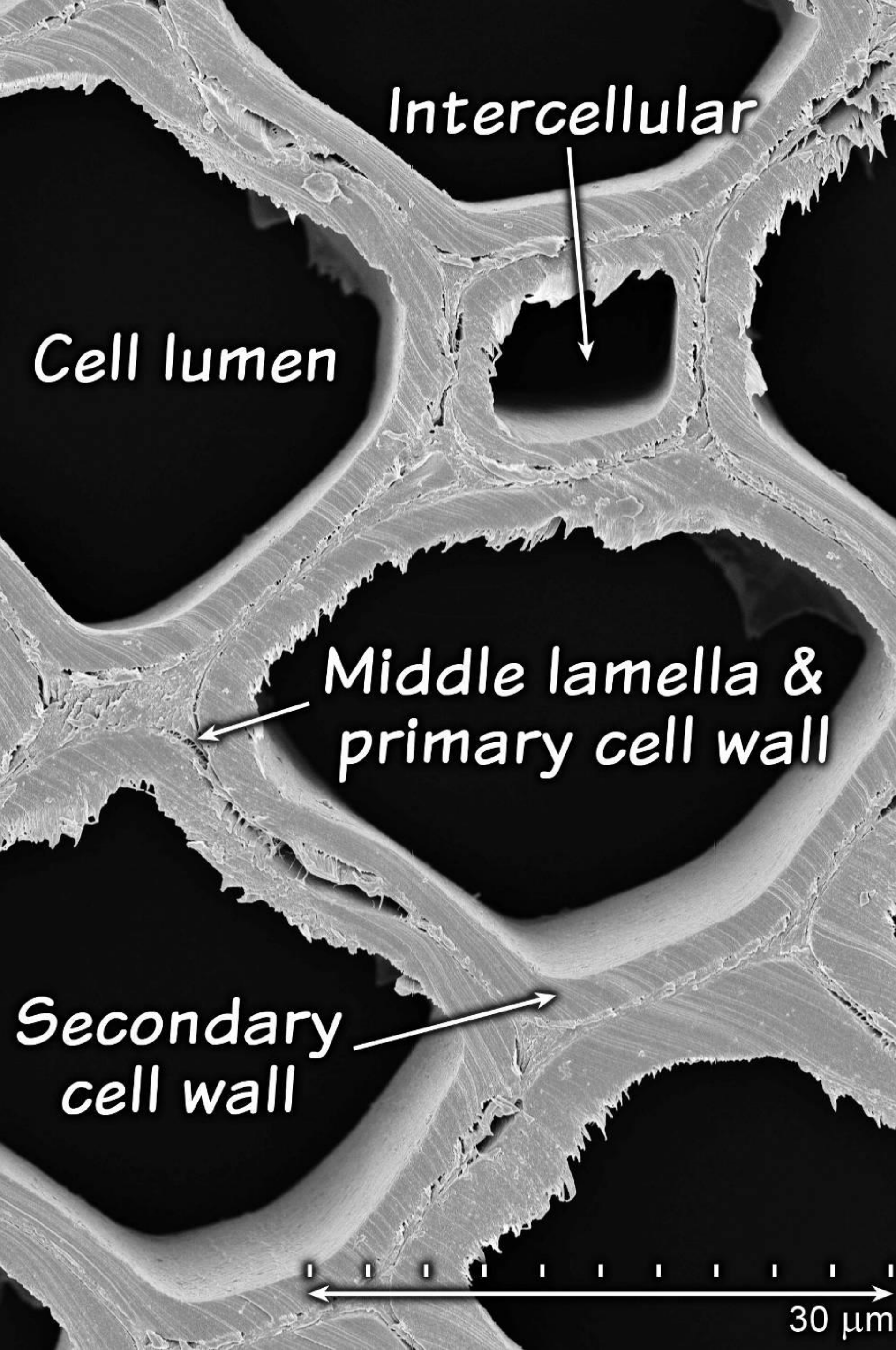

Late wood
Early wood
Created at Napier University, Edinburgh
http://cte.napier.ac.uk/firs
Creative commons: Attribution-Noncommercial-No Derivative Works 2.5 UK: Scotland
http://creativecommons.org
Early wood
Late wood

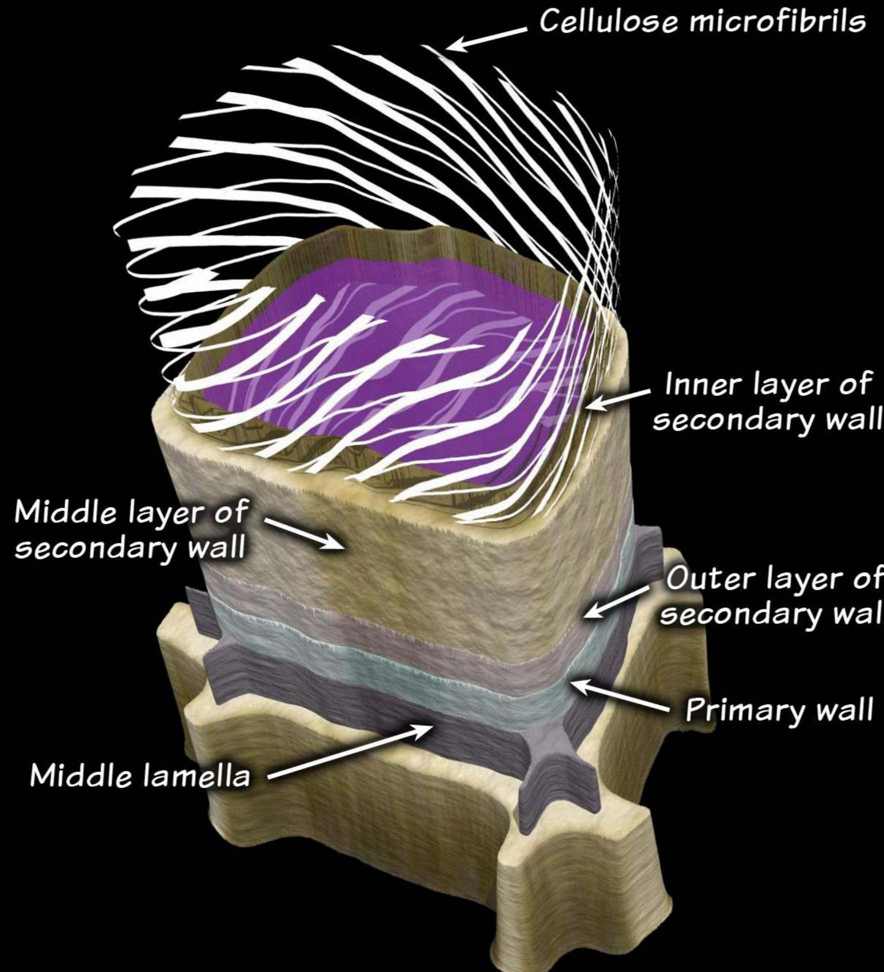


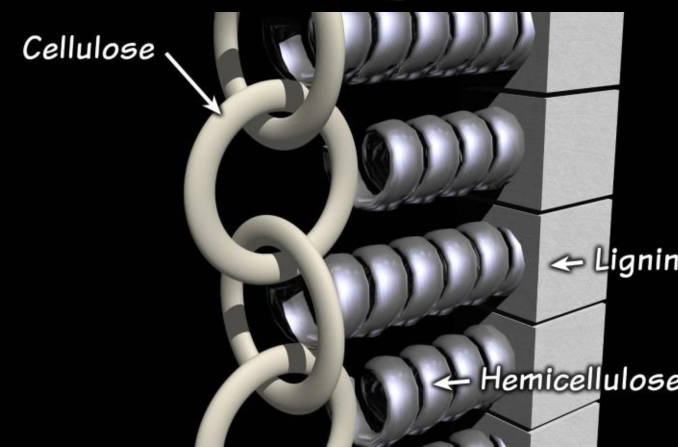
Tracheid
Ray
100 µm



Earlywood
Ray
Latewood
100 µm

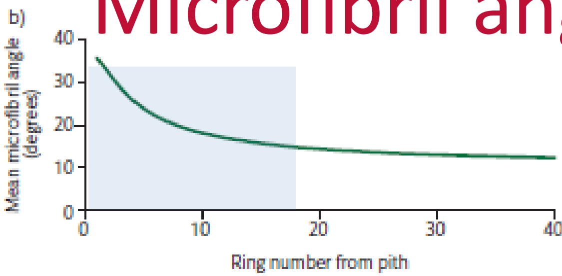

Intercellular
Cell lumen
Middle lamella &
primary cell wall
Secondary
cell wall
30 µm


Cellulose microfibrils
Inner layer of
secondary wall
Middle layer of
secondary wall
Outer layer of
secondary wall
Primary wall
Middle lamella


Cellulose
Lignin
Hemicellulose

Juvenile core

Microfibril angle



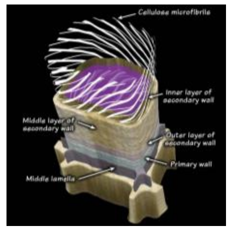


Figure 2.20 Example of the radial variation in modulus of elasticity for two specimens of Sitka spruce wood. Modulus of elasticity was estimated from data on density and microfibril angle obtained from SilviScan-3.

Stiffness, *E*

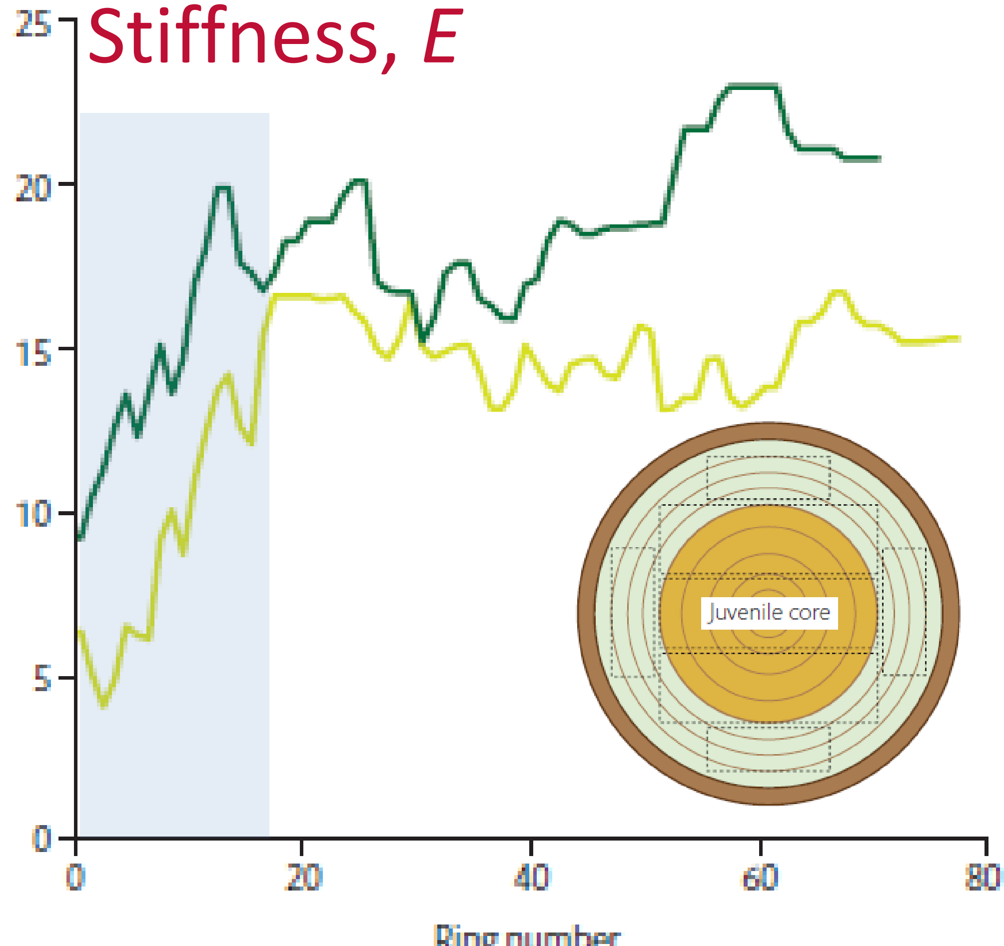
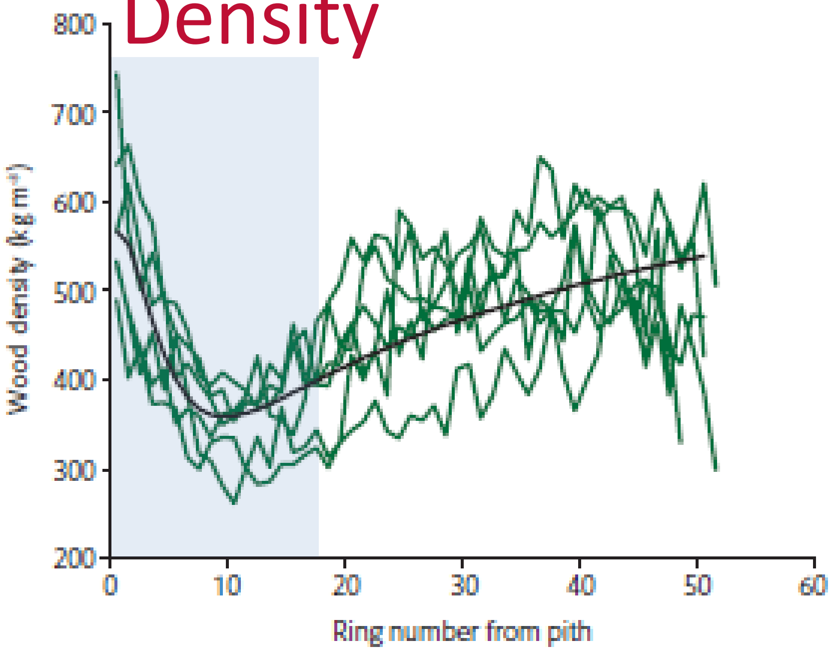


Figure 2.15 Radial profile of Sitka spruce wood density. The green lines show profiles for five individual trees sampled at Baronscourt in Northern Ireland, while the black line represents a model fitted to these data.

Density



Mechanical properties

- Amount of cell wall material
  - Wood density
- How that cell wall material is arranged
  - Grain, earlywood, latewood
- How that cell wall material is made up
  - Cellulose : lignin
  - Microfibril angle

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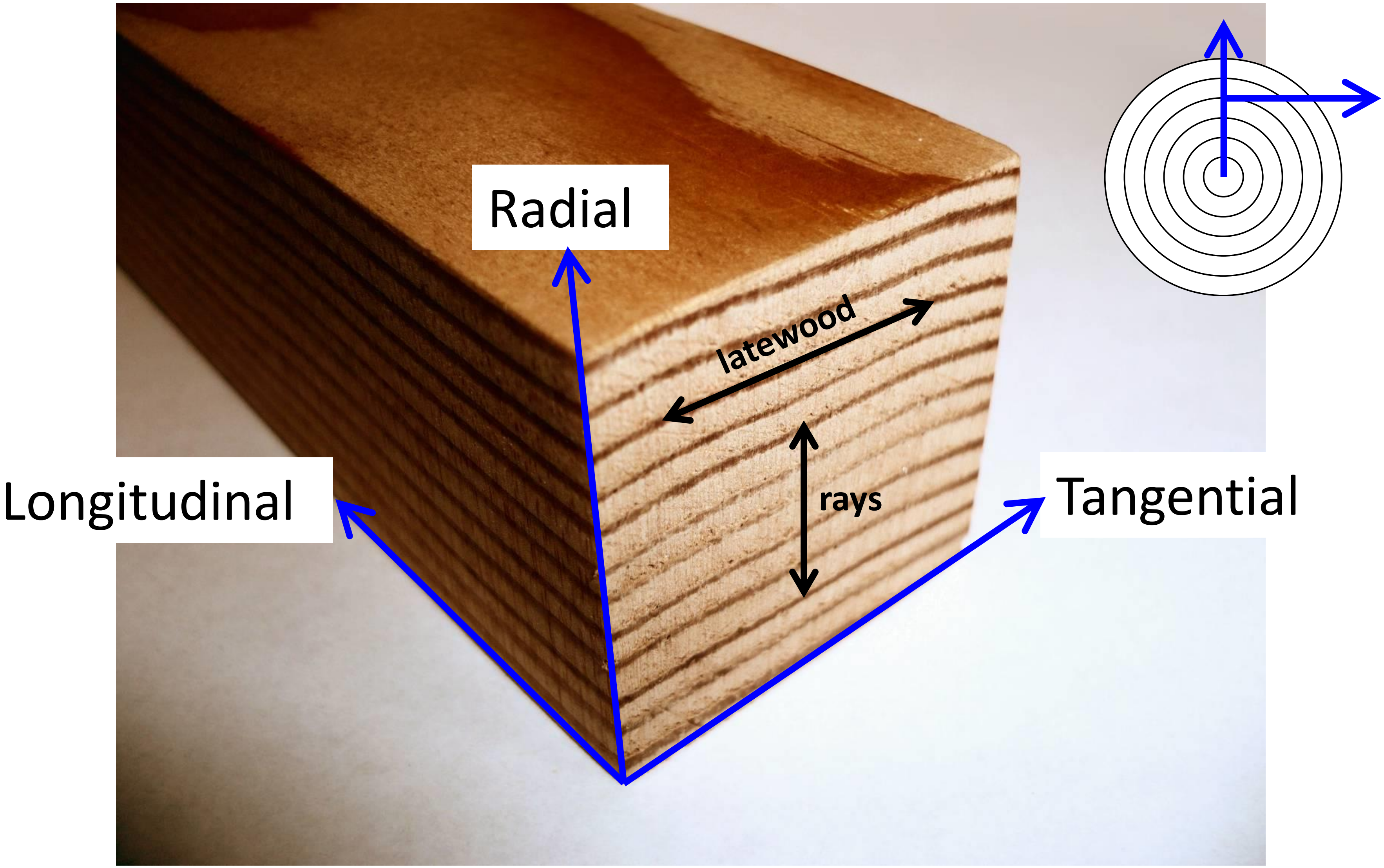
Isotropy



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	Region
km	Forest
	Stand
	Tree
m	Log
	Sawn timber
cm	Clear wood
mm	Growth layer
	Wood anatomy
	Cell
µm	Cell wall
	Cell wall layers
	Microfibril clusters
nm	Molecular

Forest Research
Forestry Commission

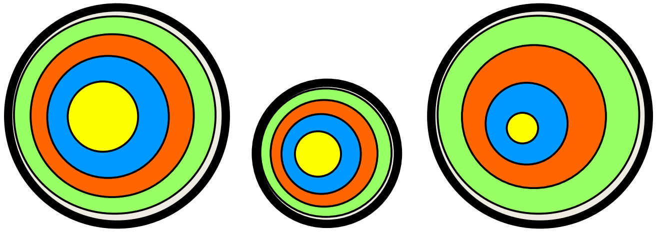
Edinburgh
Napier University

	Building
m	Assembly
	Sawn timber
cm	Details

The University of Glasgow

Factors affecting softwood quality

- Position within the tree
  - Radially & vertically



- Silviculture
  - Spacing, thinning, rotation length etc
- Site
  - Exposure, temperature, rainfall, soil type etc
- Genetics
  - Species, variety and individual

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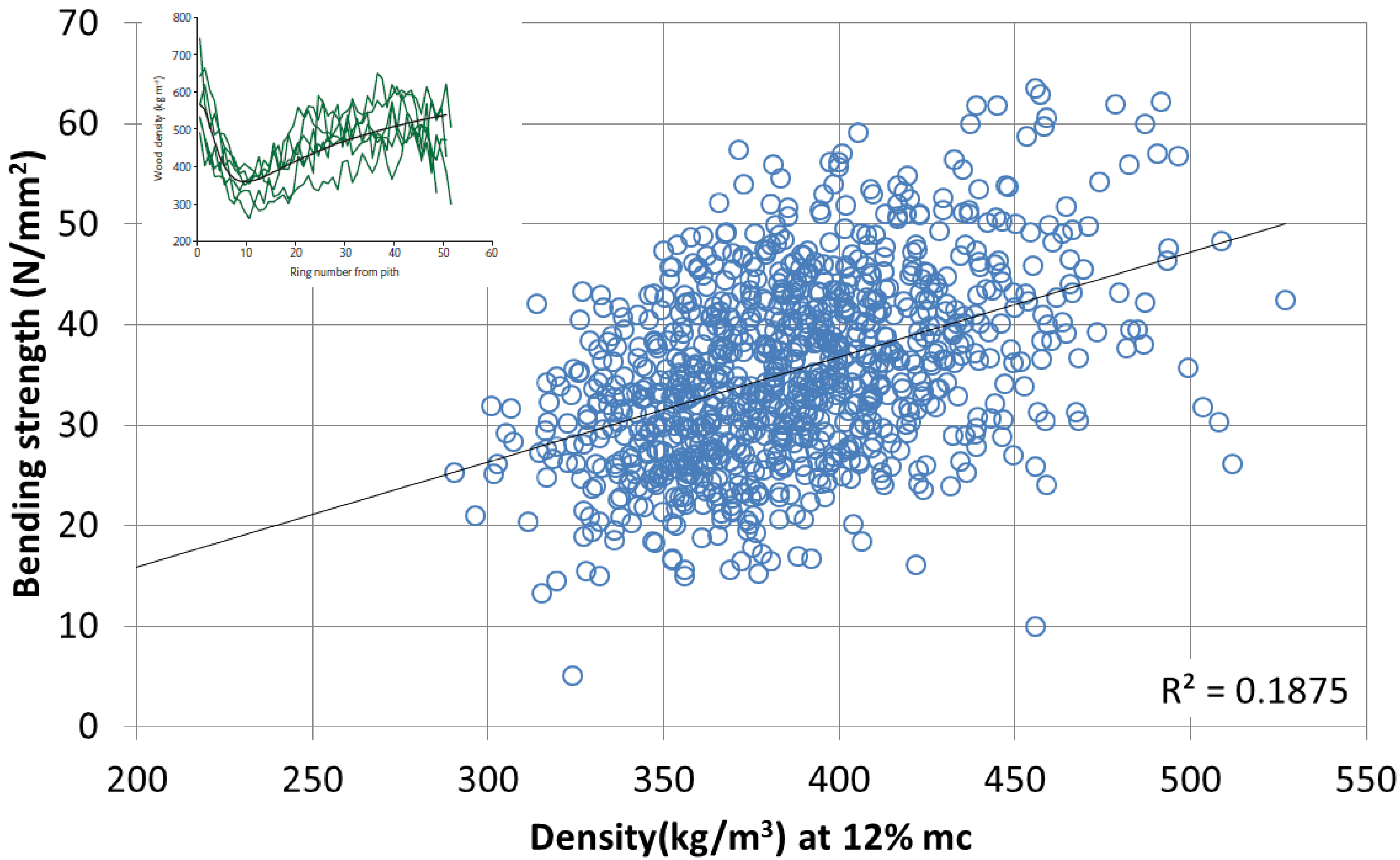
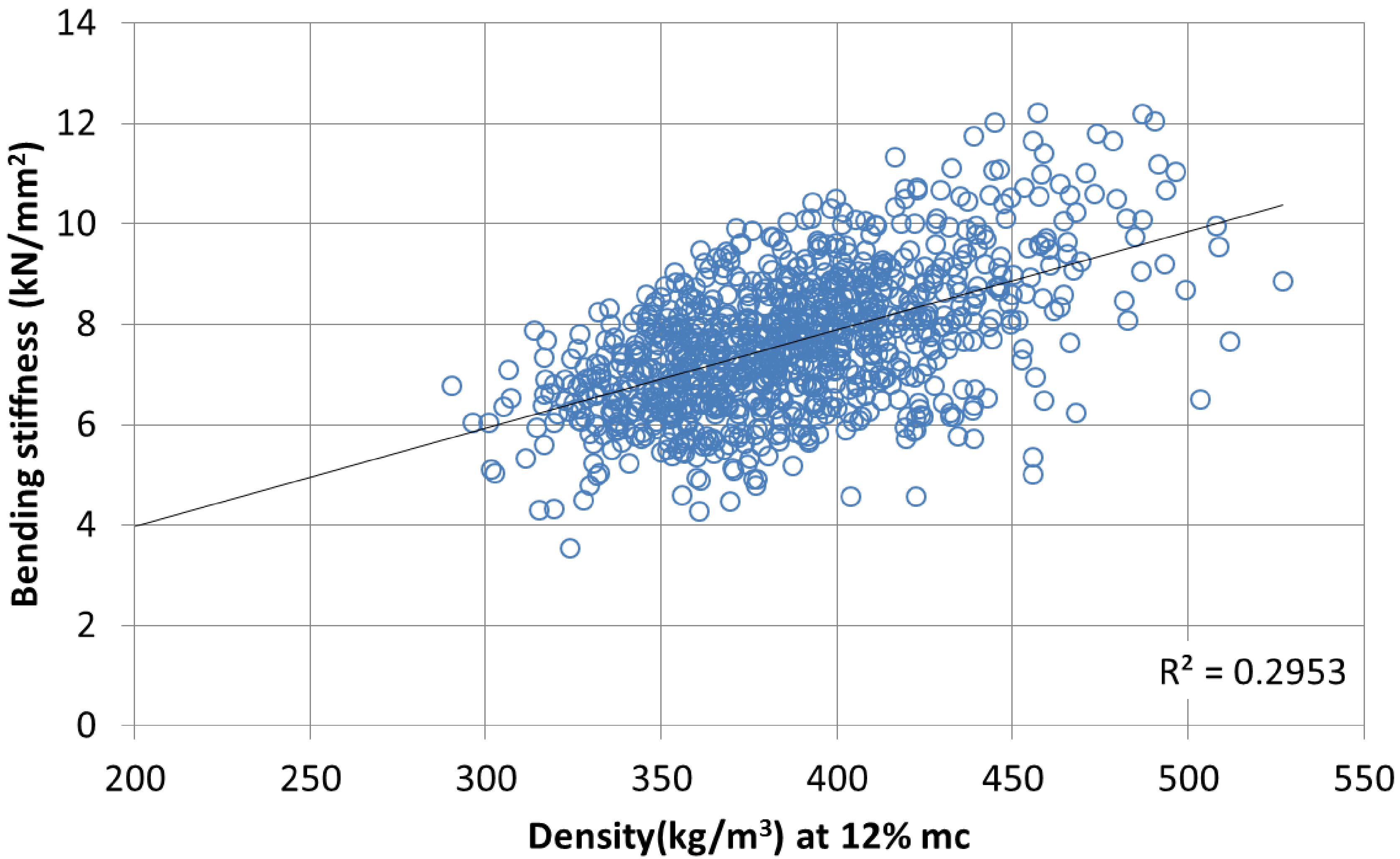
Density and bending strength



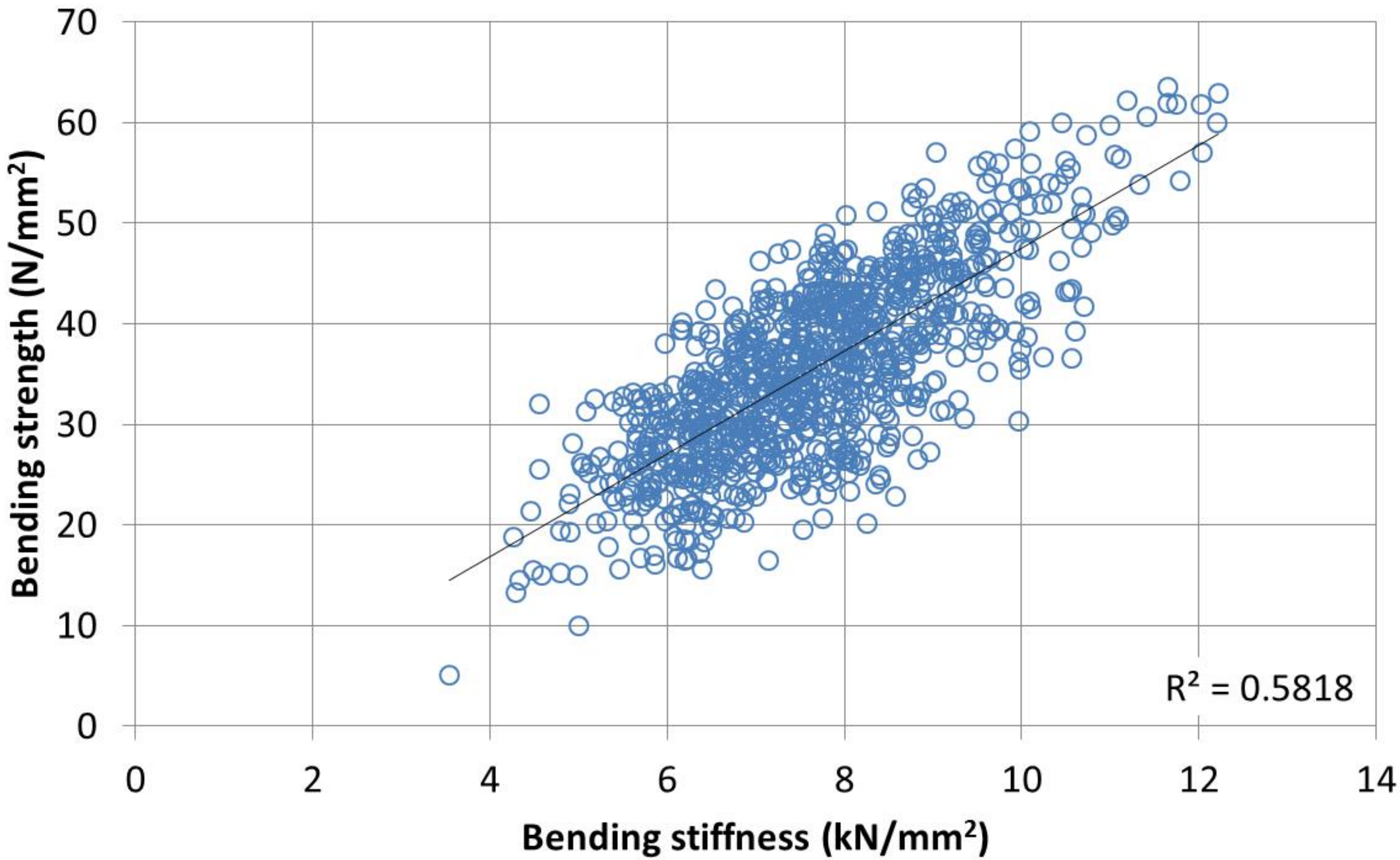
Raw data from SIRT benchmarking validation study

Density and bending stiffness



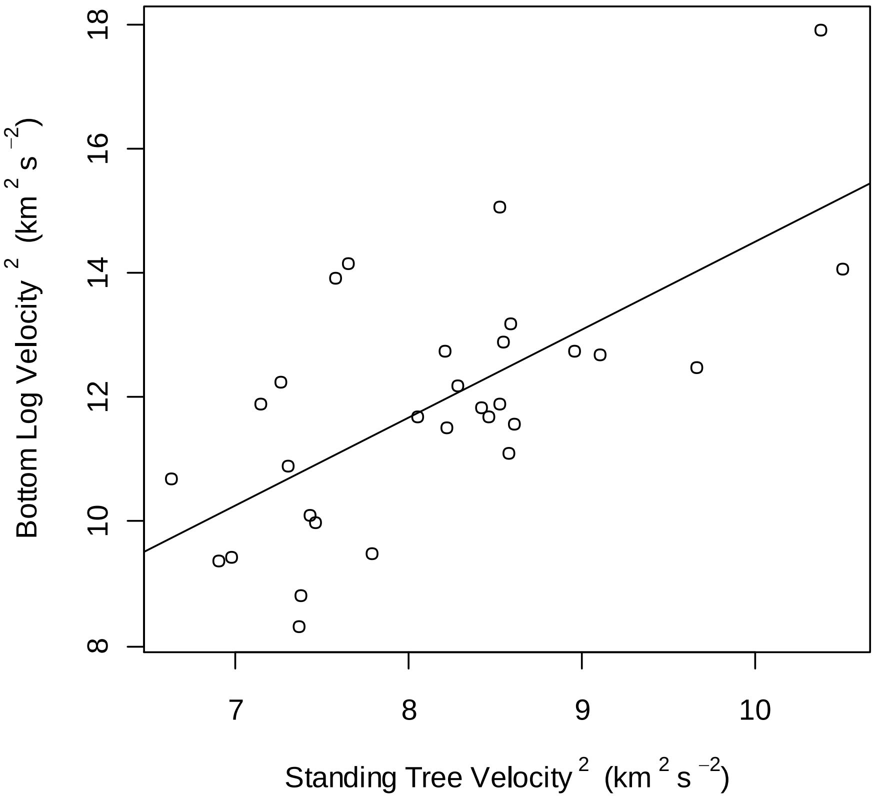
Raw data from SIRT benchmarking validation study

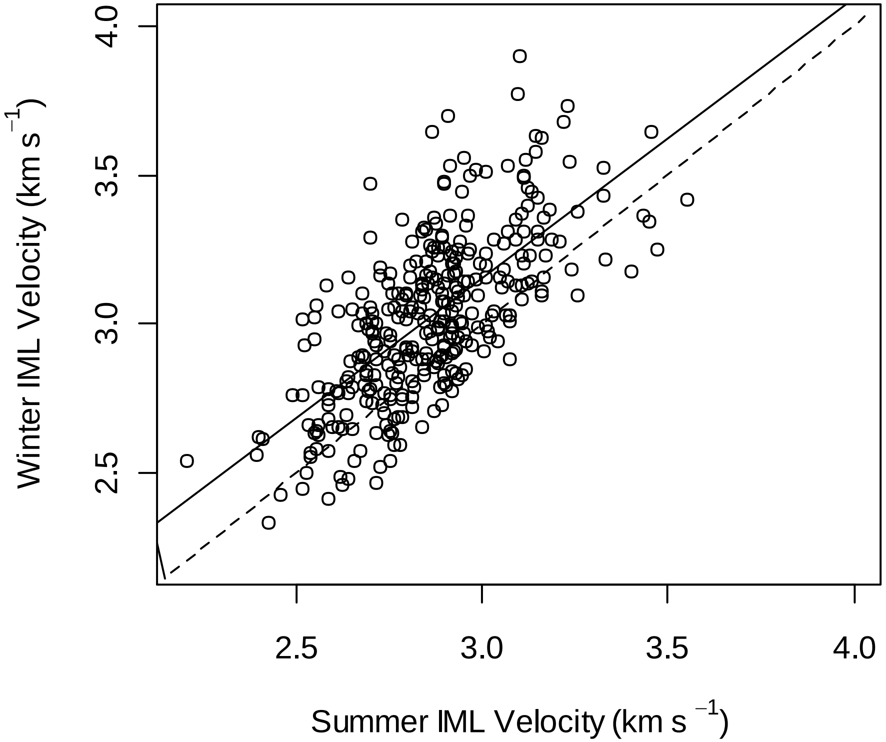
Bending strength and stiffness



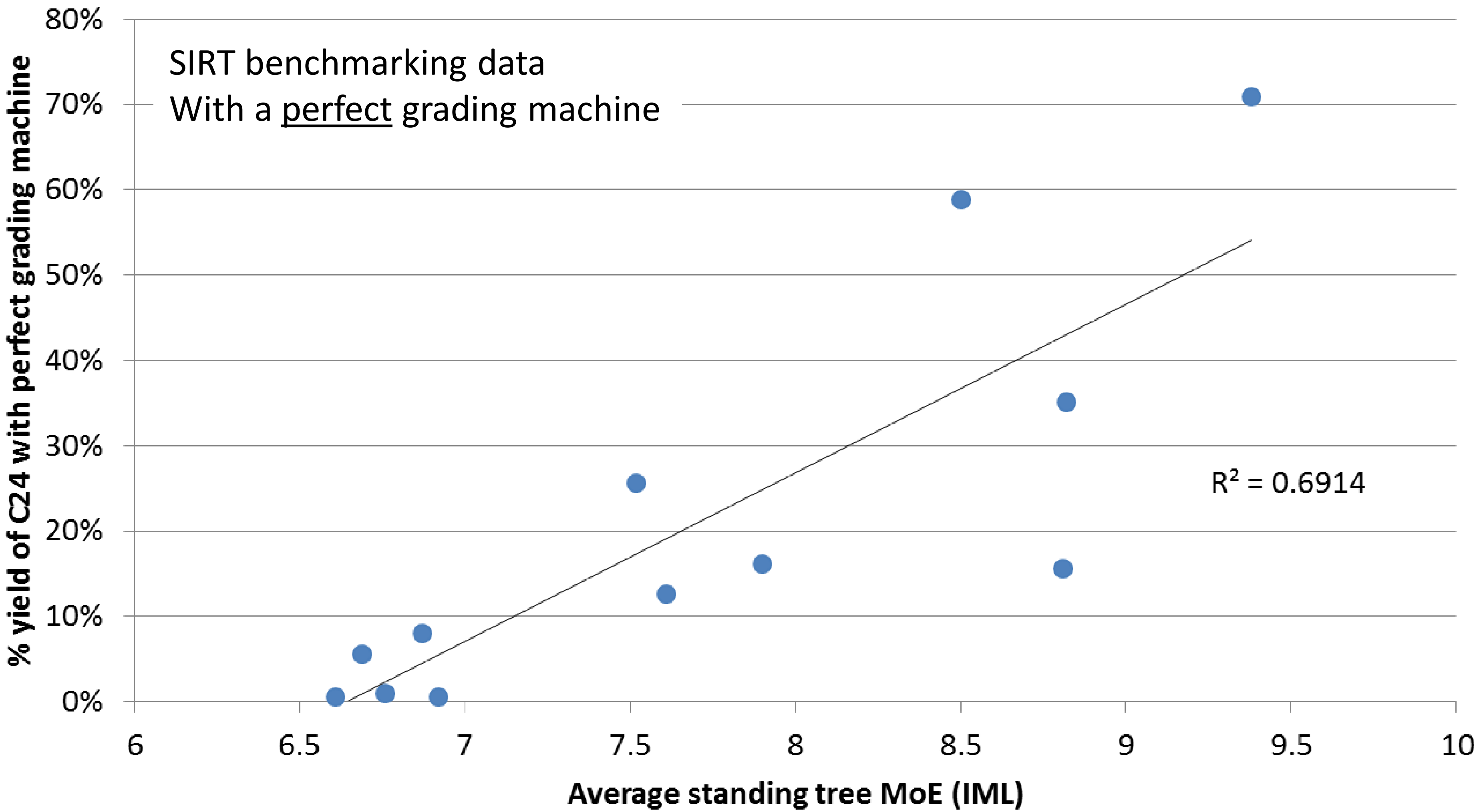
Raw data from SIRT benchmarking validation study

Standing tree measurements





Tree MoE and C24 yield



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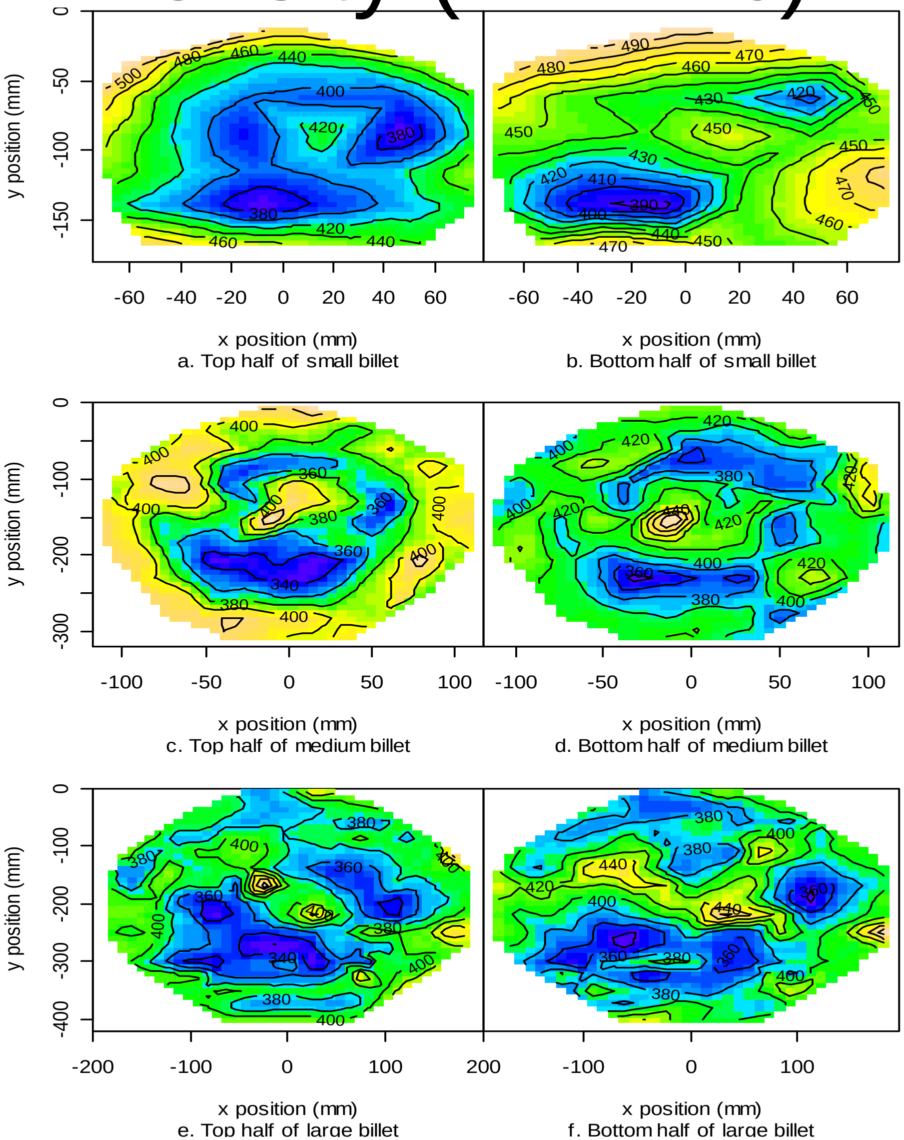
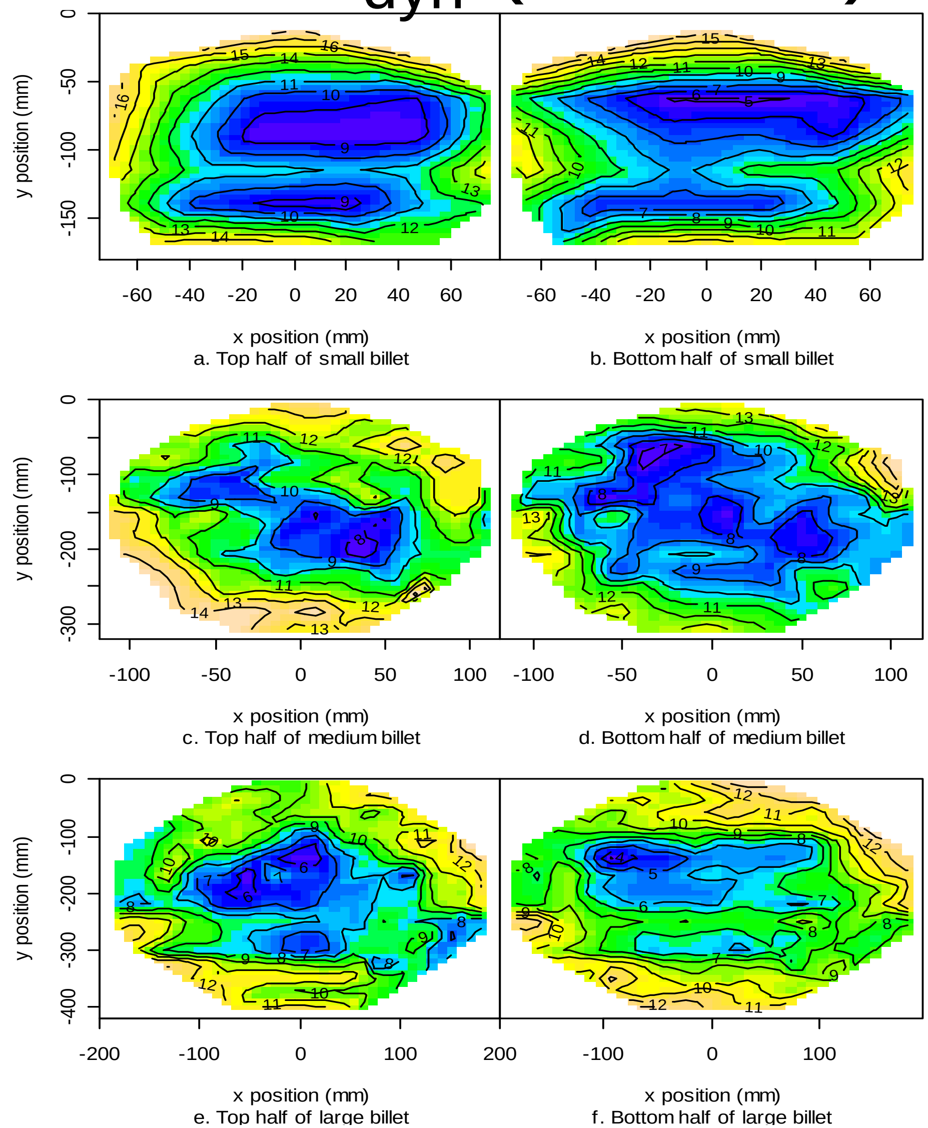
Density (12%mc)

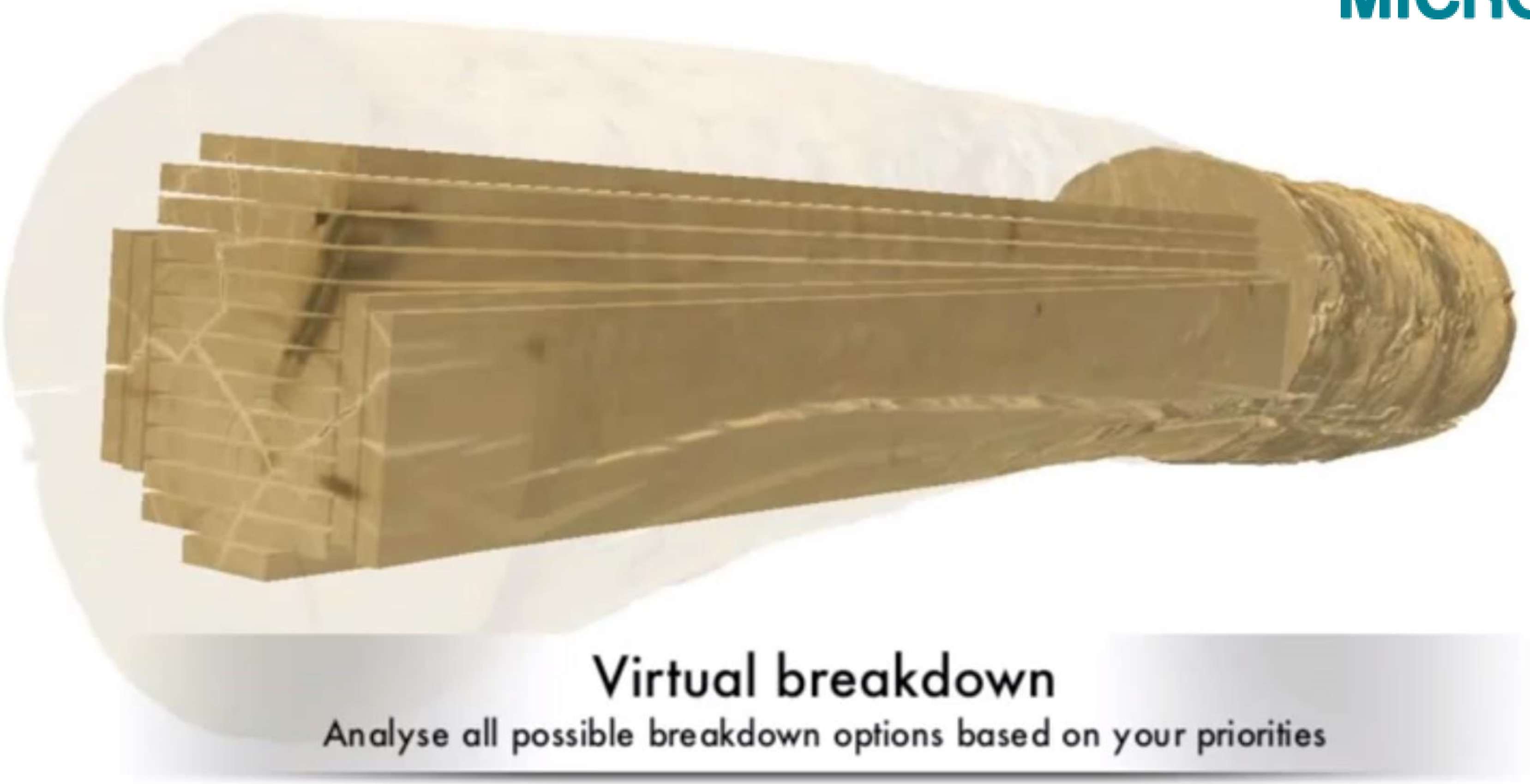


MoE$_{dyn}$ (12%mc)

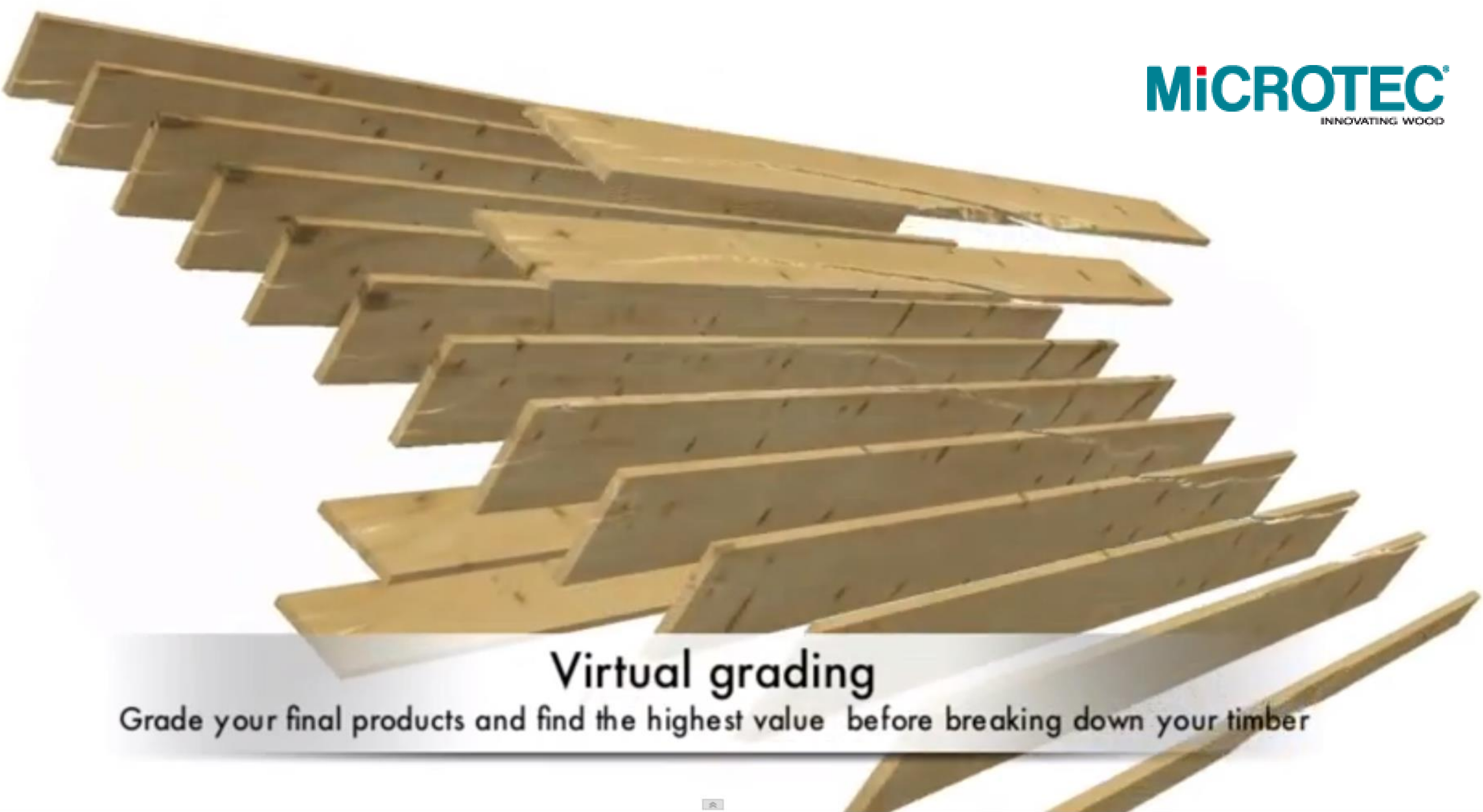


Virtual grading of the log

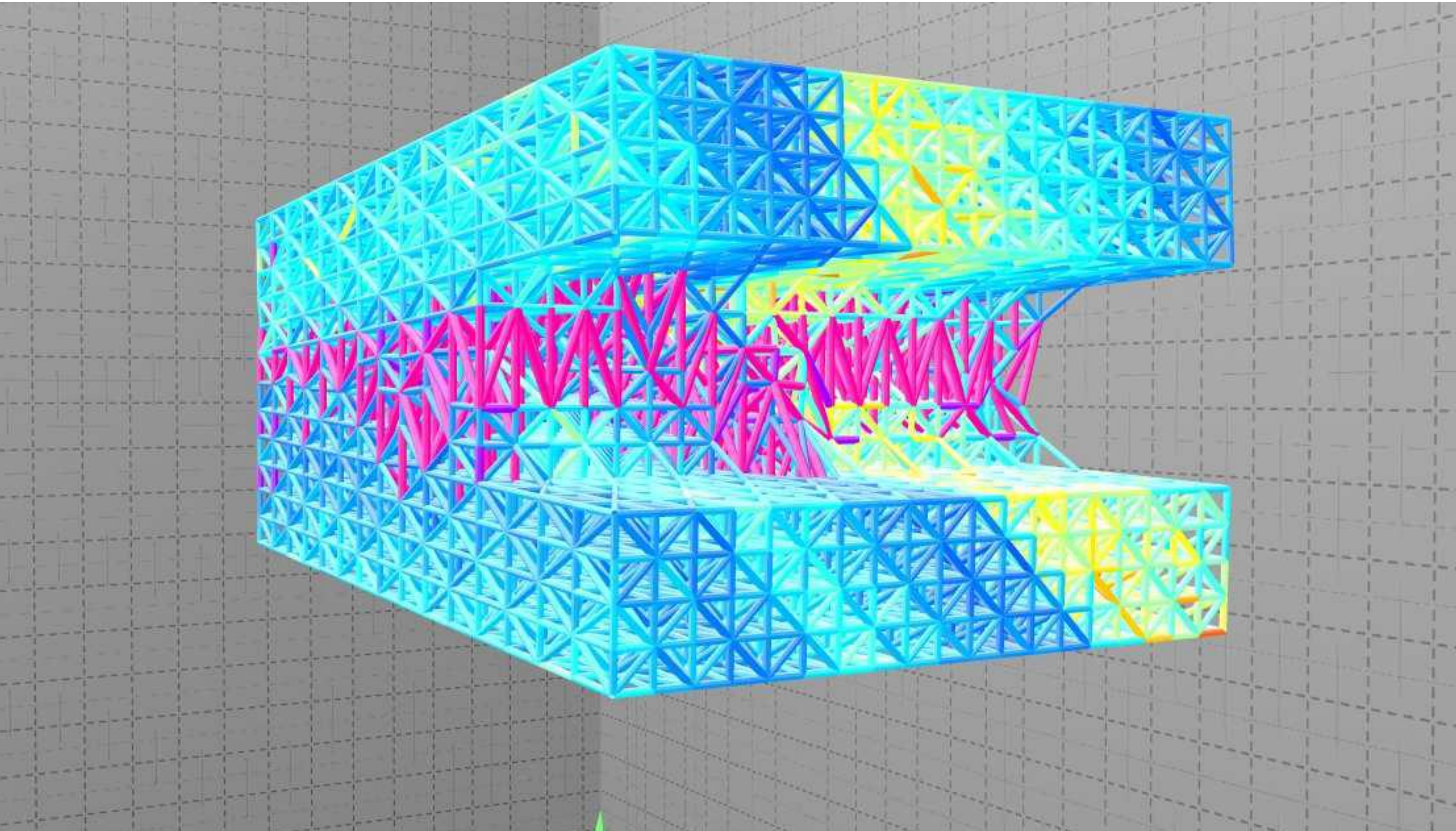
Virtual grading of the log



Virtual grading of the log



Fracture



Research needs include

- Improving the segregation of timber (green timber, logs, or, ideally, standing trees) to the most appropriate end product, reducing reject timber and wastage for the sawmill and end user.
- Improving the robustness of timber grading against shifts in resource quality due to changes in forest management, climate and origin.
- Opening up possibility to structurally grade a wider range of species with reduced requirement for mechanical testing programmes.

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Require understanding of

- The propagation of acoustic waves in wood (the main challenge being standing trees).
- How within-piece material variability at different scales governs sawn timber quality and how that variability arises from the way the trees grow.
- The relationship between non-destructive measurements (grading indicators) and timber properties and why and how this varies for a species.

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